



DRONES AND PHOTOGRAMMETRY IN IVORY COAST ARCHAEOLOGY: APPLICATIONS IN THE SHELL MIDDENS OF ÉBRIÉ LAGOON (SONGON, ABIDJAN)

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Introduction: Archaeology 2.0 on the Ivory Coast

Owing to the methodological development and evolution of the archaeological discipline itself, the role of technology has become fundamental, with recent decades witnessing the incorporation of tools that have gone a long way toward supporting and supplementing the more traditional archaeological record. The archaeological method is known to be destructive and unrepeatable, thus it is essential to correctly document each layer, structure, and discovered object in order to create a graphic record. In this regard, analogue cameras and rudimentary techniques for taking overhead photographs (i.e. ladders or poles) have been replaced over the past few years by digital techniques, including a range of new data collection devices and specific post-processing software packages: drones (UAVs), LiDAR, high precision GPS, laser scanners, and geophysics applications, to name a few. This technology has completely modernized archaeological documentation in relation to graphic documentation techniques. The drone industry has become professionalized to such an extent that there are now many studies revolving around drone use (Pierrot & Labbe 2017; Verhoeven 2022), whose importance in archaeological research has been addressed in forums such as the 'Colloque : drone et moyens légers aéroportés

d'observation: recherche, développement, applications' (Montpellier, 24-26 June 2014) and the 'International Colloquium. Beyond Excavation. Geophysics, Aerial Photography and the Use of Drones in Eastern and South-East European Archaeology' (Piatra-Neamț, Romania, 5-8 December 2016).

Traditional techniques, like manual drawing, are being substituted by digital ones, such as photogrammetry and orthophotography. Photogrammetry generates a 3D model with which to move through the space in question to collect metric and morphological data. Orthophotographs provide a deformation-free orthogonal and cartographic plane, making them ideal for the vectorization and subsequent generation of precise planimetries. The post-processing of this information with software packages facilitates the generation of much more precise ground plans, sections, elevations and profiles, among other things, in less time - in contrast to traditional methods - with practically anomaly-free georeferenced planimetries, thanks to the generation of flat and vertical planes (Aguilar *et al.* 2013). With a 3D model, it is possible to extract sections, plus metric and volumetric data, which can also serve as a basis for putting forward reconstruction proposals, using anastylosis, thus generating interesting infographic resources (Díaz *et al.* 2022). The wide-

spread adoption of these technologies and other ICTs, whose future potential is unlimited, offers the opportunity to disseminate this cultural heritage among the general public, because moving through 3D models is becoming an increasingly easier and more realistic experience thanks to virtual and augmented reality, among other means.

Many of these techniques have been applied in recent archaeological studies performed in the framework of the Ivory Coast-Spanish 'Archeo-Songon' project, in the well-known shell middens located on the shore of Ébrié Lagoon, some 50 km to the west of Abidjan, the Ivory Coast capital (Figure 1, A). As will be seen below, an exhaustive data collection methodology was employed for documenting Text Excavation 2 (site of Songon-M'Brathé), for the purpose of generating as many resources as possible, following a method that had already been used at other sites (Díaz *et al.* 2019; Portillo *et al.* 2022). Research was conducted using equipment belonging to the Prehistory and Archaeological Laboratory of the University of Cadiz (LABAP), including a DJI Mavic Air 2 drone with the DJI Fly app (Figure 2), which was occasionally combined with the use of a Nikon D7100 digital reflex camera, all with the authorization of the Autorité Nationale de l'Aviation Civile de Côte d'Ivoire (ANAC), according to the *Règlement aéronautique de Côte d'Ivoire relatif aux aéronefs civils télépilotés (RACI 3009)*. The use of drones is currently fundamental. In the case at hand, they offered a unique view of the site for understanding sedimentation and human occupation processes in the vicinity of Ébrié Lagoon, allowing to frame it in its landscape and territory. In the Ivory Coast, the use of drones is commonplace and well understood, being fully incorporated into tasks relating to crop control (e.g. the company WeFly Agri) and to monitoring deforestation of the country's fragile areas (Ouattara *et al.* 2022). As to archaeology, drones made it possible to generate an orthophotogrammetric sequence and digital copies of the entire stratigraphic sequence. This exemplifies how drone support for archaeological methods has led to a great qualitative leap forward as regards research, results dissemination, and knowledge transfer to society (Torres *et al.* 2010).

The shell middens of Ébrié Lagoon: the site of Songon-M'Brathé

The groundwork for the archaeological intervention consisted of reconnaissance flights to photograph the environment, thus offering a unique perspective of the site and its connection to the Gulf of Guinea, namely, through the coastal lagoon of Ébrié (Figure 1, B-C). Additionally, this highlighted the important contemporary alterations caused by soil tilling for growing crops and by the excavation of shell extraction pits for feeding poultry. In relation to these pits, aerial images offer an idea of the size of the shell middens of Songon-M'Brathé, discernible in the concentration of whitish blemishes, owing to the accumulation of shells, principally *Corbula* (preliminary study in Cantillo *et al.* in press).

Before planning Test Excavation 2, photographs were systematically taken to document the topography of a large area covering approximately 8.6 ha. To this end, the photographic strategy involved a layout of transversal 'strips' covering the entire site at an altitude of 30 m, in which aerial photographs, with a frontal overlap of no less than 80% and a lateral overlap of no less than 75%, were taken (Figure 1, D-E). This information was processed using Pix4dmapper software, resulting in a georeferenced orthophotography exportable in GeoTiff format, which incorporated a metadata set including the type of projection, the coordinate system, and all the necessary elements for automatically positioning images in a spatial reference system. In other words, the results can be subsequently processed with other geographic information system (GIS) software to generate very interesting data: cartographic studies, vector analyses, digital elevation models (DEMs), raster analyses, calculating the best routes between sites, generating visibility models, and so forth. Likewise, a digital terrain model (DTM), that is, a representation of the topography of the area under study in fake 3D, was generated. In this model, it can be observed how the land has been ploughed to a lesser extent, although the archaeological levels have indeed been partially disturbed in view of the abundant surface material, which is generally in a good state of conservation.

Following this approach, it was decided to grid an area for performing a systematic and georeferenced microspatial (US 200/201) collection of movable surface material. Accordingly, a 10x4 m perimeter was

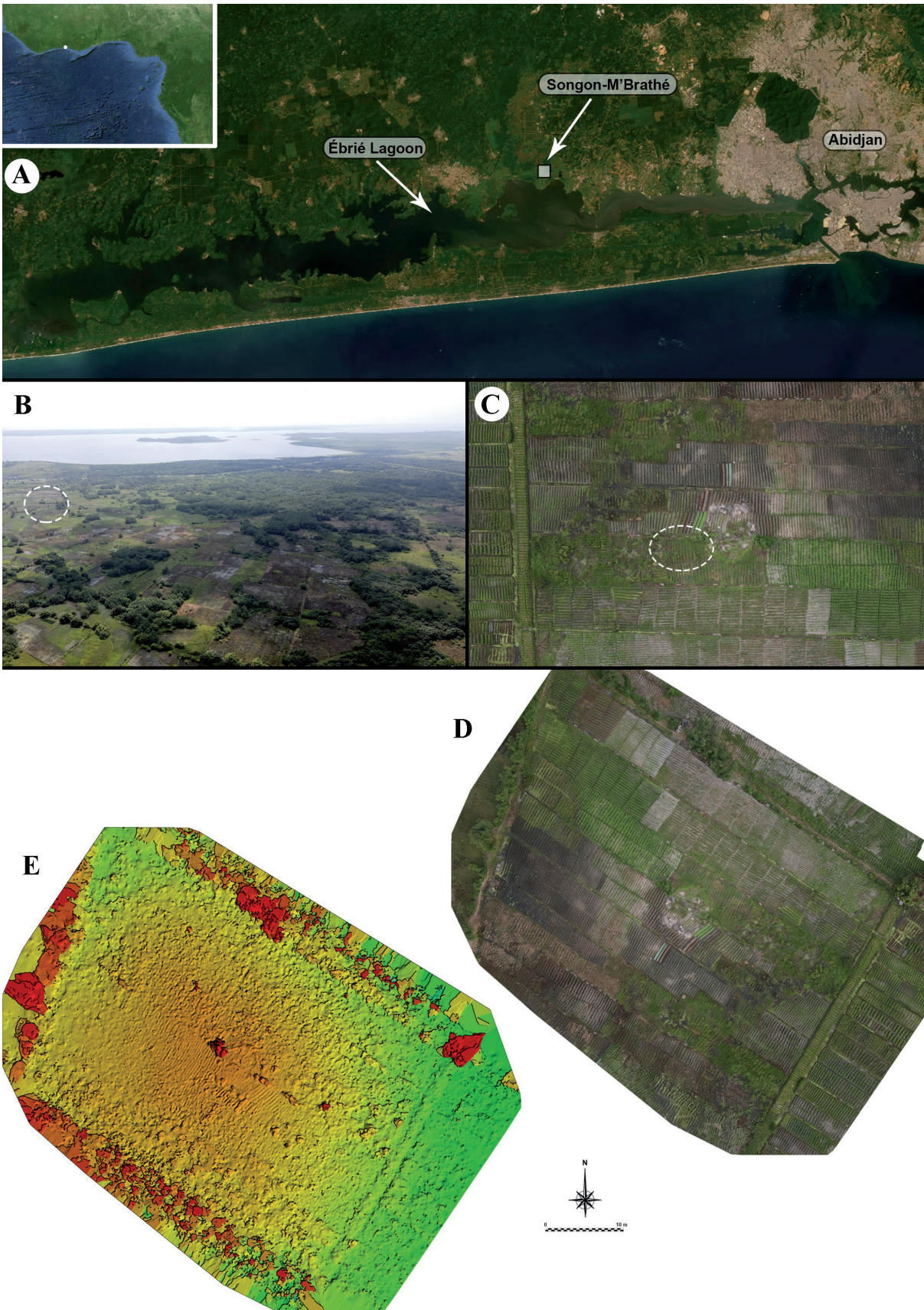


Figure 1. Location of Songon-M'Brathé in the Gulf of Guinea and in the vicinity of Ébrié Lagoon (A); photographs of the landscape indicating the site (B-C); and the orthophotography and DTM of the intervention area (D-E). (Maps by UCA, HUM-1126 Research Group.)



Figure 2. Working with the drone at the site of Songon-M'Brathé. (Photographs by UCA, HUM-1126 Research Group.)

established from the south-west to north-east and from the north-west the south-east, respectively, before dividing the delimited area into 1 m-wide 'strips' to facilitate geolocation. On this occasion, the documentation method chosen combined the traditional techniques of manual drawing, using a triangulation system, to document the location of the collected materials. This was supplemented by a georeferenced orthophotography with photographs taken from an altitude of 5 m, implementing the same photographic and post-processing techniques described above. This method facilitated the cross-referencing of the data obtained through the observation of each piece, its boundaries, and the relationship between these artefacts, with georeferenced information without distortions, such as the radial distortion phenomenon, which always provides new insights into archaeological remains.

Employing this method, twenty-eight microspatially georeferenced artefacts were systematically retrieved (Figures 3 and 4, A), of which special mention should go to a whetstone (M-16) and a large quantity of – plain and decorated – pottery belonging to the same tradition, judging by some common aspects such as the production techniques plus their decoration, details, and pastes. Other aspects include their morphological features, since most of them are closed vessels such as pots/urns, open ones being less frequent. This pottery tradition typical of the area's indigenous peoples is known thanks to the work of S. Kouassi Kouakou (2012) and E. N'Doua-Ettien (2019), among others. Notwithstanding this, these ceramic artefacts still raise

many questions, which could be answered by performing a comprehensive morpho-functional study and, to establish when they were made, radiocarbon dating of both the artefacts and some land animal bones. At present, the production techniques used seem to indicate that they predate the Portuguese occupation in the fifteenth century.

To the south-east of the microspatial collection area, a 2x2 m trench (Figure 4, C) was excavated in a sector that appears to have undergone few alterations, although one of the above-mentioned contemporary shell extraction pits (US 204), measuring 92 cm (N-S) by 1.2 m (E-O), was discovered in its southern corner. The aim of Test Excavation 2 was threefold: to document the complete stratigraphic sequence of the site and to gain further insights into the area's functionality, which at present reveals evidence of production and/or handicrafts activities; to pave the way for a systematic analysis of the plain and decorated pottery; and to record the ichthyo-malacological material to determine the extent to which marine resources were re-used in the vicinity of Ébrié Lagoon.

Subsequently, and during the archaeological work, the recording system involved three steps. Firstly, the drone was used daily to capture different kinds of images, including photographs and videos of the remains and documented layers (overhead, angled and frontal) and of the landscape and the archaeological excavation.

Secondly, photographs of each one of the documented layers were systematically taken to create

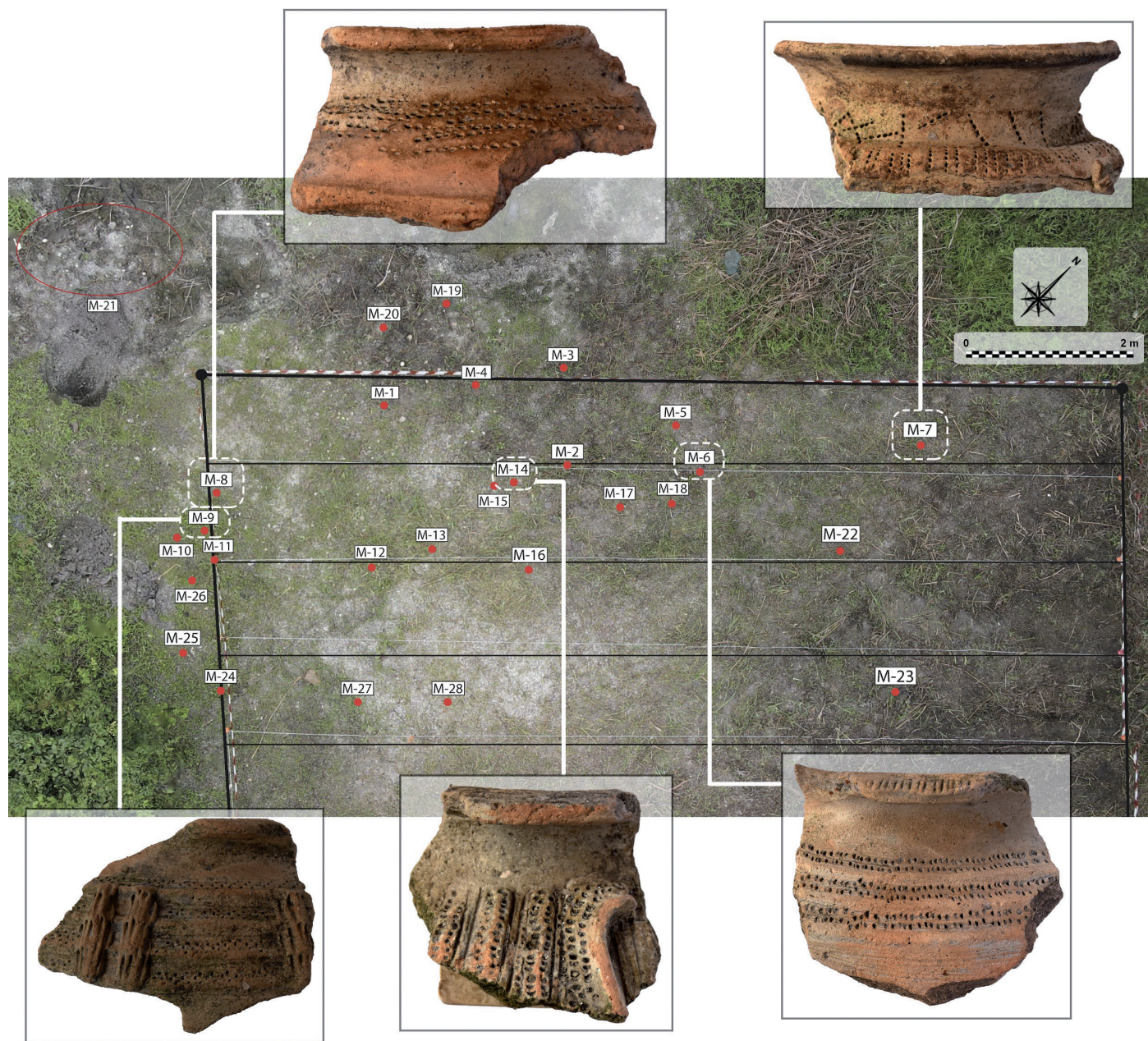


Figure 3. Map of US 200 (microspace) with the georeferencing of ceramic material (M-6, M-7, M-8, M-9 and M-14). (Map by UCA, HUM-1126 Research Group.)

digital copies with which to work in the laboratory (Marín-Buzón *et al.* 2021; Whitford *et al.* 2022). The historical phase relating to the site's indigenous occupation – without contemporary alterations – was recorded in US 202 (Figures 5, A-B and 6, A-B). To this should be added the sequence possibly linked to the formation of Ébrié Lagoon, formed by layers of shells (above all tiny bivalves – *Corbula* – and *Pachymelania aurita* and *Pachymelania fusca*), silts, and sands in US 206, 205, and 207, respectively (Figures 5, C and 6, C-D).

These data were collected throughout the excavation area, including an outward 2-m perimeter to avoid possible model distortions. The drone, equipped with a digital reflex camera, generated five photogrammetries using Agisoft Metashape software, which facilitated the orientation of the photographs with respect to each other through reference points and, consequently, the generation of a point cloud, the creation of a mesh, and, finally, the application of a photorealistic texture (see Figure 5).

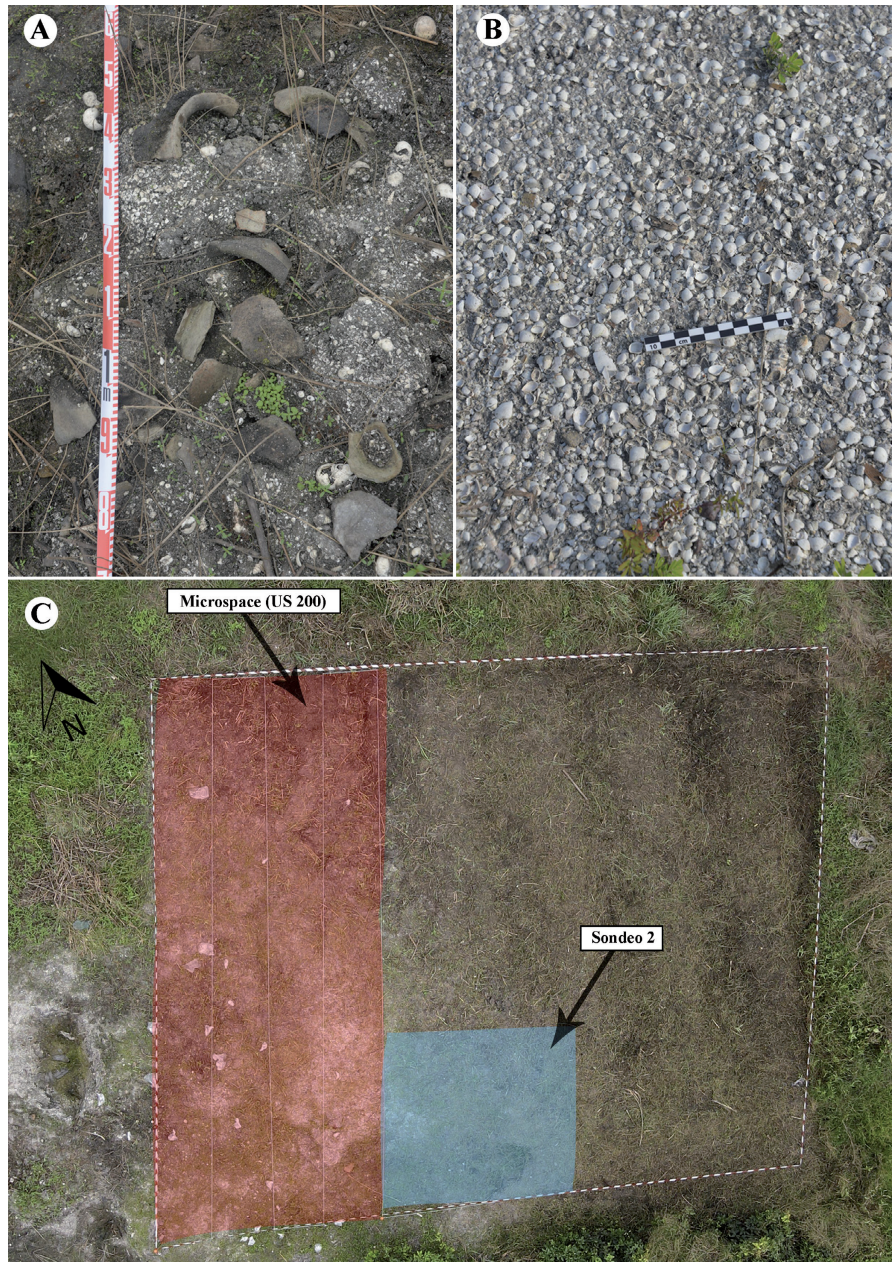


Figure 4. Concentration of pottery in the surface layer (A); remains of *Corbula* shells on the surface (B); and the location of the microspatial collection area and Test Excavation 2 (C). (Map by UCA, HUM-1126 Research Group.)

This process generated a true-to-scale 3D model exportable, for example, to .obj file format, which can be manipulated with 3D modelling programmes such as Blender, then facilitating the extraction of volumetric data, plus sections and cuttings of the site, among many other aspects. As another very interesting resource for publicly disseminating archaeological research, these digital copies can be reproduced with 3D printers and be posted and shared on 3D websites

such as Sketchfab (Scopigno *et al.* 2017). On these 3D model platforms, specific data can be labelled as detailed text or photographic information to make stratigraphic sequences and any other elements that should be highlighted easier to understand.

Metashape was employed to generate orthomosaics of the ground plan, which are very useful for illustrating the evolution of the excavation and for recording the stratigraphic sequence (Figure 6, A-D). Other

perspectives, such as the elevation of the profiles and the sections of the test excavation, can also be exported. These procedures provide distortion-free scaled images that are ideal for drawing layers and structures with Adobe Illustrator vector graphics software (Figure 6, E). As an additional advantage, all of these orthophotographs include GPS data for georeferencing Text Excavation 2 and the documented sequence with the above-mentioned software and GIS tools, such as ArcGIS and QGIS.

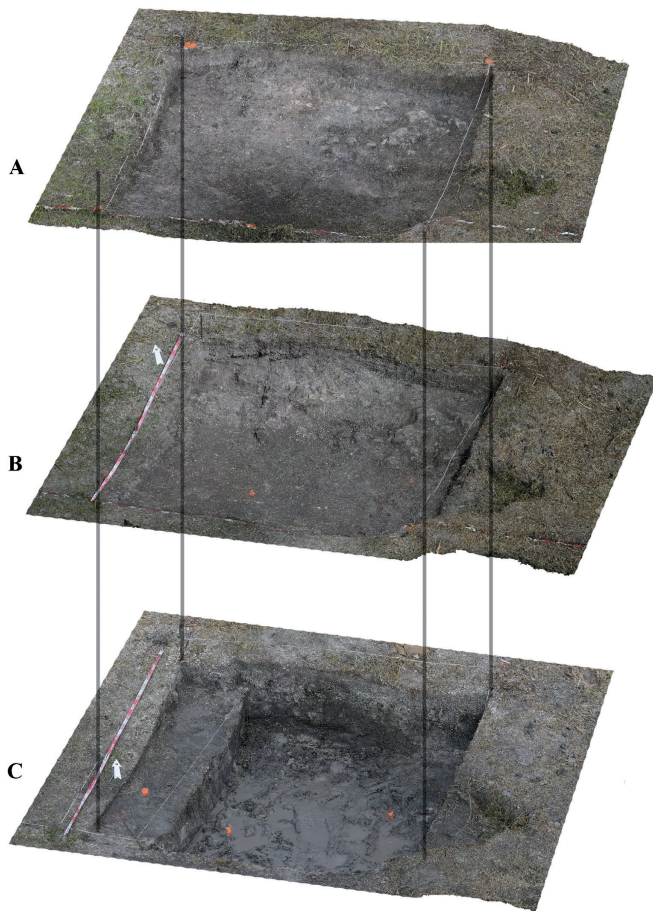


Figure 5. Photogrammetric sequence of US 202 (A), 203/204 (B) and 206/205 (C). (Figure by UCA, HUM-1126 Research Group.)

Lastly, the record of science communication and dissemination is also important. Drone aerial photographs provide a view of the territory in which the archaeological remains should be framed, and the perspective of the photographs is very useful for generating resources for knowledge transfer and results dissemination in an attractive and thought-provoking

way. Accordingly, Filmora software was used to create an informative video montage of the first excavation campaign of the 'Archeo-Songon' project, which also includes all evidence of occupation discovered in the locality of Songon-Kassemblé, some 8 km to the east.

Conclusions

It has been possible to observe how pooling all the information available provides new insights into the historical development of Ébrié Lagoon. The preliminary results obtained through the stratigraphic sequence documented in Songón-M'Brathé seem to point to as many as three historical episodes in this area of the paleolagoon (Gutiérrez-Rodríguez *et al.* 2026). The alternation of a *priori* naturally formed layers (US 206) with other layers containing ceramic material supports the hypothesis that this area underwent episodes of flooding which covered the indigenous occupation layers with layers of sediment. Thin-section microstratigraphic analyses were performed to identify the microlayers forming these natural and anthropic levels (Gutiérrez-Rodríguez *et al.* 2026). The sampled profile was documented with photogrammetry. As to future interventions, geotechnical bore holes could be manually drilled to obtain datable sedimentary cores for explaining the evolution of the sedimentation of Ébrié Lagoon.

The use of drones and the post-processing of data with software packages allowed us to discern three phases (Fiz *et al.* 2022). First, landscape views, orthophotography, and MDT illustrated the phase of contemporary land-tilling processes and shell extraction for feeding poultry. Second, the georeferenced orthophotograph of US 200 (microspace) and the photogrammetry of US 202 illustrated the site's indigenous occupation phase. Third, aerial photographs of the paleolagoon helped us gain an understanding of sedimentation processes. Moreover, we also generated 3D models of the silty clay of the lagoon's ancient bed (US 205) and some of the horizontal layers of *corbula* (US 206).

All considered, the contribution of this type of record to archaeology – call it Archaeology 2.0 – and the exponential improvement of graphic documentation techniques versus more traditional methods is unarguable. Its potential is even greater considering the applications it could have in GIS software, such as in future studies of the sedimentation of Ébrié Lagoon. Results dissemination and knowledge transfer on platforms

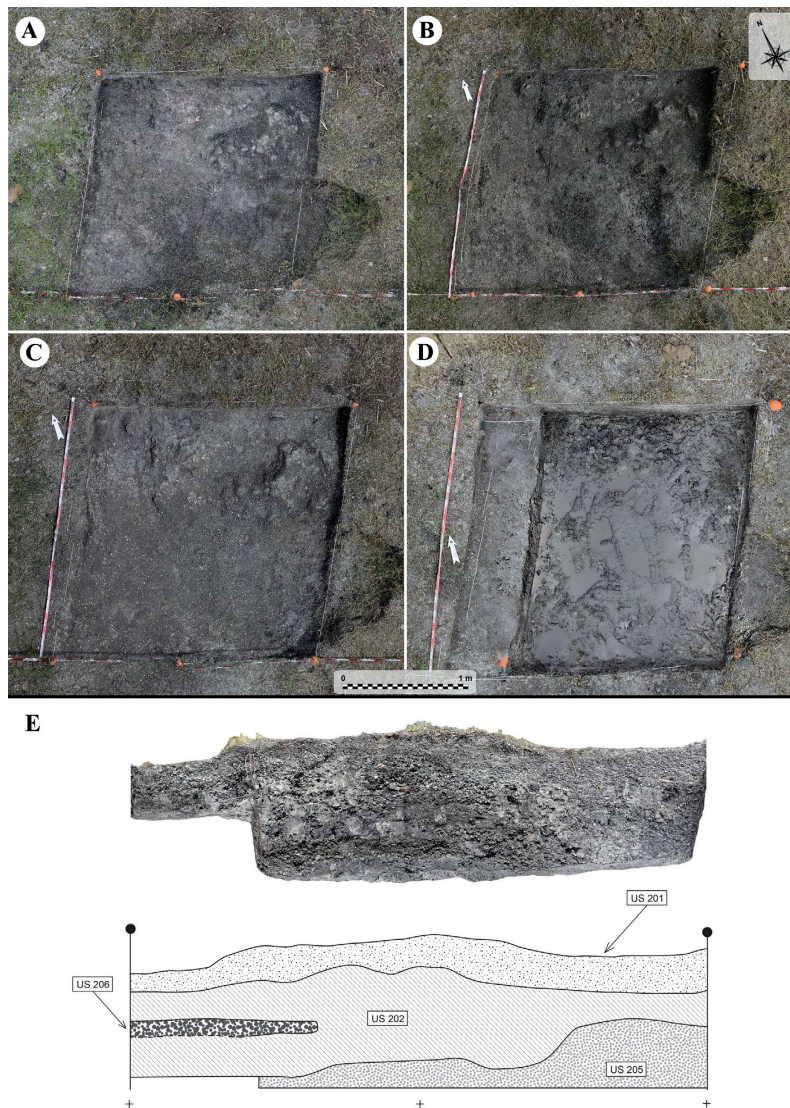


Figure 6. Orthophotographs of the documented layers: US 202 (A), US 203/204 (B), US 206 (C), and US 205 (D); photogrammetry and drawing of the stratigraphic sequence of the north-eastern profile (E). (Photographs by UCA, HUM-1126 Research Group.)

such as Sketchfab are also crucial. Our participation in the 'Atelier trilatéral dans le cadre de renforcements de partenariats en Archéologie entre les universités Félix Houphouët-Boigny (Côte d'Ivoire), de San Pedro (Côte d'Ivoire) et de Cadix (Espagne)', held in Bingerville (UFHB) on 30 January 2023, with the paper entitled 'Les nouvelles tendances en Archéologie: des drones à la photogrammétrie', reflected on the application of these technological tools and presented the methodology and procedure for exploiting drones and 3D resources to the full.

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Coulibaly, Université Alassane Ouattara). Master's student Ignace Kouakou Date and PhD candidate Nagnénégué Kone also participated in the project.

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References cited

- Aguilar Camacho, J., Granado Castro, G. & Barrera Vera, J.A.
2013. 'Aplicación de técnicas avanzadas para el registro y la documentación estratigráfica en arqueología'. *Virtual Archaeology Review* 4 (8): 130-134. DOI: <https://doi.org/10.4995/var.2013.4345>
- Cantillo Duarte, J.J., Kouassi, S.K., Bernal-Casasola, D., Gninin-Toure, A., Vijande Vila, E., N'Doua-Ettien, E., Portillo-Sotelo, J.L. & Fabrice-Loba, L.
- In press. 'Arqueomalacología en el entorno de la laguna Ebrié (Abidján, Costa de Marfil)'. *VII Reunión Científica de Arqueomalacología de la Península Ibérica, Universidad de Las Palmas de Gran Canaria (mayo, 2023)*.
- Díaz, J.J., Portillo-Sotelo, J.L., Bernal-Casasola, D. & Expósito, J.A.
2019. 'Drones al servicio de la Arqueología. Generación de planimetrías de precisión en Baelo Claudia, Tarifa, Cádiz'. *Obras Urbanas. Revista Técnica de Maquinaria y Obra Pública* 76: 4-12.
- Díaz-Rodríguez, J.J., Bernal-Casasola, D., Portillo-Sotelo, J.L., Fantuzzi, L., Fernández, A. & Castillo, G.
2022. 'Turning space into a stage. A villa maritima with italic influences in Cape Trafalgar'. In Bernal-Casasola, D., Díaz, J.J., Vijande, E., Expósito, J.A. & Cantillo, J.J. (eds.), *Blue Archaeology in Trafalgar: From research to sustainable tourism*. Cádiz: University of Cádiz, pp. 156-175.
- Fiz, I., Martín Serrano, P.M., Cuesta Moratinos, R., Subías Pascual, E., Codina Reina, D. & Cartes Reverté, T.
2022. 'Examples and Results of Aerial Photogrammetry in Archeology with UAV: Geometric Documentation, High Resolution Multispectral Analysis, Models and 3D Printing'. *Drones* 6 (3): 59. DOI: <https://doi.org/10.3390/drones6030059>
- Gutiérrez-Rodríguez, M., Bernal-Casasola, D., Kouassi, S., Portillo-Sotelo, J.L., Gninin-Toure, A., Fabrice-Loba, L., Cantillo-Duarte, J.J., N'Doua-Ettien, E. & Vijande Vila, E.
2026. 'The Songon-M'Brathé shell midden (Ivory Coast): microstratigraphic evidence of human activities and paleoenvironmental evolution'. *Archaeological and Anthropological Sciences*, 18:12. DOI: <https://doi.org/10.1007/s12520-025-02359-4>
- Kouassi Kouakou, S.
2012. *Côte d'Ivoire côtière (Grand-Bassam-Grand-Lahou). L'histoire du peuplement à partir des amas coquilliers*. Paris: L'Harmattan.
- Marín-Buzón, C., Pérez Romero, A.M., López Castro, J.L., Ben Jebania, I. & Manzano Agugliaro, F.
2021. 'Photogrammetry as a New Scientific Tool in Archaeology: Worldwide Research Trends'. *Sustainability* 13: 5319.
- N'Doua-Ettien, E.
2019. *La Céramique des amas coquilliers de Songon (Sud-Côte d'Ivoire)*. London: Éditions universitaires européennes.

- Ouattara, T.A., Sokeng, V.-C.J., Zo-Bi, I.C., Kouamé, K.F., Grinand, C. & Vaudry, R.
2022. 'Detection of forest tree Losses in Côte d'Ivoire using drone aerial images'. *Drones* 6 (4): 83. DOI: <https://doi.org/10.3390/drones6040083>
- Pierrot Deseilligny, M. & Labbe, S. (eds.)
2017. *Drones*, special issue of *Revue française de Photogrammétrie et de Télédétection SFPT* 213-214. Paris: Centre national d'Études spatiales & Institut national de l'Information géographique et forestière.
- Portillo-Sotelo, J.L., Díaz, J.J. & Muñoz-Muñoz, A.
2022. 'By land and by air. 3D scanner and drones to digitalise Roman Trafalgar'. In Bernal-Casasola, D., Díaz, J.J., Vijande, E., Expósito, J.A. & Cantillo, J.J. (eds.), *Blue Archaeology in Trafalgar: From Research to Sustainable Tourism*. Cádiz: University of Cádiz, pp. 106-123.
- Scopigno, R., Callieri, M., Dellepiane, M., Ponchio, F. & Potenziani, M.
2017. 'Delivering and using 3D models on the web: are we ready?'. *Virtual Archaeology Review* 8 (17): 1-9. DOI: <https://doi.org/10.4995/var.2017.6405>
- Torres, J.C., Cano, P.; Melero, J., España, M. & Moreno, J.
2010. 'Aplicaciones de la digitalización 3D del patrimonio'. *Virtual Archaeology Review* 1 (1): 51-54. DOI: <https://doi.org/10.4995/var.2010.4768>
- Verhoeven, G. (ed.)
2022. *(Re)Defining the Archaeological Use of UAVs*. Vienna: Multidisciplinary Digital Publishing Institute.
- Whitford, B., Boyadzhiev, K., Ivanov, M., Tyufekchiev, K. & Boyadzhiev, Y.
2022. 'A photogrammetry-assisted methodology for the documentation of complex stratigraphic relationships'. *Advances in Archaeological Practice* 10 (4): 428-439.