The underwater site of Qaitbay
New procedures for studying the sunken elements
Centre d'Études Alexandrines (USR 3134 of CNRS)

Interim report on the 2016 season

The underwater site of Qaitbay is situated off the eastern extremity of the former isle of Pharos at Alexandria, Egypt, at a point where the ancient Lighthouse of Alexandria has traditionally been located. With the support of the Honor Frost Foundation, the Centre d'Etudes Alexandrines conducted two new campaigns in 2016 on this monumental site in the waters off Qaitbay Fort, continuing its programme of underwater and terrestrial photogrammetry. There are two main aims: on the one hand, the creation of a 3D digital elevation model (DEM) of the site through automatic digital photogrammetry and image correlation, and on the other, the 3D acquisition and processing of the statuary and architectural blocks of the site in order to generate virtual anastylosis and reconstitutions of the monuments.

This project began as part of the ANR-SeARCH programme between 2009 and 2012, and was supported by the Honor Frost Foundation in 2013 and 2015, and again in 2016. This report presents the results of the two campaigns conducted in 2016, one in spring (24 April – 2 June), and the other in autumn (4 October – 3 December).

I. Work on the DEM and georeferencing

The photographic coverage of the site is carried out by means of "flight plans" with longitudinal and lateral overlaps of the order of 70 to 80%, which is superior to conventional aerial photography. This overlap rate reduces mistaken pairing by increasing the number of combined photos when matching images. The shots were taken in optimum weather conditions: little or no swell, sunny weather, sometimes overcast, but always with sufficient brightness. Too much sunlight can create a glare that is detrimental to image matching and the quality of photogrammetric processing.

Several flight plans were organised during the two 2016 missions in order to increase the area covered by the photography in 2015. The flight plans run along lines doubling back and forth,

which the diver maintains by visual orientation, checking his/her trajectory against the features of the seabed with the many ancient blocks and very uneven surface, and thanks to rulers placed on the bottom. The boundaries of the area to be covered during the flight plan are marked by measuring tapes and buoys. The major difficulty encountered in the landscape of the underwater site lies in the significant variation in the altitudes of the seabed. In some areas, there is a shift from -8 m to -4 m moving northwards, and from -9 m to -5 m while swimming to the south-east. The photos taken during these flight plans, using a proven technique in use since 2014, have nonetheless produced the expected results: the resulting DEMs are of good quality.

In 2015, the area covered was approximately 3,300 m^2 (see interim report for 2015). The work carried out in 2016 has more than doubled this area, since at the end of the two campaigns, the DEM of the Qaitbay site had increased to 7,200 m^2, more than half of the visible site covered by ancient blocks (**fig. 1**). The DEM, once completed, will offer the possibility of performing lengthwise and transverse profiles, of creating with complementary data a digital terrain model (DTM) of the site, and it already allows the production of orthophoto plans with a pixel size, which must unfortunately be adapted to the power of our computers, but which, in absolute terms, can reach a pixel resolution equalling 0.0004 m on the ground - and 3D images that are processed as small parcels for same reasons.

The georeferencing of the photogrammetric DEM is an ongoing task that was begun during the last campaign of 2016. This work will allow us to evaluate the accuracy of the DEM:

- on the one hand, its altimetric accuracy by comparing altitude differences between manually measured points (reference data recorded in FileMaker Pro databases, altitudes taken using mechanical or electronic depth gauges) and DEM plotted data,
- on the other hand, its planimetric accuracy by comparing the data of the reference GIS with the plotted data of the DEM.

This planimetric comparison had already been the subject of exercises that were not sufficiently precise, consisting of manually superimposing the orthophoto from the photogrammetric DEM upon the site plan extracted from the GIS. No altimetric comparison has yet been made.

2. Digital block models (DBMs)

A certain number of photos were taken during this excavation campaign for the creation of digital block models (DBM), both on the underwater site and in the open-air museum at Kom el-Dikka where some pieces that were lifted from the underwater site in 1995 and 1996 are now exhibited

(see list **fig. 2, A to D**).

3. Analyses using the DEM

3.1 - Position of particular blocks

In the context of the studies carried out on the site, the DEM allows us to visualise in a 3D space the position of certain particular pieces, such as those of the monumental Hellenic-style entranceway or the large statue bases, in relation to topographic anomalies, here the great fracture from which we explain the final collapse of the Lighthouse of Alexandria (**fig. 3**).

3.2 - Evidence of silting on certain zones of the site

Since 2013, the Qaitbay mission personnel have noted a significant silting up of the underwater site, following a relatively stable silting rate that had maintained since March 1998 when the first part (eastern zone) of the submerged breakwater of concrete blocks had been removed. A large area of the ancient site was thus revealed, allowing the discovery of objects still unknown on the site: lead fastenings, anchors, and fragments of amphora. The sand in the area had been removed in order to draw some blocks and very quickly the site had returned to an equilibrium.

A new, more pronounced silting process began after the removal of the remaining section of concrete blocks from the sunken breakwater (western zone) in January 2001. At the end of this operation, supervised by the Egyptian Antiquities Department, the displaced blocks of the sunken breakwater were deposited west of the archaeological site along the north-west face of Qaitbay Fort, which was to be protected after a major collapse in the winter of 2000. Indeed, part of the floor of the west gallery had disintegrated as a result of erosion undermining the ground on which the medieval fort was built. The gallery had been restored during major repairs.

The removal in 2001 of the remains of the sunken breakwater made it possible to clear a large area of the ancient site. During the missions that followed, the team realised that the cleared zone had quickly silted up again, showing that the sunken concrete dike created a "washing machine" effect between it and the fortress wall, accelerating the sapping of the quay that protected the fort. This gradual and moderate silting signalled a stabilisation of the bottom at the foot of the dike. We were able to see that the site was de-silted in the spring only to silt up again during the winter, in roughly equivalent and moderate proportions, for a little more than 10 years.

For some unknown reason, the phenomenon of silting up of this zone has suddenly accelerated. The phenomenon is visible to the naked eye, and the DEM photogrammetry programme of the site has made it possible to quantify it. We can therefore say today that the sand

level has risen permanently between 0.40 m and 0.60 m between autumn 2014 and autumn 2016, in an area of the site covered by the photographs (**fig. 4**), thus covering dozens of blocks that have been registered and mapped since 1996. This phenomenon highlights the urgency of completing the total photogrammetry coverage of the site.

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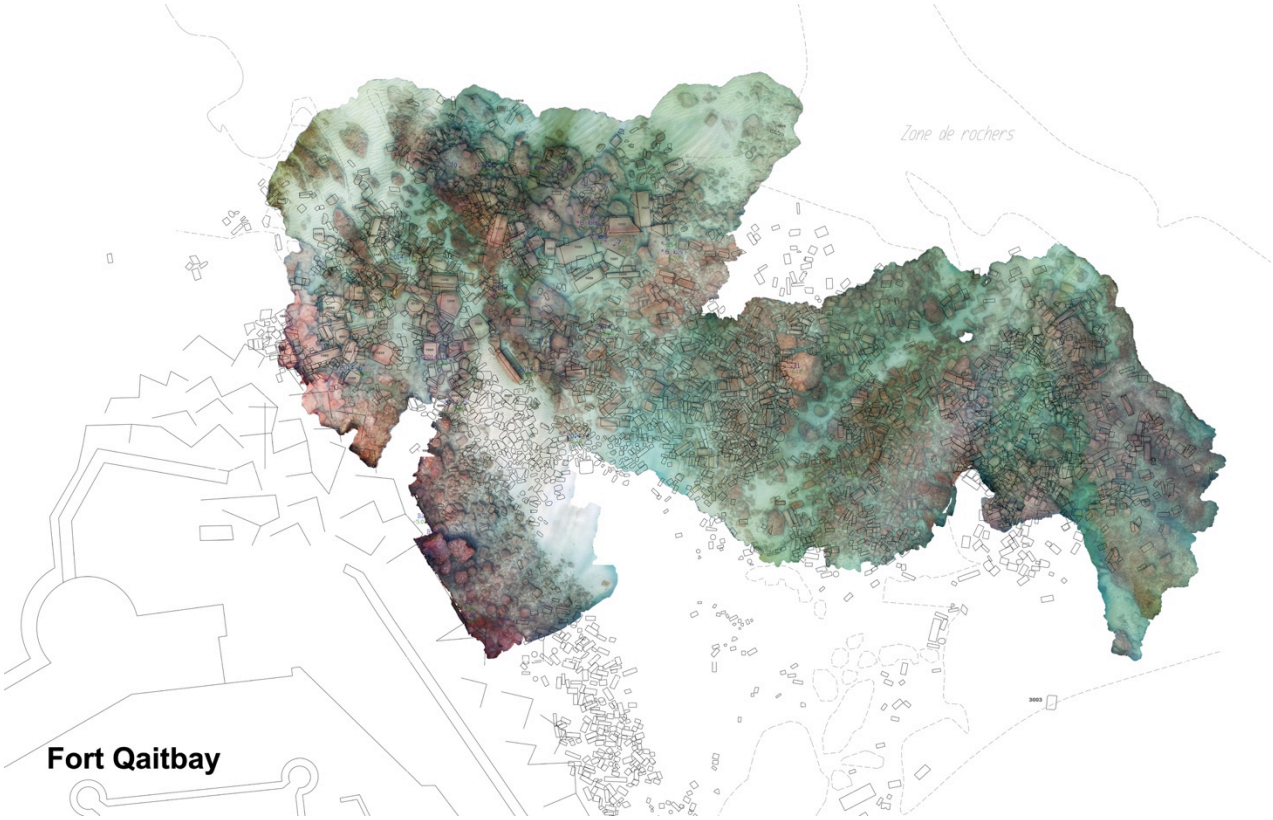

Fig. 1 – Digital elevation model (DEM) as orthophoto plan (7,200 m^2) superimposed on the GIS map of the Qaitbay underwater site

Fig. 2A – List of 3D digital models of architectural blocks and statuary created during the two campaigns

Fig. 2B – List of 3D digital models of architectural blocks and statuary created during the two campaigns

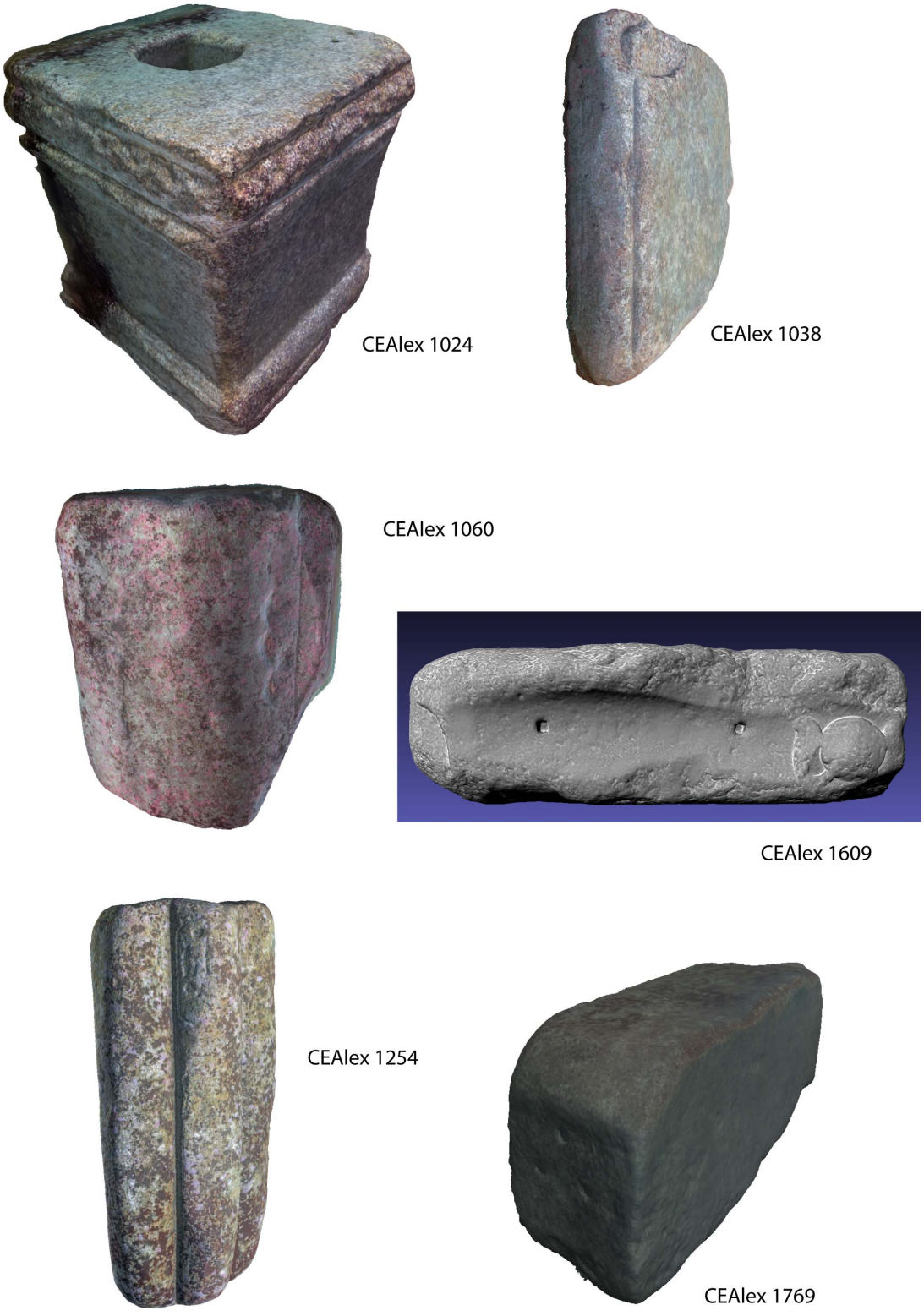

Fig. 2C – List of 3D digital models of architectural blocks and statuary created during the two campaigns

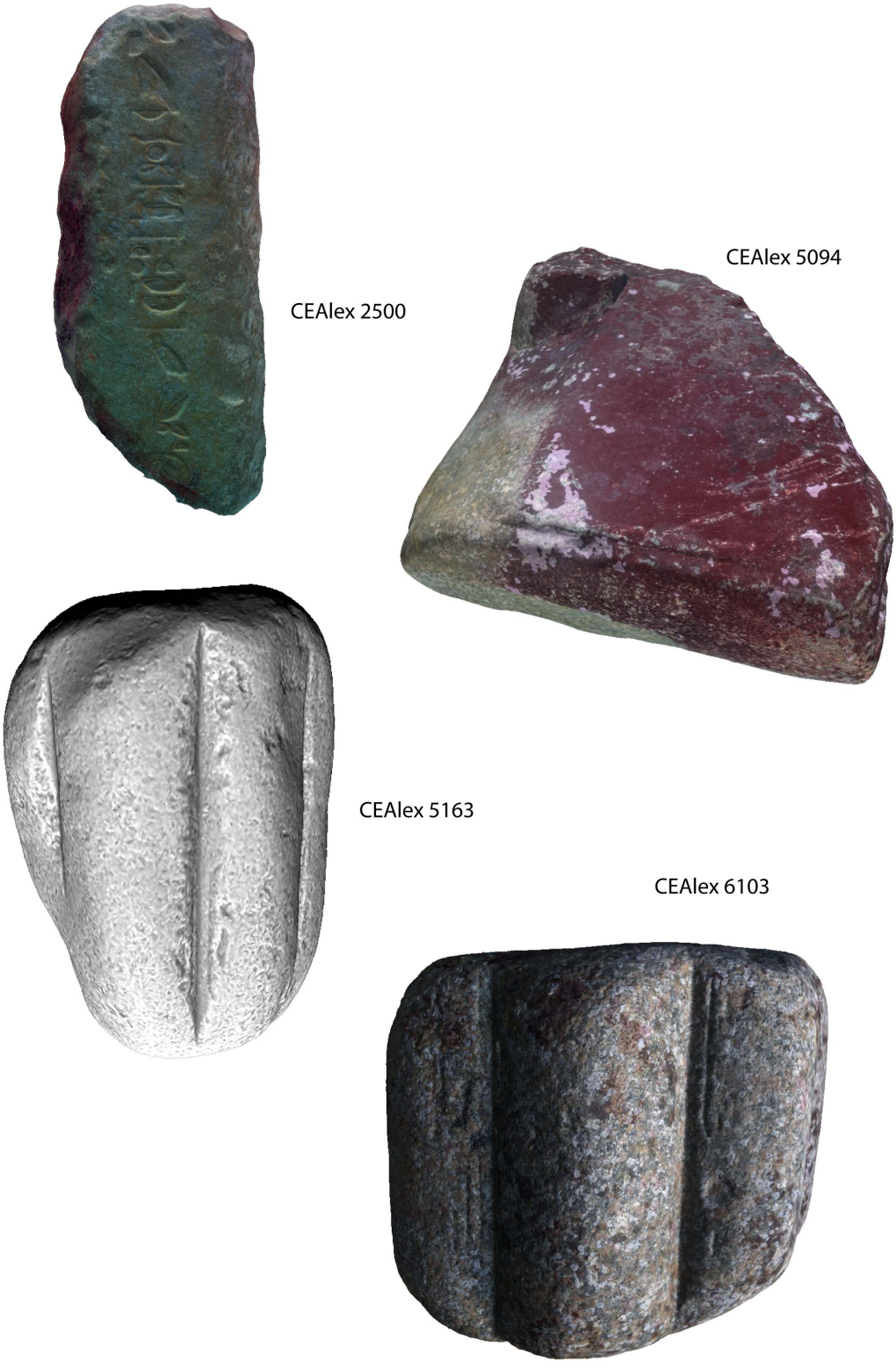

Fig. 2D – List of 3D digital models of architectural blocks and statuary created during the two campaigns

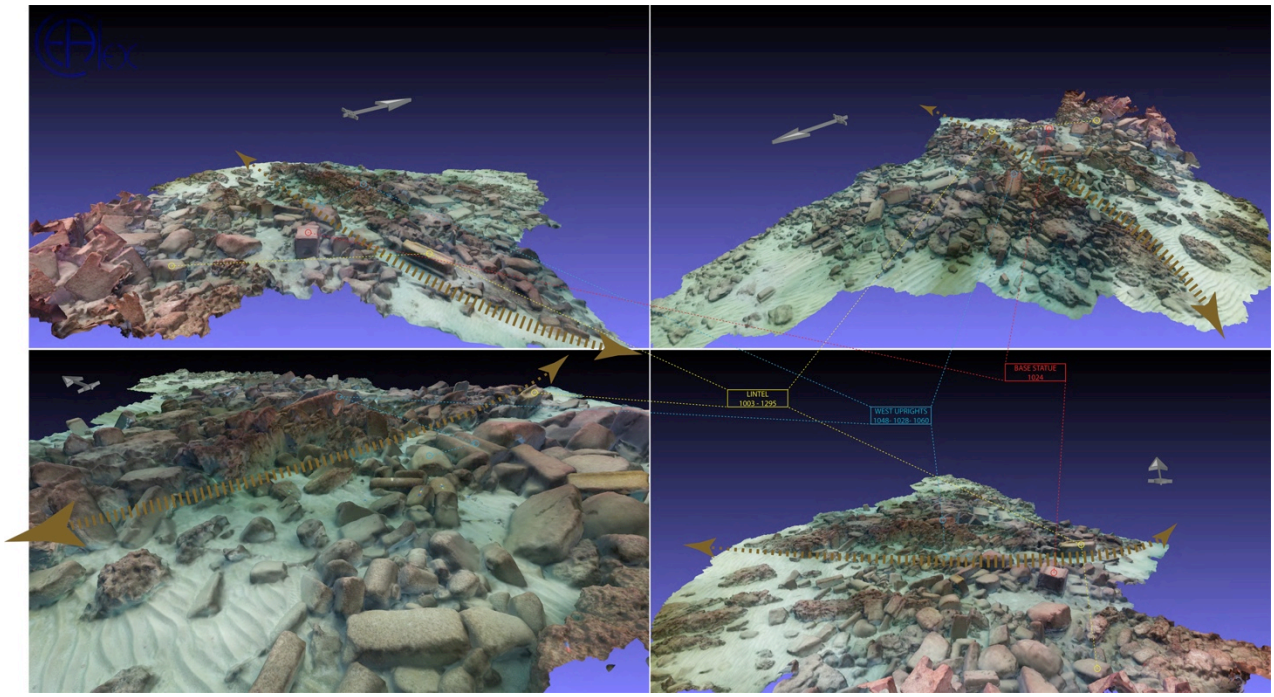

Fig. 3 – Snapshot of the digital elevation model showing the fracture and the blocks from the Lighthouse (photographs M. El Sayed, photogrammetry M. Abdel Aziz, CAD I. Hairy)

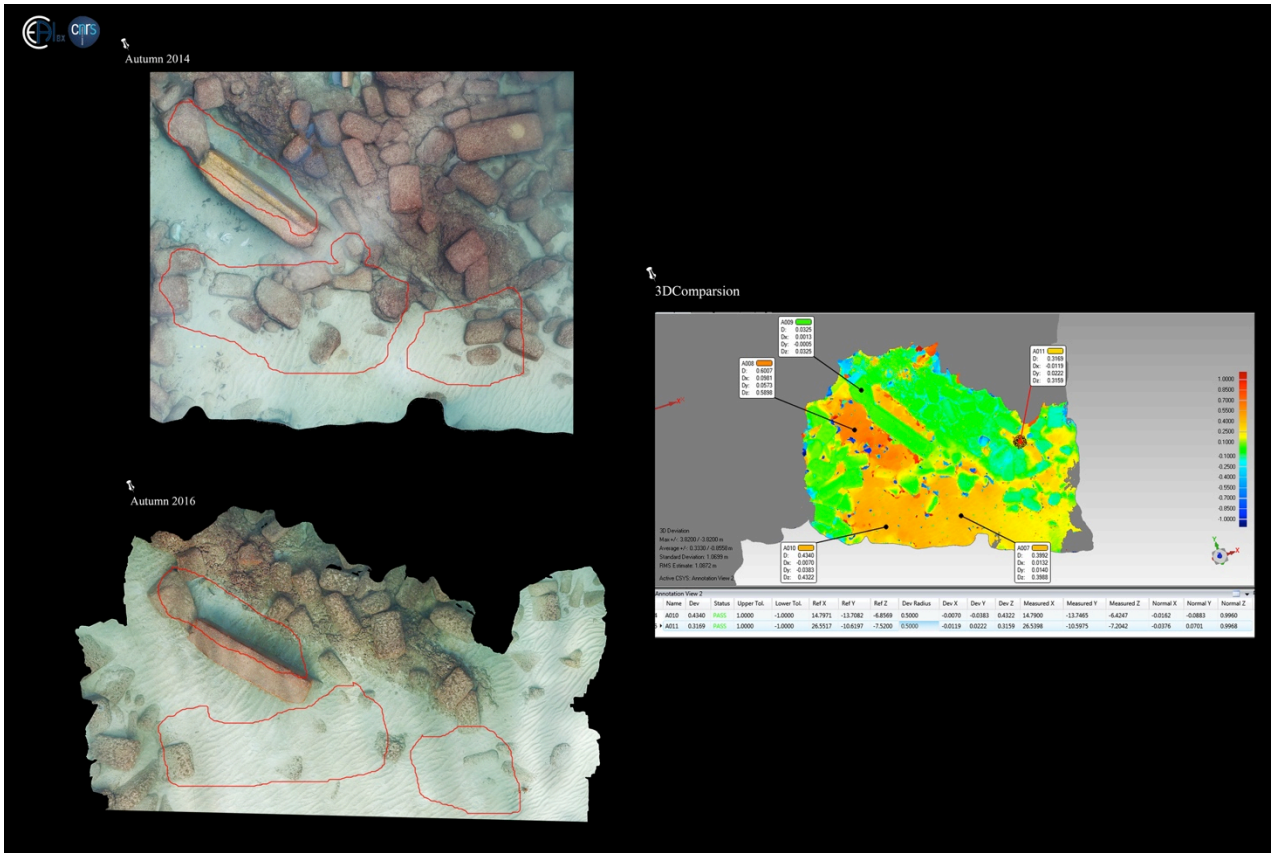

Fig. 4 – Extracts from the digital elevation models (DEM) 2014 and 2016