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An estuarine tide-scape of production: terrestrial laser scanning (TLS) of fixed fishing structures and a tidal mill in the Léguer Estuary, Brittany, France

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Abstract

Terrestrial Laser Scanning (TLS) provides rapid, highly accurate, surveys of excavations and structures at landscape scales - particularly valuable for tidal environments. Here we use TLS to record the excavation of buried tidal fixed fishing structures, and a tidal mill, within the Léguer Estuary at Le Yaudet. All the early Medieval (6th-8th Century) structures lie within, and exploit different parts of the tidal frame in a comprehensive resource exploitation system. TLS can record and quantify aspects of an estuarine landscape of production associated with seignorial control of environmental resources and offers a step-change in recording fixed fishing and allied structures.

Background

Terrestrial laser scanning TLS has been used to record artefacts from waterlogged wooden stakes (Lobb et al., 2010) to complete boats (Tanner 2013), and archaeological structures from Megalithic monuments (Abbott and Anderson-Whymark 2012) to Post-medieval interiors (English Heritage 2011). It has also been used for palaeo-landscapes (Entwistle et al. 2009) and caves - for which it has proven particularly valuable (Zlot and Bosse 2014). However, it has not yet reached its full potential as it can provide highly accurate 3D models which both record excavation and can be used to answer questions of function and context through environmental modelling. We show here how

TLS offers a step-change in recording and understanding fixed fishing and allied structures through in-situ recording, landscape analysis and functional modelling.

The inter-tidal environment is particularly challenging for conventional methods of survey and excavation, but also the most threatened archaeological zone worldwide (Pontee and Parsons 2010). There are also structures/artefacts typically found in the coastal zone, such as fixed fishing-structures (or fish weirs, basket racks) and tidal mills, that have long histories and about which we have very limited knowledge (Jecock 2011). Erosion, or erosion management, of the coastal zone typically exposes these structures and prompts recording (e.g. Rapid Coastal Zone Surveys in the UK) but rarely excavation.

Fixed fishing-structures (or mass fish capture devices) and tidal mills are particularly valuable as they provide information on wood technology, fish processing and storage, environmental cognition, cultural beliefs, delayed return economics, and social organisation. They are also intimately connected to environmental factors including relative sea level, river discharges, storminess and fish populations. Because of this they should not be seen in isolation and require setting within their environmental – or sea/landscape context. Recently several coastal surveys have targeted fixed fishing structures along the Shannon estuary, Ireland (O'Sullivan 2005), Wales (Moore-Scott 2007), Southern England (Brown et al. 2010; Royall 2013; Cooper et al. 2017) Brittany (Langouët and Daire 2009) and Normandy (Billard and Bernard 2016).

Methodological Considerations

The TLS survey used a Leica ScanStation C10 with scans registered together using High Definition Survey (HDS) targets, with a mean registration error of 4 mm. GNSS was used to survey in the target locations, creating a final registered accuracy of *c.*15 mm. The registered scans from each survey were incorporated into a single database. Standard challenges encountered with TLS are exacerbated by the environment of the inter-tidal zone. Reflectivity, the ability of a surface to return the laser signal, is reduced due to the presence of moisture or water, resulting in inaccurate or negative data. 'Shadows' or voids in the data are caused not just by the multi-faceted nature of the features of interest, creating the need for numerous setups, but also by the null or negative

responses from where the laser hits standing water. The stability of the equipment is problematic as the intertidal substrate becomes unstable with the rising tide, as the freshwater table rises in advance of salt water incursion. Logistical considerations are also exacerbated within the coastal zone as the tidal range creates a limited time frame in which to access and record archaeological remains. In many cases this also necessitated cleaning or re-excavating sites which have been inundated by sediment in every tidal cycle. In addition, in coastal environments wind and rain can be particularly challenging for equipment and the surveyor. Nonetheless, TLS offers a potential solution to the logistical difficulties associated with recording inter-tidal structures due to its relative speed, portability and high spatial resolution and accuracy.

The Sites

The sites are all located within the estuary of the Léguer River 5 km west of Lannion within the Côtes-d'Armor, Brittany (Figure 1). The Léguer river is 61.3 km long, the last 9 km of which is tidal. The river discharges to the west into the Bay of Lannion, and is thus sheltered from the stronger currents of the Channel to the north. Downstream of Le Yaudet promontory the estuary widens significantly and it is here that the majority of the intertidal structures are located. Enclosing the Baie de la Vierge is a large curved wall which is known locally as 'le mur du pêcherie' – 'the wall of the fishery' but which has been interpreted as a tidal mill (Cunliffe and Galliou 2004). To the west of the Baie de la Vierge a large rectangular line of stones is located at the higher end of the tidal range. Further to the west the short curved line of stones at Poull Mad Dogan has been tentatively identified as a fishing weir (6), along with two further V-shaped weirs to the west at Dourven (1 & 2). Along the right (north) bank of the river are the large V-shaped structure at 'Le Petit Taureau' which were excavated in 2012 and 2013 (by Daire and Langouët). The excavations have revealed four distinct phases of weir built in stone (7), with an earlier timber phase identified through excavation in 2012 and 2013 (5). Further downstream another smaller V-shaped structure, Corps de Garde, is evident (3).

The Léguer estuary is a Site du Réseau Natura 2000, a designation applied to maintain fish stocks. Today the estuary has migratory species of sea trout (*Salmo trutta*), Atlantic salmon (*Salmo salar*), and European eel (*Anguilla anguilla*), and was likely home to the same species when the structures within the estuary were in use. Historical evidence

also exists for the catching of a large shoal of herring (*Sardina pilchardus*) behind 'Le Mur du Pêcherie' (Cassard 2003) – an event notable for being unusual, rather than representing the intended purpose of the structure.

Results

Structures within an Intertidal Landscape

In 2006 the *Association Manche Atlantique pour le Recherche Archaéologique dans les Íles* (AMARAI) commenced the 'Maritime Fish-traps of Brittany' project, to quantify and characterise fishing structures around the Breton coastline (Langouët and Daire 2009). The fieldwork compiled a database of over 550 structures. One key site identified for further investigation was the large V-shaped structure in the Léguer estuary at 'Le Petit Taureau', which had at least four phases and so presented an unusual opportunity to look at the development of such structures over time. A programme of excavation in 2012 led to the discovery of a much earlier timber built V-shaped fishing structure directly underlying one phase of the stone alignments. The excavations revealed a line of wattle and post construction, supported by a finely crafted mortice and tenon sill-plate with triangular stanchions similar to the 'hurls' known from Irish weirs, which would have been filled with stones to stabilise the walls of the structure and prevent their destruction in strong tides or storms. The structure represents a substantial investment of skill, with finely constructed mortice and tenon construction, dated through dendrochronology to the 615 AD (Bernard and Langouët 2014). The TLS survey of the timber-built fishing structure was carried out while the excavation was ongoing, in June 2013. The excavated sections of the late 6th to early 7th century V-shaped structure were recorded, along with the extant 16th-18th century stone-built structures (Figs. 2-4). In addition a stone-paved trackway leading down to the beach (Figure 5), contemporaneous with the later structures, was also surveyed, as was the smaller V-shaped fishing structure at Corps de Garde to the west of the site. In November 2014 a return visit was made to scan the structure in the Baie de la Vierge, to the west of the promontory of Le Yaudet in order to survey in other features in the estuary.

The georeferenced TLS survey was imported into AutoCAD to generate two-dimensional sections of each structure. These sections were then plotted against each other with reference to the local mapping frame (IGN69) and zéro hydrographique (ZH), the French equivalent of chart datum (Figure 6). The cross-sections enable a direct visual comparison of the vertical placement of structures across the estuary within the tidal frame, and immediately allow some conclusions to be drawn. The most obvious is the relative heights of the structures at Le Yaudet and 'Le Petit Taureau', suggests that the structures were exploiting different ends of the tidal frame and therefore fulfilling very different functions.

The relative heights of two phases of structure at 'Le Petit Taureau' initially suggested that the later structure sat higher in the tidal frame, potentially suggesting a shift in the RSL at this point. However, the cross-section of the *c*. 7th weir indicates that the timber sill beam had curved over a large underlying rock, implying that the structure has been pushed downward into the sediment by the weight of the overlying stone-built phase. This implies that the 7th century AD structure originally sat at a higher position within the tidal frame, by as much as 0.5m. The earlier phases of the structure at 'Le Petit Taureau' were first exposed due to an industrial level of sand extraction in the late 20th century, causing channel migration and displacement of sediments through the estuary. This relationship between the structures and the sediment is important, as it suggests that the various phases of rebuilding of the structure, and the increased height at which subsequent phases were built, could therefore be attributed to the gradual increase of the level of the foreshore due to sedimentation caused naturally and/or by the structures themselves. The scan of the trackway (Figure 5) also shows ongoing erosion of the cobbled surface, and the intensity of return image clearly differentiates between sand burying the lower part of the structure and the stone.

Scanning and Volumetric Modelling 'Le Mur de Pêcherie' in the Baie de la Vierge

The first archaeological investigations of 'Le Mur du Mêcherie' (Figure 7a) carried out in the 1970s included an excavation across a sluice (Pinot 1991; Figure 7b). The structure was then comprehensively surveyed as part of the investigations into the site at Le Yaudet (Cunliffe and Galliou 2004), and a stone by stone plan produced (Figure 7c). The excavation had uncovered the base of the presumed sluice, and so provided valuable

information about the positioning of a diagnostic feature in relation to the tidal frame. Alignment of the Pinot drawing with an elevation generated from the laser scanning data allows the accurate placement of this significant feature within the tidal frame (Figure 7b). The results compare well with the tide mill uncovered at Nendrum, Northern Ireland, where the base of the millrace pond sat approximately 0.5 m below MHWN (Browne 2007). This supports the hypothesis that the structure at Le Yaudet is most likely the reservoir wall for a tide mill. A comparison of the sections also reveals slight differences in the morphology of the structures at 'Le Mur de Pêcherie' compared to those at 'Le Petit Taureau'. The walls of the 'Le Mur de Pêcherie' slightly inclined at an angle of around 6° from the vertical, differing in profile from the structure of 'Le Petit Taureau' which has pronounced perpendicular construction in the areas of extant blockwork. Similarly in plan the structure differs, resembling a gentle arc rather than the V-shape which defines the other fishing structures within the estuary. The structure is also perforated by several openings which appear to have functioned as sluices, and which have no comparable features with the structures at 'Le Petit Taureau'.

The placement of the structures within the tidal frame can also be used to explain their differences in size and morphology. The large fixed fishing structures at 'Le Petit Taureau' are situated between the MLWN and the MLWS levels, where 74% of low tides fall. It follows that the principal investment in the construction of fixed fishing structures would be within this area, as it would maximise the return of investment by providing the greatest tidal exposure and potentially thus the largest amount of fish. The smaller weirs at Dourven and Corps de Garde fall below the level of the MLWS but crucially not below the level of the LAT. There is therefore no reason to assume that they were not contemporary with the large structure at 'Le Petit Taureau', as they would still have been exposed, and therefore been functional, during extremely low tides. Approximately 15% of low tides fall within this range and it may be postulated that the relatively small size of the weirs and their position within the tidal frame are not due to their relative antiquity, as originally proposed by Langouët et al. (2012), but to the lesser exposure of this area of the foreshore.

As noted above, a comparison of the heights and morphology of the various structures across the estuary supports the view that structure in the Baie de la Vierge at Le Yaudet

is the reservoir for a tide mill as suggested by Cunliffe and Galliou (2004). The majority of the tidal mills in France are from the Brittany region and in 2016, a new inventory was completed and 140 tidal mills are now identified from archaeological data and historical records (accessible at: http://patrimoine.bzh/gertrude-diffusion/dossier/les-moulins-a-maree-de-bretagne/19934f6b-e5d4-42a0-ba6d-ec8b00638295). The Baie de la Vierge is ideal for a tide mill, being an unused inlet that could easily be blocked off (Charlier *et al.* 2004). The placement of the structure at the top end of the tidal frame is consistent with the siting of tide mills, which required a tidal coefficient of 65 to 70 (Wailes and Gardner 1938). In practice this meant that they were sited at a point in the tidal frame three hours above the turning tide (Charlier and Menanteau 1997). The barrage is referred to in the *Vita S. Euflam* (*Life of Saint Efflam*) the earliest version of which is thought to have been written down in the twelfth century (de La Borderie 1892, 289–90 cited in Cunliffe and Galliou 2004). It is referred to as a device for trapping fish, omitting any mention of a milling function suggesting that by the 12th Century the mill and all knowledge of it had disappeared (Cunliffe and Galliou 2004). The presence of 7th century AD constructions on the north side of the estuary, and the association of the structure with the Life of St Efflam, suggests that the 'Mur de Pêcherie' is of an early medieval date. In this case it would be directly comparable to the 7th century AD sites of Ebbsfleet (AD 691-2) in Kent, England (Hardy *et al.* 2011), Nendrum (AD 619-621) in County Down, Northern Ireland (McErlean and Crothers 2007), and Little Island (AD 630) in County Cork, Ireland (Rynne 2000). All of these examples are on narrow tidal-creeks and on sheltered parts of the coast, with those that also use a freshwater source placed where a small stream enters an estuary, as it is the case at Le Yaudet. There is also evidence of cultivation and several corn drying mills at Le Yaudet associated with what was probably a significant early monastic settlement (Cunliffe and Galliou 2004). The lack of evidence for a wheelhouse is not as problematic as it might seem, as most mills of an early date, such as Nendrum, Ebbsfleet or Killoteran were constructed almost entirely of wood (Hardy *et al.* 2011). Horizontal mill wheels, common in tide mills of most periods, would have sat above the wall. The suggestion that the structure had the primary function of a mill and millpond does not preclude its use for catching fish, indeed the tide mill at Nendrum was originally thought to have been a fishing structure prior to its extensive excavation (McErlean and Crothers 2007).

Work by Browne (2007) on Nendrum mill provides a model by which this volumetric data can be used to assess the potential mill output. To calculate the volume behind the 'Mur de Pêcherie' the point cloud was interpolated into a surface by fitting a TIN (triangulated irregular network) creating a Digital Elevation Model (DEM). A flat plane was then introduced above the DEM at the height of MSL, MHWN, MHWS and HAT (Figure 8). This allows a visualisation of the different tidal states and the calculation of the potential of the reservoir by calculating the volume between the plane and the mesh. Tide mills were unusable on neap tides or when the wind held up the waters, and in any case the MHWN level falls below the level of the structure. A calculation of the volume of the reservoir during MHWS will therefore give the average volume of water on usable tides. This was calculated for the extant remains and then calculated for a range of heights which may represent the extent of the original structure. The excavations by Pinot (1991) show that the functional part of the structure lay at least 1m below present ground level, and the lack of a binding course on top of the current structure suggest it may have been at least one course higher than the current extant remains. Calculations were therefore made for the extant remains plus additional heights at 0.5 m intervals (Table 1).

	MHWS	**HAT**
Extant remains	9926	26189
Extant remains +1m	28177	51241
Extant remains +1.5m	40253	65730
Extant remains +2m	53764	81210

Table 1. Estimated potential volumetric capacity (in cu m) of 'Le Mur de Pêcherie'

The volume was then calculated using the formula by Browne (2007) to calculate the potential annual output of the mill, based on the characteristics of the mill at Nendrum. Although the morphological data from the site is incomplete, known 7th century AD tide mills show a great deal of consistency. The modern tidal range at Nendrum is *c.* 3.4 m. The Nendrum millpond has area of 2000 m^2, which at MHWS created a volume of water of approximately 1800 cu m. According to Browne (2007) this allowed the tide mill to generate an annual power equivalent to 50 tonnes of milled barley per year. A comparison with results of the volumetric analysis at Le Yaudet suggests that it could have had a volume nearly 16 times greater than that of Nendrum, allowing as much as

800 tonnes of barley to be milled per year supporting a population of over 1000 (assuming 20 bushels per head per year).

The Léguer Estuary: A Landscape of Production

Le Yaudet headland, which has significant earthwork fortifications dating from the Iron Age and Roman periods, continued in importance through the early Medieval and Medieval periods as a religious centre for pilgrimage linked with the lives of St. Enora and St. Efflam - prominent 6th century Irish missionaries (Cassard 2003; Cunliffe and Galliou 2004). The number, size and persistence of the fixed-fishing structures, including the creation of the rock-cut and constructed track to them (Figure 5) and the tidal mill suggest a large and stable local community under monastic or seignorial control. The TLS survey also provided the opportunity to examine the relationships of the structures within the tidal frame, as different structures require fixed areas of the tidal frame to operate. Intertidal structures have the potential to be used as benchmarks for sea level, and previous work in the Léguer estuary by Langouët *et al.* (2012) has taken this approach and assumed that the dates of the intertidal structures within the estuary can be calculated by comparing their varying heights (Table 2). In this approach the base of each intertidal structure is assumed to be at the level of the 'plus haute basse mer de morts-eaux' (PHBMme) or lowest neap tide.

No	Site	Nb(m)	δ(PHBMme) (m)	Attributed Age
1	Trédrez, Dourven-A	0.40 ± 0.20	3.70 ±0.10	Bronze Age
2	Trédrez, Dourven-B	0.70 ± 0.20	3.40 ± 0.10	Bronze Age
3	Servel, Corps de Garde	1.70 ± 0.10	2.40 ± 0.10	Iron Age
4	Ploulec'h, Baie de la Vierge	2.38 ± 0.10	1.70 ± 0.20	Gallo-Roman to early Medieval
5	Servel, Petit Taureau (D)	2.45 ± 0.05	1.60 ± 0.10	650 AD
6	Ploulec'h, Poull Mad Dogan	2.80 ± 0.30	1.30 ± 0.30	Early Medieval
7	Servel, Petit Taureau (A	2.90 ± 0.10	1.20 ± 0.10	Late 15th century

Table 2. Surveyed heights of inter-tidal structures within the Léguer Estuary.

The difference between this level and the modern datum is then calculated (δ(PHBMme)), and used to provide a relative date. However, it is suggested here that the structures operated, contemporaneously within the tidal frame. This makes the

assumption that the tidal frame has remained roughly the same since construction. This is a difficult assumption to test as an accurate enough historical sea level curve does not exist for this location. The tidal gauge at Roscoff has been recording tidal height data since 1973, during which time the monthly mean has risen from 6834 mm to 7037 mm above RLR (revised local reference) datum. However, this short period accounts for only two full metonic cycles (period of 19 years in which the sun, moon and earth return to the same relative positions) and so cannot easily be projected backwards over several centuries. It is therefore difficult to use this as a model of the RSL over past 1500 years at the site. What can be said, however, is that none of the structures at the site lies outside the tidal frame, all are submerged for at least some of the tides, and none are below LAT. If there had been a significant shift of the relative sea level in either direction, one or more of the structures would likely lie outside the tidal frame. Additionally all of the structures are in the appropriate location within the tidal frame to fulfil their original function, as all of the presumed fixed fishing structures are situated between the MLWS and MLWN levels, whilst the 'Mur de Pêcherie' is perfectly positioned to function as a tide mill. The difference in heights between the 7th century timber weir and the later overlying structures appears to have been caused by sedimentation rather than a change in RSL. In contrast, examples of fishing structures from other locations in Brittany, as well as comparable sites in Wales and Essex, have been found below the level of LAT (O'Sullivan 2003).

Conclusions

In assessing the function of the varying sites within the Léguer estuary, the application of TLS has made a significant contribution. The TLS modelling of the 'Mur de Pêcherie' of its morphology, tidal-frame position and volumetric potential in association with an early monastic settlement all make a strong case for its usage as a tide mill. The TLS survey at a landscape level shows several structures operating for several different purposes within the tidal frame. This exploitation of different parts of the intertidal and coastal zone across this small estuary implies a control of the landscape as a whole, most likely from the settlement and monastic community at Le Yaudet, - a fortified early Medieval settlement with a sheltered landing place, one large fishweir to exploit the majority of tides, one or more smaller weirs for the more extreme tides, and a tidal mill for flour production. This would certainly be in keeping with the concept of a monastic

community and the early Medieval concept of self-sustaining communities with an emphasis on fish-eating in keeping with the 6th century Rule of St Benedict which also stated that monasteries should have mills (Wikander 2000). The association of Le Yaudet with 6th century Irish monasticism, and the very similar tide mill sites at Nendrum and Little Island, provides an interesting wider geographical context.

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Figue 1. Intertidal structures: Léguer estuary 1. Dourven-A 2. Dourven-B 3. Corps de Garde 4. Baie de la Vierge and the 'Mur de Pêcherie', 5. Petit Taureau (D) 6. Poull Mad Dogan 7. Petit Taureau (A).

159x97mm (220 x 220 DPI)

Figure 2. Petit Taureau fish weir under excavation (M. Lobb)

157x117mm (150 x 150 DPI)

Figure 3. TLS scans of Petit Taureau and detail under excavation and photo (bottom right)

242x109mm (150 x 150 DPI)

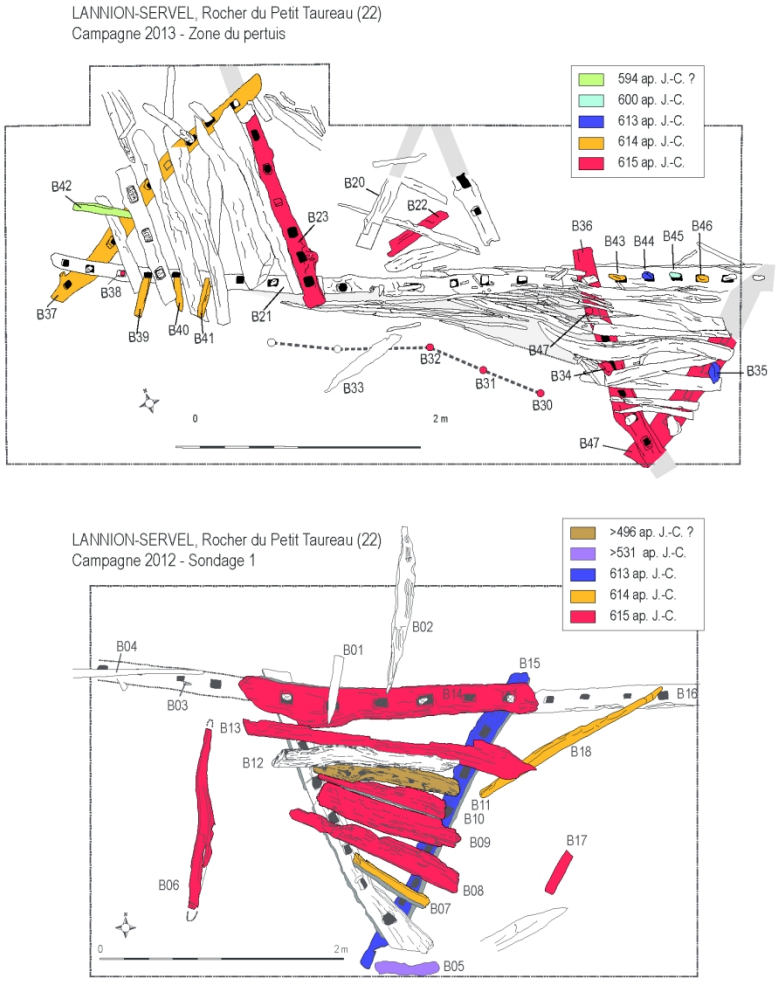

Figure 4. Plans of the Petit Taureau fish trap with dendrochronological dates.

210x297mm (200 x 200 DPI)

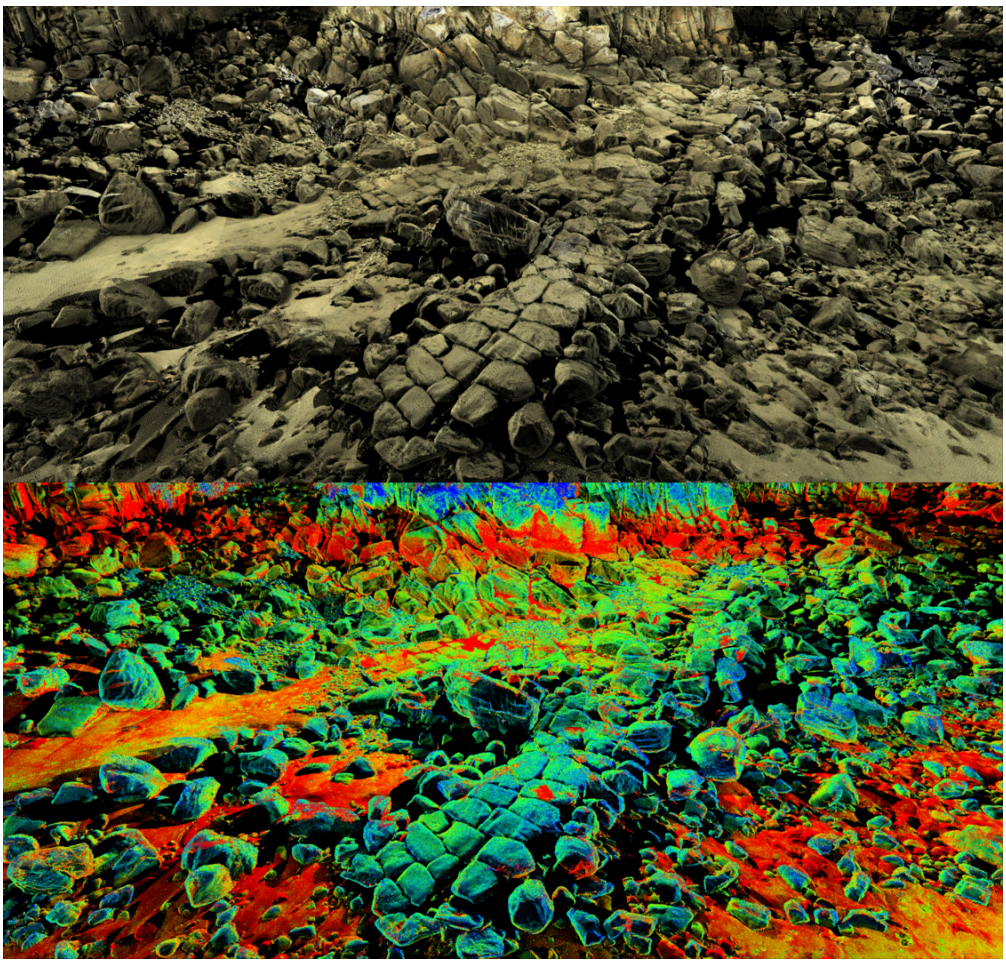

Figure 5. The stone-paved trackway leading down to Petit Taureau. Photo draped (top), intensity draped (bottom).

190x181mm (150 x 150 DPI)

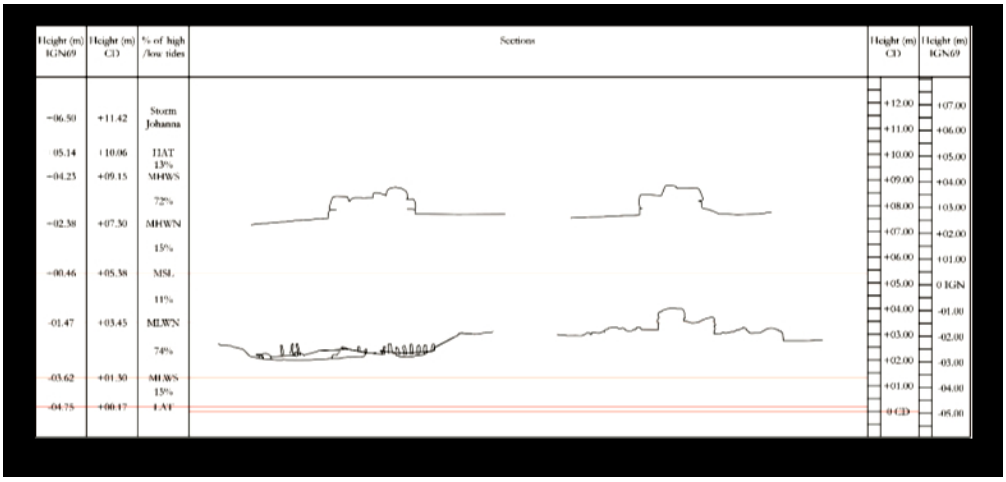

Figure 6. TLS heights of structures within the Léguer estuary. The red lines indicate the various heights of the tidal state (shown left). The top profiles show cross-sections of the structure at Le Yaudet, while the bottom two profiles show a section across the excavated 7th century timber structure (left) and extant stone 16th-18th century weir (right). HAT = Highest Astronomical Tide, MHWS = Mean High Water Spring, MSL = Mean Sea Level, MLWN = Mean Low Water Neaps, MLWS = Mean Low Water Springs, LAT = Lowest Astronomical Tide

132x62mm (150 x 150 DPI)

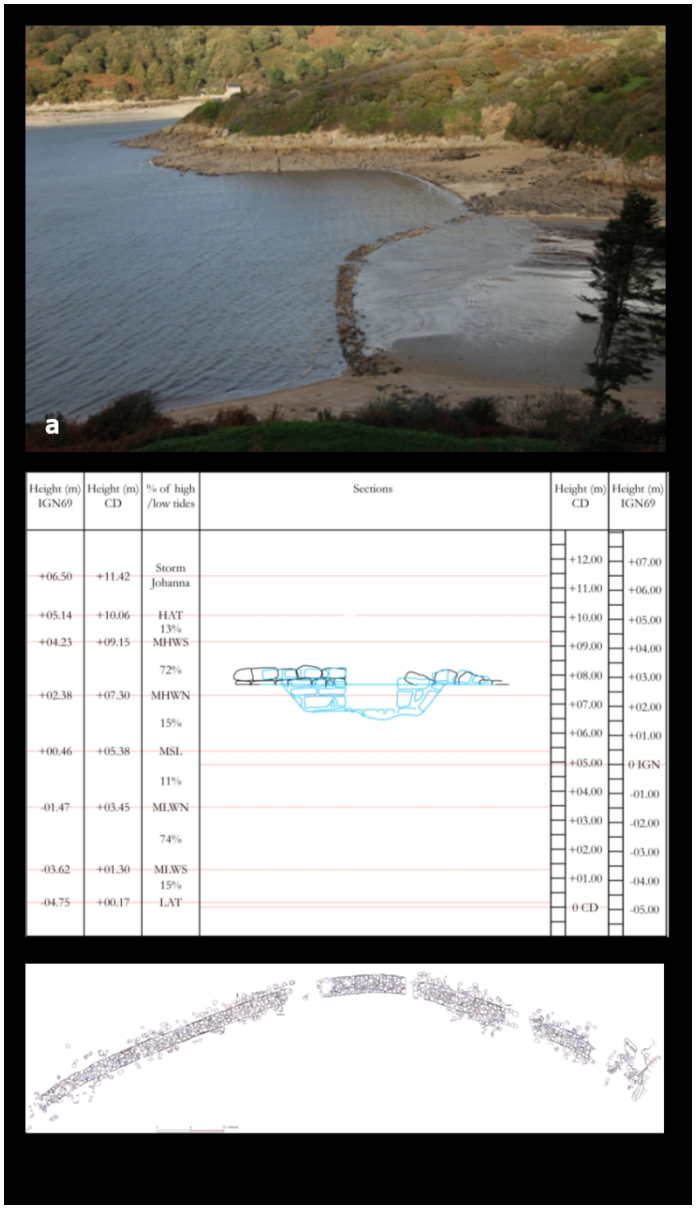

Figure 7 (a) The stone intertidal structure at the foot of le Yaudet from the west at mid tide, (b) Pinot (1991) elevation (blue) rectified to point cloud elevation (black), the red lines indicate the heights of the different tidal states (c) Plan of structure at Le Yaudet produced by total station survey (Cunliffe and Galliou 2004).

141x246mm (150 x 150 DPI)

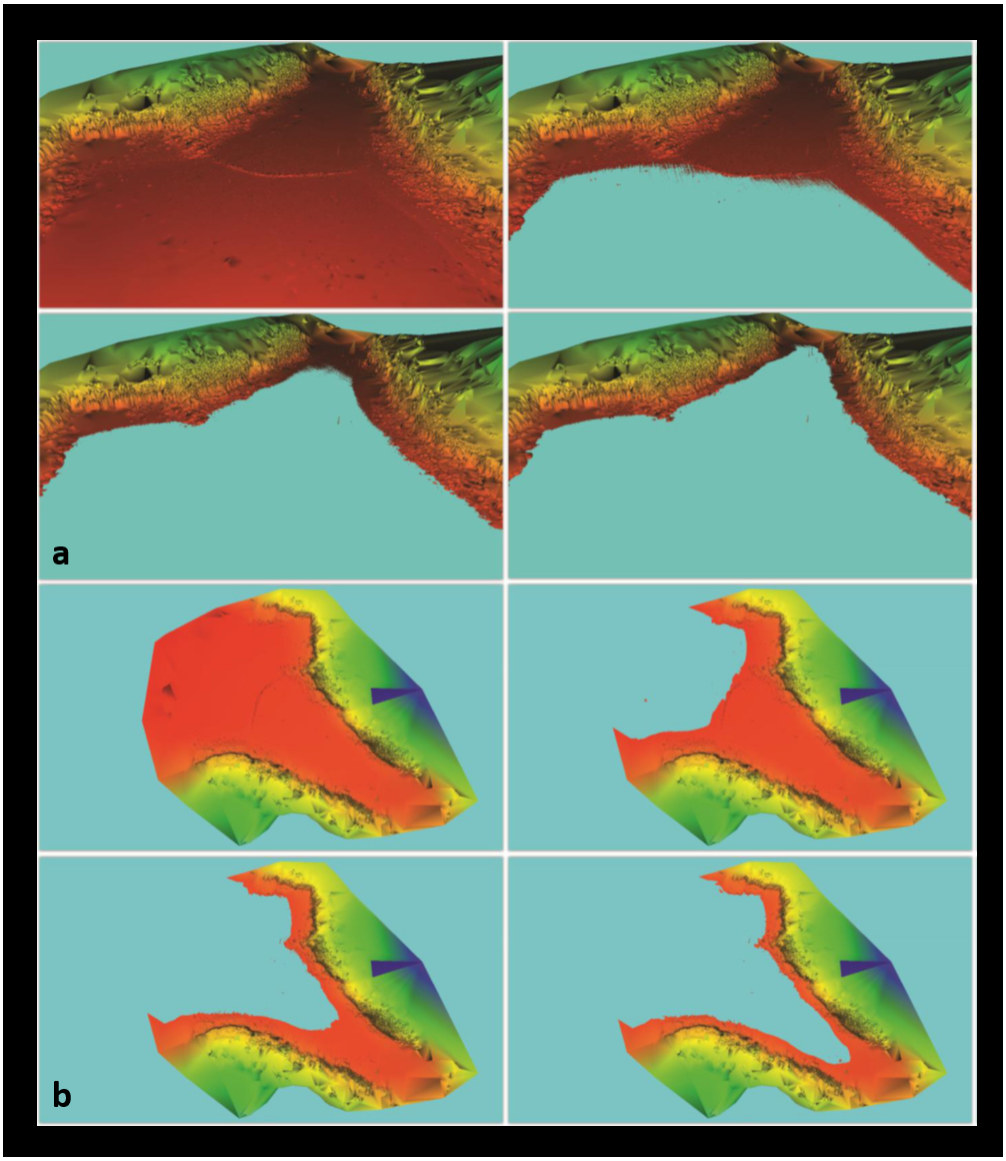

Figure 8. (a) NE view of the TLS survey of the structure at Le Yaudet with virtual water levels set to MSL (top left), MHWN (top right), MHWS (bottom left) and HAT (bottom right), (b) NE view of the TLS survey of the structure at Le Yaudet with virtual water levels set to MSL (top left), MHWN (top right), MHWS (bottom left) and HAT (bottom right).

169x195mm (150 x 150 DPI)