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THE TOTAL STATION AS A TOOL FOR RECORDING PROVENANCE IN PALEONTOLOGY FIELDWORK: CONFIGURATION, USE, ADVANTAGES, AND DISADVANTAGES

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ABSTRACT: **Fossil data collecting is an essential stage of every paleontological undertaking. Although there is a consensus regarding the fundamental importance of sedimentary and stratigraphic context, there is still some debate surrounding the need to record the exact position of a fossil in relation to other elements within the same deposit (provenance). Here we provide a practical guide for the in-field use of the Total Station (TST, electronic equipment for *xyz* coordinates measurements), a tool that has seen wide application in archaeology but has been largely neglected in paleontology. With the TST, recording the provenance of *in situ* fossils can be done quickly and with great precision. We also present a configuration tutorial showing how to use the equipment, based on our experience in the Solimões Formation (upper Miocene, Acre basin, Brazil), highlighting both its advantages and disadvantages for recording fossil provenances.**

INTRODUCTION

Throughout the history of paleontology a number of field techniques have been proposed, ranging from the recording of precise geographical coordinates to the plethora of fossil collecting methods now available (Kummel and Raup 1965; Raup and Stanley 1978; Eberth et al. 2007). Beginning in the late seventeenth century with Nicolas Steno's law of superposition, paleontologists have shown a serious concern for accurately preserving the stratigraphic context of fossil material, and the best means of how to go about this task (Brookfield 2004; Lyman 2012).

Despite ubiquitous consensus about the necessity of recording stratigraphic position, less attention has been paid to issues of fossil provenance. Provenance can be defined as the precise location of a fossil (or an artifact in archaeology) in three-dimensional space relative to a *datum* or reference point (Lyman 2012).

From the early-middle nineteenth century onward, the subject of provenance has been highlighted in archaeological textbooks, not just epistemologically, but with reference to the development of different fieldwork techniques (Lyman 1994, 2012; McPherron 2005; Birkenfeld et al. 2015). In paleontology, although given comparatively little mention, there are nonetheless some papers and textbooks that present methodologies and techniques for recording the exact position of fossils prior to extraction, ranging from the manual meter-grid system to advanced mapping with electronic devices (Camp and Hanna 1937; Leiggi and May 1994; Rogers 1994; Organ et al. 2003; Jennings and Hasiotis 2006; Eberth et al. 2007; Adams 2009; Vila et al. 2010; Hubbe et al. 2011). Nevertheless, the discussion about provenance and its methodological and practical importance remains much more advanced in archaeology (Lyman 2012).

The speed and efficiency with which spatial data can be captured and organized have increased rapidly with the introduction of new technologies, and the precision of recording of provenance has increased accordingly. The Total Station Theodolite (TST) is an electronic device used for decades in archaeology but has few reported applications in routine paleontological practice (Romano and Schoenbrun 1993; McPherron 2005; Conolly and Lake 2006; Jennings and Hasiotis 2006; Marean et al. 2007; Adams 2009; Vila et al. 2010; Bernatchez and Marean 2011; Domínguez-Rodrigo et al. 2012; Bertog et al. 2014; Rovinsky et al. 2015; Birkenfeld et al. 2015; Camacho et al. 2015; Martínez-Moreno et al. 2016).

Here we present a paleontology-focused guide on the use of the manual TST. This basic tutorial is intended to be of utility to all users, including those new to the device. Drawing on our field experience of collecting vertebrate fossils in the Solimões Formation (upper Miocene, Acre basin, Brazil), we also discuss the main advantages and disadvantages of its use, highlighting the importance of mapping the spatial distribution of fossils whenever possible.

TOTAL STATION—TST

The Total Station is an electronic/optical instrument composed of an electronic theodolite (angle measurements), an electronic distance meter (EDM), and a computer or microprocessor (Fig. 1A).

The measurement principle is simple: (1) The EDM emits a beam of infrared light that is modulated at a controlled rate; (2) The beam is reflected back, usually, by a reflecting prism (Fig. 1B); (3) using trigonometry principles the TST automatically calculates the angle and distance between the device and the object of interest. Basically, the unknown distance is yielded multiplying the total number of cycles by its wavelength and dividing by two (Ghilani and Wolf 2012). As a rule, when

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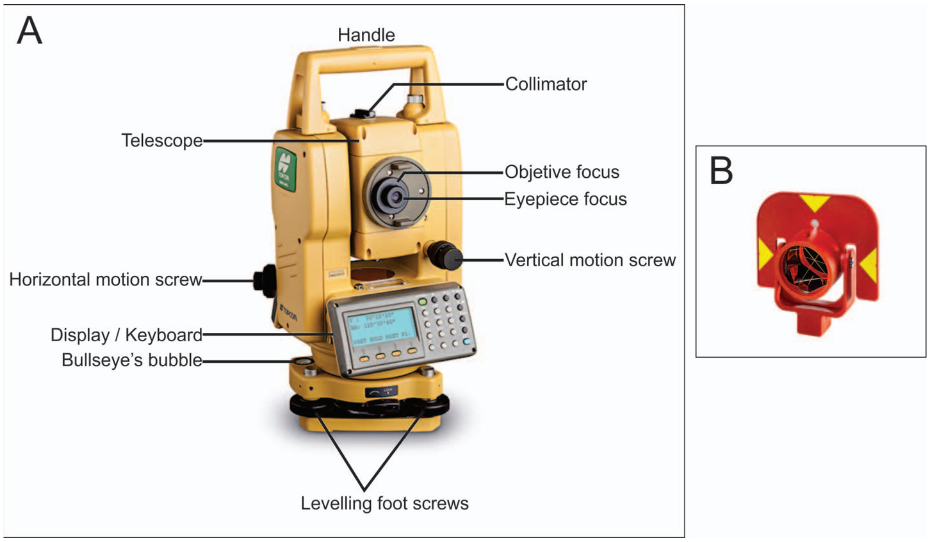

FIG. 1.—**A**) Total station main parts (Topcon model GTS). **B**) Glass prism (model Leica).

properly calibrated, the error margin of measurements is less than 1 cm per kilometer.

The upper part of the TST, also called the *alidade*, includes the axis system, the telescope, graduated circles, and all other necessary elements for measuring angles and distances (Fig. 1A; for more details, see Ghilani and Wolf 2012).

Using the TST

Here we present a basic tutorial for setting up and using the manual model of TST. In order to avoid the loss of field data all the steps contained within should be followed systematically.

We outline the steps for a free-stationing survey from measurements of two known points. This is the simplest setup with which to work, and one that saves time in the field. However, it is possible to use three or more reference (known) points, and this can be useful for detecting and correcting wrong or inaccurate coordinates at a later time.

1. *Fixing two points on the ground*. We suggest two stakes or chisels with a well-established center point (Fig. 2). One is the fixation point (FP), other is the reference point (RP, also referred to as the backsight point). Both points will be used throughout the duration of the fieldwork and must be well fixed within the ground. For paleontological sites excavated across multiple seasons, these points will need to be the same each time. In these cases, we suggest cement both the FP and RP firmly on the ground avoiding any disturbance.
2. *Fixing the TST*. Place the tripod over the FP and hold the TST using the central fixing screw. The equipment should be at a comfortable height (Fig. 2). In order to confirm that the TST is exactly over the FP, turn on the laser plummet (in older models the plummet is optical, usually a peep-hole that lets you see what is directly beneath the total station).
3. *Leveling up*. Once fixed, the TST must be leveled exactly over the FP. Leveling is done using foot screws and the bullseye's bubble (Fig. 1A). To check that the unit is properly leveled, rotate the TST 180° (the bubble should remain within the setting circle). Only turn on the equipment after confirming that the TST is positioned exactly over the FP. This step can be time-consuming for the first few times.
4. *TST Configuration:*

4.1. *Setting up the FP*. Once properly leveled, the TST can be switched on. Start a new job by entering any name (it can be the name of the site or location) and follow the steps suggested by the appliance manufacturer for initial setup. Regardless of the model of TST, some information must be inserted, such as the height of the station relative to the FP, as well as its *xyz* coordinates. These steps are necessary to "tell" the device its exact location. We suggest that the FP coordinates coincide with the exact GPS coordinates, but nothing prevents them from being arbitrarily defined. Write down all this information as well as that of the following steps in your field book each day. By keeping precise notes the researcher can quickly and accurately check all the coordinates and steps from one day to the next.

4.2. *Setting up the RP*. (1) Place the prism over the RP. If necessary you can fix the prism on a stadia rod bubbling it (Fig. 3). In this case, prior to recording the RP, the rod height must be entered within the TST. If a stadia rod is deemed unnecessary, the height of prism must be set at zero; (2) With the collimator and telescope (Fig. 1A) locate the prism center and lock the TST using the vertical and horizontal motion screws (Fig. 1A); (3) In the TST menu select the option Zero (this can vary from device to device). This procedure zeroed the angles at the RP; (4) Mark the RP, saving it to the device's memory.

5. *Marking points*. Once configured (FP and RP) you can begin to mark fossil positions, numbering them as you see fit. Do not forget to save every time you mark a point. Ideally, write down the coordinates in the field book as well.

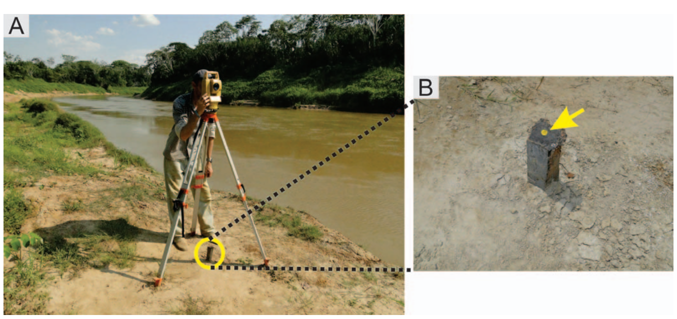

FIG. 2.—Total station leveled over the fixation point (yellow arrow in B).

Steps 2 to 5 should always be carried out again when: (1) The TST needs to be removed and placed again upon the reference point; (2) The tripod is accidentally moved while in use; (3) In extreme cases of severe thermal variations, a reconfiguration might be necessary.

Whenever possible, observe the optical level (bubble) to verify that there has been no change of position due to thermal variation. More advanced devices slow down the operation process when it is not properly leveled, but this is not the rule for most models of TST.

FIG. 3.—Glass prism fixed on a stadia rod.

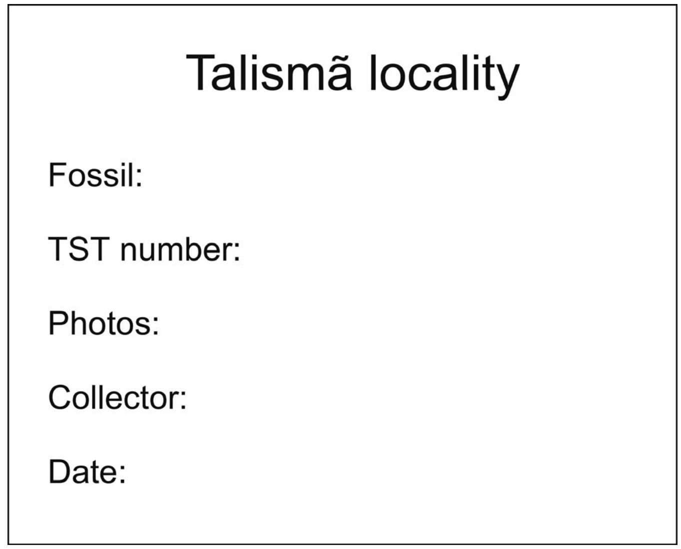

FIG. 4.—An example of a field tag used in the Talismã locality (Solimões Formation, upper Miocene, Brazil), including the TST number.

This concludes our basic tutorial for correct use of the equipment; however, each model will have its own specifications. We recommend that the researcher is familiar with the core functions and settings of their respective TST model. As initial attempts at setting up the device can be challenging for inexperienced users, we highly recommend either seeking formal training or—at the very least—undertaking a preliminary "dry run" or two prior to entering the field.

Field Tags

For all fossils with TST points, we suggest also including a paper field-tag, containing information such as locality or site, stratigraphic unit, photographs, TST number, date, and collector (Fig. 4). The *xyz* coordinates can be noted on the tag as well, reducing the risk of information loss due to any unforeseen circumstances (e.g., damaged equipment, memory erasure). To prevent the tag from being degraded upon contact with the fossil, we suggest storing it in a small plastic bag.

An alternative that has recently been used in archaeology is the generation of individual barcode labels, increasing the speed and accuracy of recording provenance (for more details see Dibble et al. 2007 and Bernatchez and Marean 2011).

Data Processing

Software.—All data can be downloaded from TST to a computer using equipment-specific software (varying from model to model). Once downloaded, the data can be processed by software such as Excel, ArcGIS, Autocad (Adams 2009; Diez-Martín et al. 2014) and Surfer (Ortega et al. 2016). TST data (site topography and the three-dimensional location of fossils) for the Solimões Formation outcrops were downloaded as a Microsoft Excel spreadsheet and later processed in Autocad 2014 and Surfer 10 software (Golden Software 2011) (Figs. 5B, 6B).

Topography.—It is also possible to create topographic maps utilizing the TST. For detailed mapping, it is advisable to record as many points as possible. The more points, the higher the 3D image resolution (e.g., at the Tanzanian Sam Howard Korongo archaeological site more than 4000 points were measured to reconstruct the topography; see Diez-Martín et al. 2014). To construct schematic stratigraphic sections, the TST can also provide accurate width and thickness measurements (Figs. 5A, 6A).

REMARKS AND CONSIDERATIONS

In archaeology and paleoanthropology, the discussion regarding the use of TST goes beyond gathering accurate field provenance information of artifacts and organic remains. The generated spatial data, together with digital cameras and geographic processing software, has enabled high-

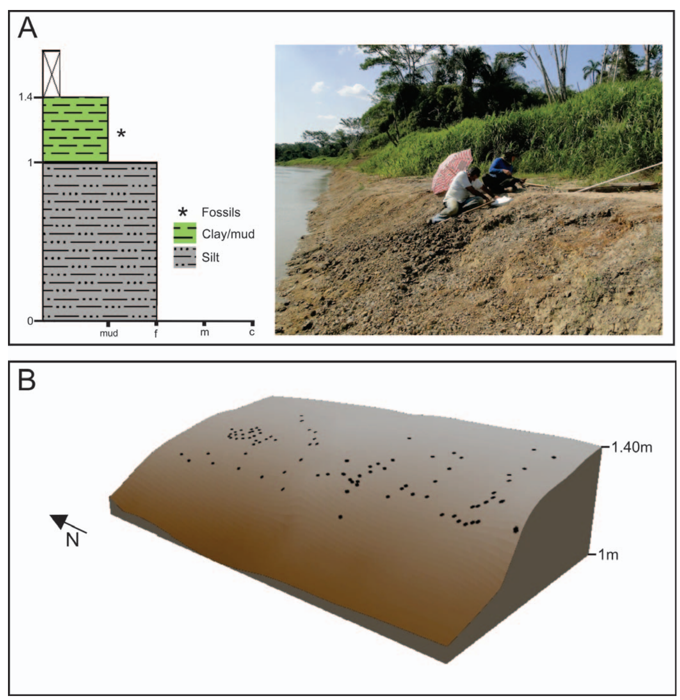

FIG. 5.—**A**) Niterói locality (right, UTM 19L 629983 E/8879539 S) and a representative stratigraphic section (left). **B**) 3D image of the Niterói fossiliferous layer with the position of each fossil (black dots), generated using Surfer 10 software.

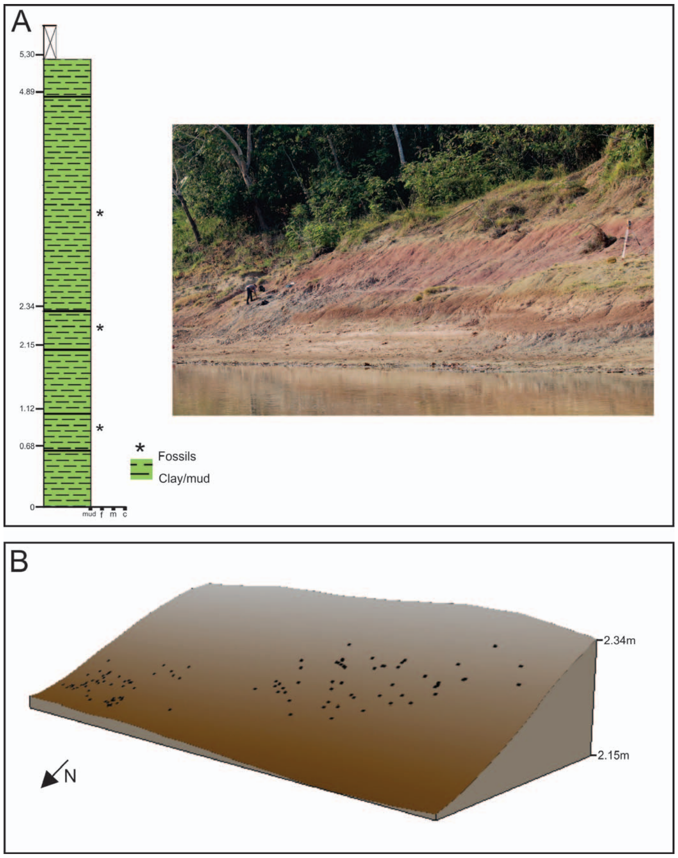

FIG. 6.—**A**) Talismã locality (right, UTM 19L 510475 E/9029741 S) and a representative stratigraphic section (left). **B**) 3D image of Talismã main fossiliferous layer with the position of each fossil (black dots), generated using Surfer 10 software.

resolution photomicrographs of stratigraphic profiles, informing decision-making processes regarding the location of samples for dating, furnishing a better understanding of site formation processes, and guiding the interpretation of the taphonomic history of artifacts and organic remains (Bernatchez and Marean 2011; Fisher et al. 2015). There is also discussion surrounding the need to generate a system for the digital cataloguing of paleoanthropological data, aiming at not only the availability and accessibility of the data itself, but also the standardization of data collecting protocols, allowing for a synthetically broader and analytically comparable treatment of all available records (Reed et al. 2015).

Lyman (2012), in a historical study of how paleontologists and archaeologists record in-field provenance, identifies a lack of formal methodologies in paleontology textbooks, in marked contrast to what is seen in standard archeological practice. According to the author, this underdevelopment may be related to the lack of a standard set of agreed-upon field procedures between paleontologists, as well as the primary focus of paleontological analysis (namely taxonomy and phylogeny).

We know that a fossil deposit carries with it a history of deposition and accumulation of organic remains and/or traces, however, provenance information is increasingly needed for a range of high-resolution paleontological studies (e.g., paleoecological/paleoenvironmental reconstructions, temporal/spatial mixing). Hence, we agree with Lyman (2012) that the growing interest in paleoecology, taphonomy, and paleoclimatology means that the accurate recording of fossil provenances is becoming ever-more essential. Studies of Pleistocene and Holocene taphocenosis have also witnessed, in recent years, an increase in both the availability and accuracy of dating methods (Long et al. 2015; Rixhon et al. 2017).

Therefore, a more precise understanding of the spatial interrelationships of fossils within a collection area may be crucial for subsequent paleoecological and paleoenvironmental analyses. A good example of this is the work of Hubbe et al. (2011), in which fossils from a cave in southeastern Brazil were excavated and analyzed following taphonomic collecting protocols. Through detailed mapping of each fossil occurrence, the resulting provenance record was of paramount importance in assessing temporal and spatial averaging within the assemblage (Hubbe et al. 2011).

To date, our experiences with the use of TST in the Solimões Formation has been encouraging, allowing for the virtual reconstruction of the entire excavated area, including the precise provenance of each fossil. The fine-scale reconstruction has allowed for a greater degree of accuracy in taphonomic analyses, such as temporal and spatial mixing (e.g., geochemical analysis), and is helping us to understand the spatial distribution of taphonomic signatures, as will be illustrated by the two examples presented below.

Example 1.—Geochemical analysis of bones from PRJ20 fossil locality has been performed to understand the assemblage diagenetic history. Fossils recovered with TST provenance information were analyzed by LA-ICP-MS (laser ablation inductively coupled plasma mass spectrometry) to quantify the rare earth elements (REE). Among the REE, cerium (Ce) is a good paleoredox indicator (Trueman and Tuross 2002; Kocsis et al. 2016). Under oxidizing conditions, Ce assumes a tetravalent state (Ce^{4+}) and is removed from solution mainly onto particle surfaces. As a result, Ce is less abundant than others REEs in solution, causing negative Ce anomaly in bones fossilized under oxidizing conditions. The opposite is expected in anoxic environments (German and Elderfield 1990; Trueman and Tuross 2002). Just a single analyzed specimen (specimen 63) presented a discrepant positive Ce anomaly (Fig. 7B). Different REE profiles at the same taphocoenosis can be related to time and space averaging (Martin et al. 2005; Trueman 2007). With the TST provenance data, however, it was possible to recover the exact location of specimen 63 (Fig. 7A), approximately one and a half meters below the others, indicating that different Ce anomaly profiles can be related to different depositional context instead of time and space mixing. This stratigraphic level will be the target of a more intense prospection in further field work, since anoxic environments enhance the preservation of organic remains (Allison 1988).

Example 2.—Talismã is one of the most fossiliferous localities of the Solimões Formation (Fig. 6A). A large number of vertebrate fossils (e.g., crocodiles, frogs, rodents) and mollusk shells were collected in the last 20 years (Negri 2004; Cozzuol 2006; Hsiou 2010). Although widely studied there is no stratigraphic control or provenance data available for fossils collected from this locality prior to our efforts. With the TST we were able to reconstruct the main fossiliferous layer of Talismã taphocoenosis (Figs. 6B, 8A). TST provenance data are allowing a better understanding of the distribution of taphonomic signatures over the entire field area. Although sedimentological and geochemical analyses are still ongoing, we have been able to refit bone fragments that were collected distant from each other, such as specimens 83 and 124 (Fig. 8B, 8C). In such cases, the hypothesis of pre-burial fragmentation can be undeniable attested, regardless of breakage patterns. Once the provenance data of all fossils are recorded in-field, the understanding of issues such as reworking (i.e., fragments of the same specimen found at different levels) and pre-burial fragmentation/dispersion are easily accessed, either visually (i.e., 3D images) or simply based on the geographical coordinates, acquired by the TST, in electronic spreadsheets.

The examples reported here illustrate how the provenance, with the help of TST, is of paramount importance, yielding data that enhance the strength of taphonomic and paleoenvironmental analyzes. It should also be noted that most Solimões Formation outcrops are river banks, exposed only in drier months. Inclined planes make mapping fossils a hard task. This limitation has been largely overcome with the TST.

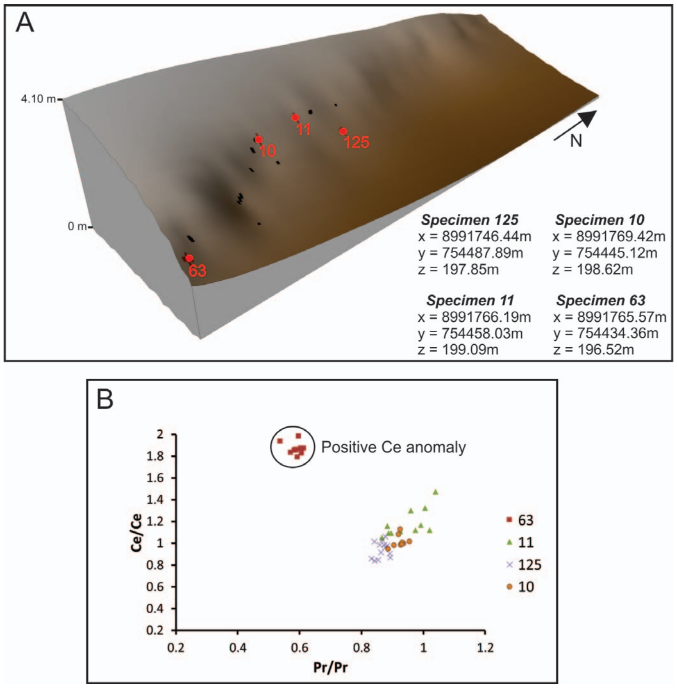

FIG. 7.—**A**) 3D image of the PRJ20 fossil locality (UTM 19L 754453 E/8991769 S) with provenance information of fossils (black dots), generated using Surfer 10 software. Red dots mark the specimens analyzed for REE concentration (*xyz* coordinates in the bottom-right corner). **B**) *Ce/Ce* versus *Pr/Pr* diagram after Bau and Dulski (1996), highlighting the discrepant positive Ce anomaly of specimen 63.

However, we highlight some operational disadvantages:

1. *Costs involved in the acquisition, rent, and calibration*: There are a variety of TST models available at different price points. There is also the possibility of renting, which may be an economically viable alternative in the short term. It needs to be highlighted, however, that TST is a high-precision instrument that requires periodic calibration (at least annually). Calibration costs must be taken into account when purchasing a new one.
2. *The weight and volume occupied by the TST:* This might represent a potential issue in situations where space is limited, e.g., during transportation.
3. *Battery lifespan:* TST uses rechargeable batteries. Hence, long-term fieldwork without access to electricity can present a serious practical issue. In this case, it is advisable to refer to the manual for battery lifespan.

There are also a number of instances in which use of the TST may prove impractical, such as underwater fossil collecting, densely packed bonebeds, isolated occurrences, or collection of fossils that are not *in situ*. In the case of microfossil deposits, the TST can be used to map the locality in three-dimensions. Even in cases where large blocks of rock are collected, the TST can be useful, simply by taking points at the block boundaries. Once the area of interest has also been mapped, the spatial interrelationships of the fossils (contained in the block) may be virtually reconstructed back in the lab. Even if the use of the TST is not possible, grid system mapping is an operationally and economically feasible alternative in the majority of paleontological contexts (Rogers 1994; Organ et al. 2003; Ghilardi 2004; Eberth et al. 2007; Chiba et al. 2015).

The combination of TST with already widely used methodologies (e.g., element orientation, field sketches) is essential to gather as much information as possible, particularly in bonebeds. Applying a suite of

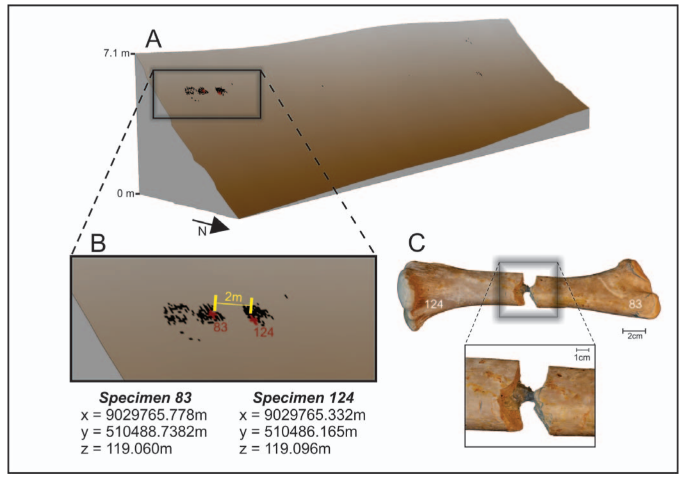

FIG. 8.—**A**) 3D image of Talismã locality, generated using Surfer 10 software. **B**) Location of specimens 83 and 124 and the distance between them, followed by *xyz* coordinates. **C**) Refitted crocodilian right tibia (specimens 83 and 124).

techniques increases both the efficiency of data collection and the subsequent analysis, broadening the range of potential analytical methods as well as providing unique opportunities to compare data sets among fossil assemblages (Behrensmeyer 1991).

CONCLUSIONS

Some field methods have been used by paleontologists to prevent the loss of fossil provenance information. In this respect, the Total Station (TST) can be a useful tool.

The high precision spatial measurements on the field (*xyz* coordinates of each fossil; site topography), fast data processing in electronic spreadsheets and specialized software, and 3D reconstruction of the entire fieldwork area are the main advantages of the TST. Costs involved in acquisition/rental/instrument calibration, weight and volume occupied by the device during transport, and battery lifespan are the main disadvantages. Usually, the device comes with only two batteries. For very long works without access to electricity, this can be a serious limiting factor.

The Total Station is a high precision piece of equipment. We stress the need of following the steps proposed in the tutorial, preventing the loss of field data. We also highly recommend prior training in the lab.

The fossil record yields information that goes beyond those provided by taxonomy and phylogeny of organisms or traces. Neglecting provenance can irreversibly compromise not only the quantity but also the quality of this information.

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