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Description of contents of unopened bamboo corsets and crates from Quarry Ig/WJ of the Tendaguru locality (Late Jurassic, Tanzania, East Africa) as revealed by medical CT data and the potential of this data under paleontological and historical aspects

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ABSTRACT

The German Tendaguru Expedition from 1909 to 1913 to Southern Tanzania (then the German colony Deutsch-Ostafrika) was one of the most successful field campaigns for fossil vertebrates. Forty still originally packed and unopened bamboo corsets and six wooden crates containing vertebrate fossils excavated at Quarry Ig/WJ in the Tendaguru area are preserved at the Museum für Naturkunde Berlin. Studies of the containers with a medical CT scanner made it possible to visualize the packed fossil specimens, which had either a clay protection cover, were still in sediment, or were found as clusters of small vertebrae and tin cans filled with small bones. The majority of bones belong to the small ornithopod *Dysalotosaurus,* supplemented by a few remains of the thyreophoran dinosaur *Kentrosaurus* and sauropod dinosaurs. Criteria for the prioritization of preparation of the material are defined based on their paleontological importance plus their historical value as evidence for an excavation campaign carried out under colonial conditions. Therefore, it is suggested that a few of the original containers be preserved in their original condition. This study provides a nondestructive way to assess information about historical, unprepared fossil material, as well as virtual access to these containers. In its original preservation, the described whole suite of containers is historical evidence of the hard and substantial excavation work of many local people from the Tendaguru area, and it documents historical collection practices including colonial preparation and field practices at the Tendaguru fossil site.

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INTRODUCTION

The German Tendaguru Expedition (GTE), one of the most successful paleontological field campaigns worldwide, was undertaken between 1909 and 1930 and was equipped by the Museum für Naturkunde Berlin (MfN). As the locality Tendaguru in the southern part of today's Tanzania was part of the German colony Deutsch Ostafrika then, the GTE was carried out under colonial conditions. Over four years, field crews of African workers from the Lindi region led by staff members from the MfN excavated around 230 tons of dinosaur material. They combed through an area of over 100 km^2 and opened more than 70 single quarries in the vicinity of the locality Tendaguru (Janensch, 1914a, 1925a, 1929; Heinrich, 1999a; Maier, 2003; Heinrich and Schultka, 2007; Heumann et al., 2018). In the Kimwera language of the resident Mwera people, “Tendaguru” means simply “steep hill”, a denomination that was adopted as the proper name for the hill site by the Germans in the early twentieth century (pers. comm. Dr. Amandus Kwekason, NMT to DS in 2021). Regardless of a huge number of invertebrates, charcoal, fish, small reptile bones and teeth, pterosaurs, and even early mammals, the dinosaur finds are the most prominent of the locality and are mainly responsible for the famous reputation of the Tendaguru among vertebrate paleontologists.

The Late Jurassic Tendaguru Formation (Aberhan et al., 2002; Bussert et al., 2009) comprises six members (Lower Dinosaur Member, *Nerinella* Member, Middle Dinosaur Member, *Indotrigonia africana* Member, Upper Dinosaur Member, and *Rutitrigonia bornhardti-schwarzi* Member). The Tendaguru Formation was deposited in a marginal marine to continental setting with several marine transgression cycles, with the three Dinosaur Members being reconstructed as tidal flat, lagoonal, and coastal paleoenvironment (Bussert et al., 2009). Only a few dinosaur bones have been documented from the Lower Dinosaur Member. In contrast, the Middle and Upper Dinosaur Member of the Tendaguru formation yielded dinosaur remains that are famous for their extraordinary preservation and their taxonomic richness, comprising members of all major dinosaur groups present in the Late Jurassic (Sauropoda, Theropoda, Thyreophora, Ornithopoda).

At least 12 different species of dinosaurs from the Tendaguru are currently considered to be valid. The largest taxonomic variety of taxa is preserved in sauropods (e.g., Janensch, 1929; Bonaparte et al., 2000; Remes, 2009; Taylor, 2009; Tschopp et al., 2015; Mannion et al., 2019), and re-evaluation of the material, even after more than 100 years of study, has led to the discovery of new taxa (Remes, 2007; Mannion et al., 2019). A high taxonomic diversity also seems to be present in the theropods from the Tendaguru area, although their fossil record is complicated by a dominance of isolated teeth and only few skeletal remains, which makes taxonomic determination in most cases difficult (Rauhut, 2011). However, the rich skeletal remains of *Elaphrosaurus bambergi* stand out as the best known Late Jurassic theropod from Africa (Janensch 1920; Rauhut and Carrano, 2016). In contrast, there is only one thyreophoran *(Kentrosaurus aethiopicus),* and one ornithopod *(Dysalotosaurus lettowvorbecki)* taxon documented from the Tendaguru area, though both taxa are represented by a multitude of isolated and partly associated bones. This disparity is also matched by the spatial distribution of the taxa: whereas remains of sauropod and theropod dinosaurs were documented from virtually all quarries, remains of *Kentrosaurus* are restricted to a few quarries close to the Tendaguru (Janensch, 1925a, 1929; Heinrich, 1999a), and *Dysalotosaurus lettowvorbecki* is so far only known from one single quarry “Ig/WJ” north of the Tendaguru, where thousands of bones and even few partial skeletons were preserved in mass accumulations in four different bonebeds (Janensch, 1955; Heinrich, 1999a; Hübner et al., 2021).

Collection History, Status Quo of Investigated Specimens, and Locality Information from Quarry Ig/WJ

Whereas ca. 95% of the dinosaur material from Tendaguru stored at the MfN had been fully prepared, the sheer amount of excavated dinosaur bones accounts for the presence of a few still unprepared plaster jackets and bones in the collection. Among these is a suite of 40 original and unopened bamboo transport corsets plus six wooden transport crates, comprising about 1% of all the dinosaur material from Tendaguru. According to the ink labels glued onto the transport containers, all are filled with fossil material from Quarry Ig/WJ.

Quarry Ig/WJ was first named by Werner Janensch “Ig” for the “iguanodontid” bones that have been found there and were later determined to belong to a small dryosaurid, *Dysalotosaurus lettowvorbecki* (Pompeckj, 1920; Janensch, 1914a, 1955). The quarry is located ca. 2.3 km north-north-west from the Tendaguru (Heinrich, 1999a) and stratigraphically belongs to the Kimmeridgian Middle Dinosaur Member (Aberhan et al., 2002; Bussert et al., 2009; Hübner et al., 2021). Quarry Ig/WJ was initially excavated from 1910 to 1911 under supervision of Werner Janensch and Edwin Hennig, who provided the first field crew from Berlin at the Tendaguru site (Janensch, 1914b; Heinrich, 1999a; Maier, 2003). In 1911, they were joined by Hans von Staff (Maier, 2003; Hübner et al., 2021). From 1912 to 1913, the same quarry was exploited by crews led by Hans Reck, who had replaced Janensch and Hennig in the field. Reck renamed the quarry to “WJ” (referring to the initials of Werner Janensch) and started with new field numbers, because he had no overview about all field numbers that had been assigned to specimens from Ig before (Reck, 1912-1913; Maier, 2003). By that, Reck avoided also mixing the content of different bone beds from Quarry Ig/WJ retrieved from the second excavation campaign with those of the first. Consequently, the outside labelling of the unopened bamboo corsets and crates as “Ig” and the excavation dates between 1910-1911 demonstrate that all these materials were excavated during the first field campaign at the Tendaguru hill under the supervision of Janensch and Hennig.

A recent paper studying the taphonomic conditions of Quarry Ig/WJ determines the presence of four different bonebeds in at least three stratigraphic levels within the Middle Dinosaur Member (Hübner et al., 2021). The remains of *Dysalotosaurus lettowvorbecki* appear in these bonebeds as mass accumulations and the quarry is interpreted as a tidal channel deposit (Hübner et al. 2021). The collection catalogue of the MfN lists rare additional finds of *Kentrosaurus aethiopicus*, *Giraffatitan brancai*, and undetermined sauropod and theropod teeth. Janensch (1925b) also mentioned a dorsal vertebra of *Elaphrosaurus bambergi* and a theropod manual phalanx. Thus, these bonebeds can be described as mixed, multitaxic, and monodominant assemblages (Heinrich, 1999a; Hübner et al., 2021).

A picture by Hans Reck’s wife Ina, who accompanied him during his time at the Tendaguru, vividly shows the excavation situation at the site, with large amounts of sediment being moved around and the busy and persevering work done by the local people (see Hübner et al., 2021 for image). The bones were closely packed in the sediment, and it was decided to mostly take them out in blocks ranging from one to 25 kg (Janensch, 1914b; Hübner et al., 2021). Therefore, it was often impossible to identify single bones before preparation in Berlin. The usual practice for the dinosaur material from Quarry Ig/WJ was to number whole slabs with single field numbers, and list field numbers and order of specimen samples in the GTE field catalogues (Janensch, 1909-1911; Reck, 1912-1913; Figure 1A). However, the sheer number of specimens from Quarry Ig/WJ soon made it impossible to list every specimen. After preparation at the MfN in Berlin, the bones were inventoried under their field numbers, which the specimens were referred to by in publications (e.g., Janensch 1955). In the case of clay jackets that contained several specimens with the same field number, the field numbers were supplemented either by letters or subnumbers. Since 1990, new MfN specific collection acronyms and collection numbers (MB.R.xxxx in the case of fossil reptiles) were introduced, and have been used since in combination with the old field numbers for all specimens from the GTE.

In the field, the slabs were packed as jackets, for which a mixture of reddish-brown clay from the nearby Namundo Plateau, and *gummi arabicum* with some stabilizing coconut fibers was usually used as replacement for plaster of Paris (Maier, 2003) and spread onto the slabs wrapped in cotton cloth (in German called “Hüttenlehmknollen”, this kind of package is in this text referred to as “clay jackets”) (Figure 1B). From a conservation perspective, the clay material used to form the clay jackets seems to be a very good and sustainable material for conservation, and the intactness of the clay jackets in the collections of the MfN until today proves that it is as stable as plaster of Paris. Smaller bones were collected in any receptacles that were available, e.g., tin cans, baobab fruit capsules (Hennig, 1912) (Figure 1C-D), and split-up bamboo stalks (Maier, 2003; Heinrich and Schultka, 2007), or wrapped into savanna grass. The material was then packed into special containers (Figure 1E-G) that were produced directly at the

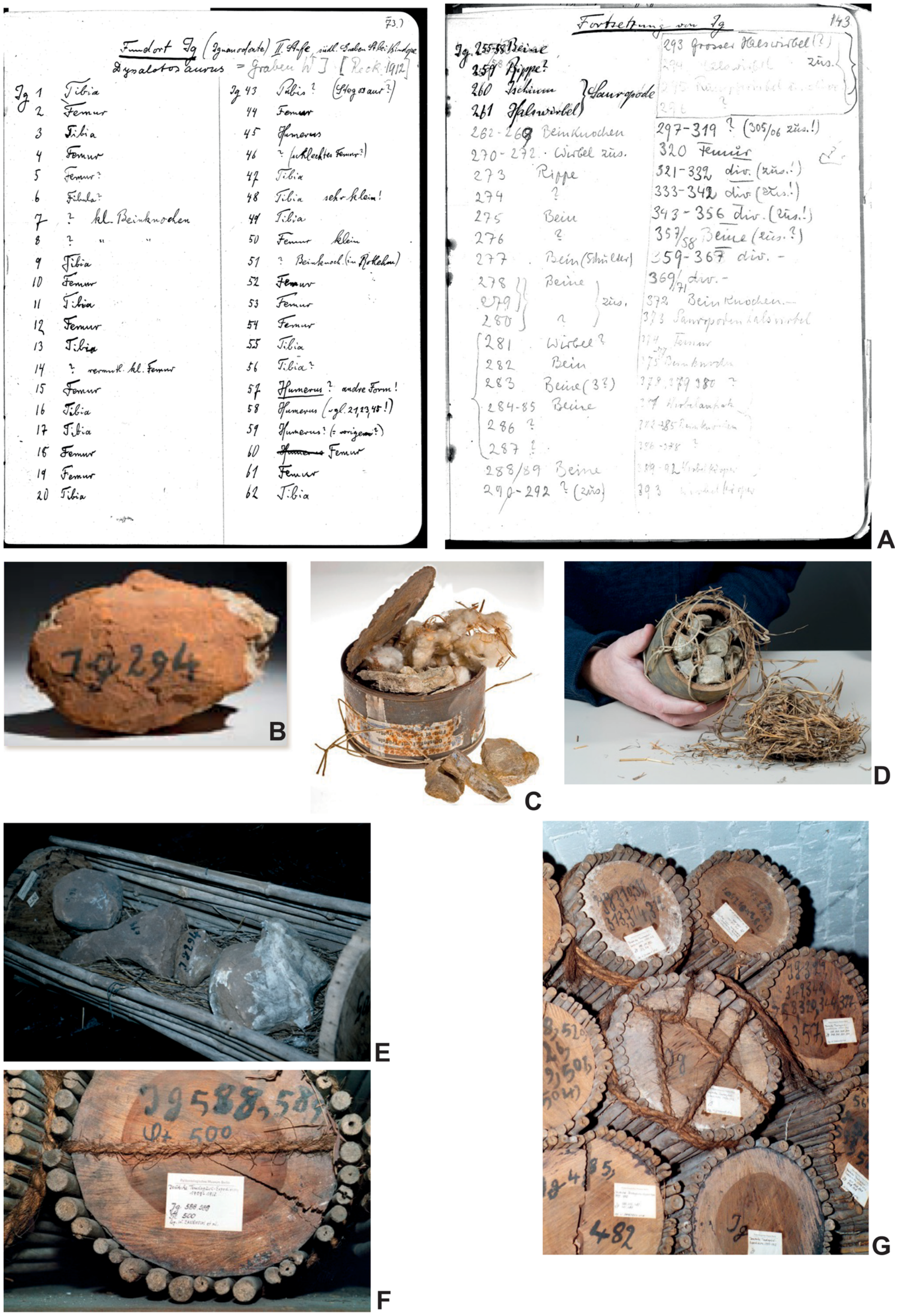

FIGURE 1. A) Entries in field catalogue of Janensch (1909-1911) for Quarry Ig/WJ page 73 and page 143. Photographs of original packed items from Quarry Ig/WJ.**B)** clay jacket Ig294, **C)** tin can filled with small bones from Quarry Ig/WJ and padded with pieces of cotton, scale bar for B) and C) is 50 mm. **D)** baobab fruit capsule filled with small bones and vertebrae from Quarry Ig/WJ, padded with a bundle of savanna grass, not to scale, **E)** opened bamboo corset from Quarry Ig/WJ containing four clay jackets (one partially with plaster of paris) on a thick layer of savanna grass (this photograph is also used in Heinrich and Schultka, 2007: Abb. 32), **F)** Close-up of one of the studied bamboo corsets in the collection of the MfN with original ink labelling and paper label visible, scale bar for E) and F) is 80 mm. **G)** Section of several bamboo corsets as stored at the collection of the MfN, not to scale. Photographs B) to E) by Carola Radke, and photographs F) and G) by Hwa Ja Götz, both MfN.

Tendaguru site by the workers, who nailed bamboo sticks interconnected by a thin wire to the outside of locally retrieved hardwood discs (Maier, 2003) (Figure 2). Each "standard" load, including the bamboo corsets and crates, had a weight of between 30 and 50 kg and was assigned to one carrier (Vennen, 2018b). The loads were then transported by these carriers in an arduous four-day march to the coast and subsequently shipped to Germany (Figure 2; Maier, 2003; Heinrich and Schultka, 2007; Vennen, 2018b).

Since 1909, the incoming huge amount of fossil material from the Tendaguru area at the MfN led to a situation in which the museum building became more and more crammed with dinosaur bones (Vennen, 2018a). Those specimens considered to belong to partial skeletons and material that was designated to be mounted for exhibition purposes, as well as complete and scientifically valuable bones, were given priority for preparation (Maier, 2003; Vennen, 2018a). From Quarry Ig/WJ, more than 15,000 bones of *Dysalotosaurus lettowvorbecki* arrived at the museum. A considerable number of specimens from this bulk was given to other institutions in Munich (Bayerische Staatssammlung für Paläontologie und Geologie, BSPG), Stuttgart (Staatliches Museum für Naturkunde, SMNS), Tübingen (Museum für Geologie und Paläontologie of the University of Tübingen, GPIT), Göttingen (Geowissenschaftliches Zentrum, University of Göttingen, GZG), and Hamburg (Maier, 2003; Hübner et al., 2021). However, from 1943, during the second world war, massive bomb raids caused substantial damage to these institutions, and in February and March of 1945, the eastern and western wings of the main building of the MfN were destroyed and a lot of the already prepared *Dysalotosaurus* material was lost (Maier, 2003), including most of the more complete skeletons (see Janensch, 1955) and related documentation. Luckily, larger amounts of unprepared material remained in the collections of Stuttgart, Tübingen, and Göttingen, with a part of that material prepared after WWII and used together with the specimens at the MfN for the skeletal mounts and scientific descriptions of the taxon (Janensch 1955, 1961; Galton, 1981, 1983; Maier, 2003; Hübner and Rauhut 2010; Hübner 2018; Hübner et al., 2021).

Today, the *Dysalotosaurus* material at the MfN comprises only one collection cabinet, a mounted skeleton at the exhibition, and some unprepared material in the collections (Figure 1F, G), contrasting with the huge number of originally found specimens. Although most of the field numbers from Quarry Ig/WJ were listed in the GTE field catalogue (see above, Janensch, 1909-1911), nneither packing lists nor pre-WWII inventories of the material have survived, so the exact content of the remaining bamboo corsets and wooden crates is not known. Reasons the bones in the suite of containers from Quarry Ig/WJ have not yet been prepared include the time-consuming process of preparation and the prioritization of material from the GTE, which considered to be more scientifically important. It has also been deemed necessary to prepare the material of each container in its entirety to maintain the connection of material presumably collected together.

Objective of This Study

An important step for providing information about Tendaguru was a comprehensive historical reappraisal of the GTE and utilization of its results by Heumann et al. (2018). Beyond that, comprehensive documentation of the colonial collections themselves is of major importance as it helps to make the material globally accessible. The fossil vertebrate collection from Tendaguru is of great significance to paleontologists and historians alike, as it is one of the most important dinosaur collections worldwide and one of the best documented excavations that took place under colonial conditions. Every step to enhance accessibility of the collection data is important, for example the publication of 3D models of dinosaur vertebrae (Díez-Díaz et al., 2020).

The scientific cooperation between the MfN, the Leibniz-Institute for Zoo and Wildlife Research (IZW), and the Charité hospital made it possible to investigate the full suite of all 40 unopened bamboo corsets plus the six crates from Quarry Ig/WJ with computed tomography. Regarding the objective of making information about GTE material increasingly available, this work aims to describe, figure, and discuss the content of these containers, none of which have been prepared or unpacked. With the help of this data, it is possible to reconstruct and describe the unprepared, poorly known content of the bamboo corsets and crates in great detail. Our descriptions relate both to the bone material preserved, and the packing material used and thereby exemplifies the documented field practice (see also Heinrich and Schultka, 2007). The new data allows the expansion of the expedition inventory to include the fossil content of Quarry Ig/WJ. Scientific questions focusing on the taphonomy of Quarry Ig/WJ (see Hübner et al., 2021), along with those on the composition of its dinosaur

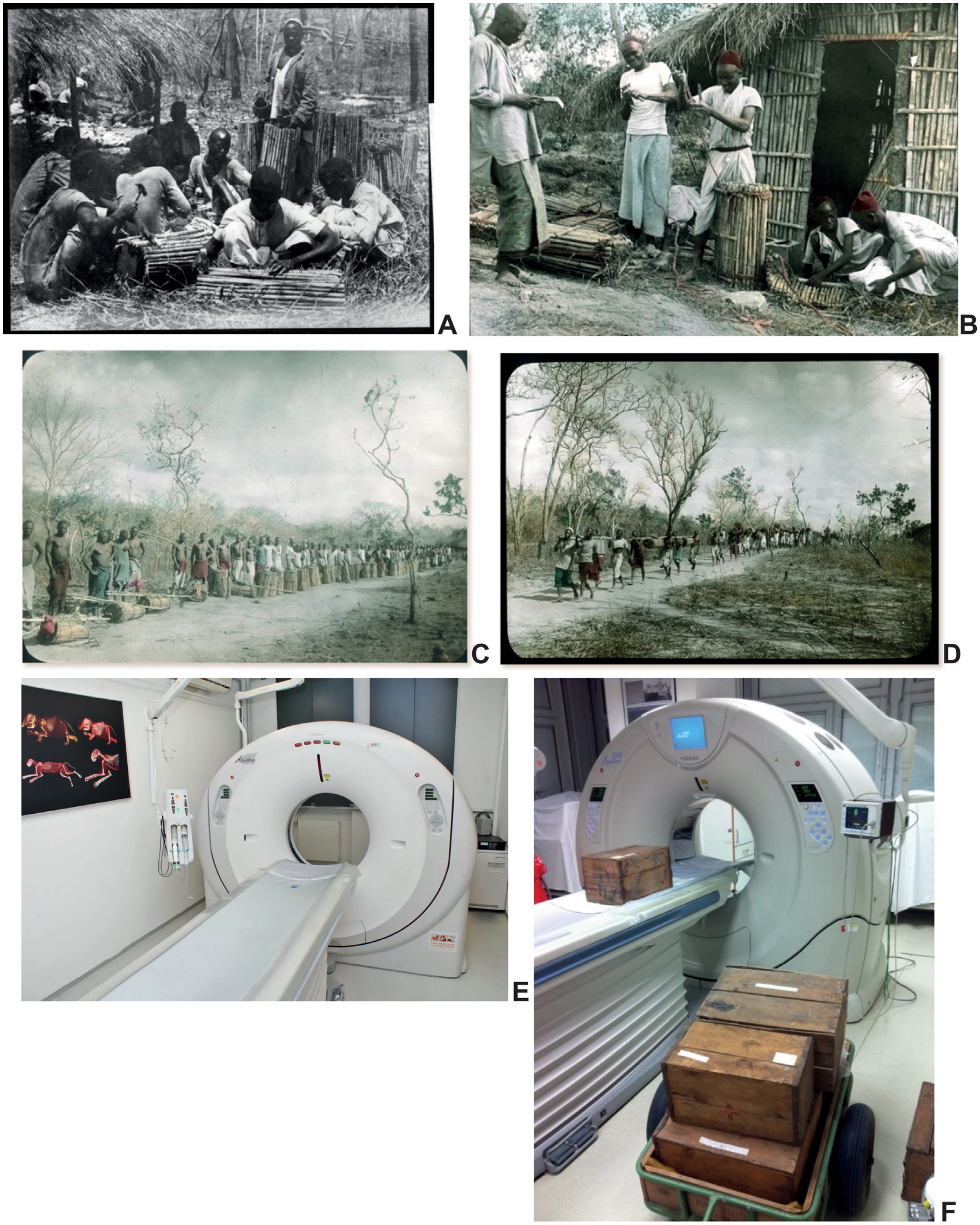

FIGURE 2. Photographs of packing and transport of bamboo corsets on the Tendaguru hill, **A)** MfN HBSB PM_B_IV_0072, and **B)** MfN HBSB PM_B_V_156, local workers producing and filling bamboo corsets, **C)** MfN HBSB PM_B_V_160, workers have gathered to start their march to Lindi with the bamboo corsets, **D)** MfN HBSB PM_B_V_168, long column of carriers following the small foot path to Lindi with bamboo corsets either between them or carried on the head. **E)** Aquilion CX CT scanner at the IZW, this machine was used to scan all 40 bamboo corsets, **F)** wooden crates from Quarry Ig/WJ on their way through the Toshiba Aquilion One CT scanner at the Charité, photograph by Oliver Wings.

fauna (e.g., Heinrich, 1999a; Hübner et al., 2021) would benefit from the digitization of hitherto undocumented material.

The CT data described here provides a broad documentation of the connection between the bones in slabs and the packing of the specimens. From this we are also able to define criteria for the prioritization of preparation of specific bamboo corsets without eroding the possibility of studying the suite of containers from Quarry Ig/WJ as a whole. A workflow for the whole process, from CT scanning over documentation and preparation to final collection storage, is also provided here. A further purpose of the description of these containers is to preserve original documentation on field practices and handling of paleontological specimens from an excavation in a remote area during the beginning of the twentieth century. Finally, we have made the raw data downloadable via a DOI (see Materials and Methods), allowing researchers globally to not only reproduce our findings, but also to use the data to define and answer other research questions across multiple disciplines.

MATERIAL AND METHODS

Forty bamboo corsets and six wooden crates have been investigated. The field numbers and content of these containers are listed in Table 1. Original (raw) computed tomography (CT) data and QuickTime movies of all containers are available under the following DOI: https://doi.org/10.7479/d1pq-2g96. All the containers are labeled on the outside with either field numbers or the quarry token "Ig", allowing the determination of which samples derive from Quarry Ig/WJ.

The CT scans of the 40 bamboo corsets were taken at the IZW in 2010, by using a high-resolution 64 row multislice CT scanner (Aquilion CX; Toshiba, Otawara, Japan) (Figure 2E). For each bamboo corset, a separate 134 spiral scan with a 0.5 mm interval was made and saved as a DICOM stack. CT images were taken with a setting of 135 kV and 250 mA. Data reconstruction (bone algorithm) was done with a VITREA Workstation (Vitrea 2, Version 4.1.2.0, Vital Images, Inc, Minnetonka, Minnesota, USA) and an Oxirix Workstation (Osirix V 3.9.4, 64 Bit).

The CT scans of the six crates were taken at the Charité hospital in 2011, using a 320-section multidetector CT unit (Aquillion ONE; Toshiba, Otawara, Japan) (Figure 2F). A helical scan mode with a rotation time of 1.0 second was chosen. The tube voltage was set to 135 kVp, and a tube current of 450 mA was used. Axial images were acquired with a section thickness of 0.5 mm. Data reconstruction (bone algorithm) was done with an OsiriX Workstation (OsiriX v.5.5, 64 bit).

For image analysis, OsiriX v.5.5.1 for 32 bit was used on a Mac OsX 10.8.2. The material was studied directly within the CT sections of the bamboo corset with either a "bone" or a "muscle" filter applied. Successive virtual deletion of surrounding sediment by changing contrast allowed visualization of individual bones. Three-dimensional (3D) volume rendering helped to display bones both with and without sediment (via contrast adjustment) to aid in identification. Three-dimensional volume reconstruction of the specimens helped identify the different elements when bones were individually packed. The CT scan was not very sensitive to metal, e.g., nails around the bamboo drums and the tin cans, allowing a depiction of the specimens with no disturbances from the metal (e.g., irradiation). Corsets in which multiple different specimen types were packed together, i.e., tin cans with many smaller bones and assemblages of vertebrae (see Results) were best visualized with a 3D maximum intensity projection (MIP); however, identification of the single elements was, due to size and resolution, not possible (see also discussion).

The following acronyms were used for the description of the sample and the labelling of the virtual data: **"Ig 88"** and similar refers to field number labelling on bamboo corsets and crates; **"Ig_NN1"** and similar refers to bamboo corsets without field number labelling; and **"Ig_2022_1"** and similar refers to wooden crates.

Taxonomic identification of bones was based on comparison with *Dysalotosaurus* bones, the morphology of which is well known (Janensch, 1955; Hübner, 2018). As the only ornithopod known from Tendaguru it is separable from all other dinosaurs occurring in the Tendaguru area (i.e., sauropods, theropods, and the other ornithischian dinosaur *Kentrosaurus*). Since Quarry Ig/WJ is known for mass accumulations of bones of *Dysalotosaurus lettowvorbecki*, all small fragments that could not be identified directly are assigned to this taxon. However, the unidentified bone fragments of *Dysalotosaurus* were not counted in the total composition of the sample. It is unlikely that these small fragments belong to a larger dinosaurian taxon such as *Kentrosaurus*, or non-dinosaurian vertebrates, although the possibility of this cannot be excluded. Isolated vertebral centra (without determination of which region of the vertebral column

TABLE 1. List of unopened bamboo corsets and wooden crates from the GTE, with content as derived from CT data. PPL is Preservation Priority Level and can be scored with 1, 2, or 0. *Specimens with asterisk were measured and used in Hübner et al. 2021. Abbreviations in samples: **"Ig 88"** and similar, field numbers on bamboo corsets and crates; "**Ig_NN1**" and similar, bamboo corsets without field numbers; "**Ig_2022_1**", wooden crates.

Container and Labelling	Conservation type	Taxa	Bone elements (number) and preservation	Mention in Field catalogue of Janensch, 1909-1911	PPL 1/2/0	Rationale for PPL Scores 1 and 2	Preservation in original condition preferred?
Bamboo corset "Ig 88"	12 clay jackets, separate cluster of vertebral and elongate bone fragments	*Dysalotosaurus*	4 vertebral centra, 1 distal femur*, 1 distal humerus, several fragments of dorsal ribs	No reference	1	Material of *Kentrosaurus*	No
		Kentrosaurus	2 caudal vertebral centra (one of them with separate neural arch), 1 haemapophysis, 1 distal humerus, 1 distal femur, 1 ilium, 1 ischium	Ig 88, dorsal vertebra of stegosaur			
Bamboo corset "Ig 122, 124, 266, 267, 269, 270, 272, 276"	5 clusters wrapped in Savanna grass, 4 with vertebral centra, 1 with long bone remains	*Dysalotosaurus*	More than 50 dorsal, sacral and caudal vertebral centra; 1 distal femur*, 1 tibia in single parts, long bone shaft fragments	Ig122, femur; Ig 124 = unreadable; Ig266, 267, 268, leg bones; Ig 270, 272, vertebrae; Ig. 276, ?; Ig 125-243, leg bones	0	Preservation because of savanna grass wrapping and different packing types	Yes
Bamboo corset "Ig 133, 151, 152, 191"	4 complete long bones broken in pieces and with sediment	*Dysalotosaurus*	3 femora* of different sizes, 1 tibia	Ig 125-243, leg bones	2	Sediment slabs makes screen washing possible	No
Bamboo corset "Ig 189, 211, 213"	8 clay jackets, some loose rocks in the corset	*Dysalotosaurus*	1 dentary fragment and 2 other skull fragments; 1 dorsal rib shaft; 1 ischium; 1 tibia in 3 pieces, 2 proximal tibiae	Ig 125-243, leg bones	1	Cranial and dentary material of *Dysalotosaurus*	No
Bamboo corset "Ig 202, 203, 204, 212, 214,231"	10 clay jackets, one unprepared tibia in 7 parts	*Dysalotosaurus*	3 femora of different sizes, 1 tibia, 1 fibula, all bones broken in several pieces	Ig 125-243, leg bones	0	Different complete hindlimb bones of *Dysalotosaurus*	No
Bamboo corset "Ig 230"	8 clay jackets, cluster of vertebral centra and dorsal rib fragments	*Dysalotosaurus*	At least 25 dorsal, sacral and caudal vertebral centra, dorsal rib fragments	No reference	1	*Giraffatitan* cervical rib	No
		Giraffatitan	Cervical rib in several single pieces	No reference			
Bamboo corset "Ig 233, 279, 299, 306, 315, 321, 325, 326,328"	13 clay jackets, cluster of small unprepared bones	*Dysalotosaurus*	1 femur, 1 tibia, 2 fibulae, 1 dorsal rib, 1 iilum fragment, other undetermined long bone fragments	Ig 125-243, leg bones; Ig279, leg bones; Ig 297-319, ?; Ig 321-332, together, diverse	2	cluster of unprepared small bones	No
Bamboo corset "Ig 248, 249, 250, 253, 254"	Long bones unprepared and in parts	*Dysalotosaurus*	1 femur*, 1 tibia, 1 fibula, 3 metatarsals, all in fragments	Ig 247-250, leg bones; Ig 253-254, leg bones found lying together	2	metatarsals of *Dysalotosaurus*	No
Bamboo corset "Ig 256, 262, 264, 273, 282"	9 clay jackets, one unprepared tibia in 7 parts	*Dysalotosaurus*	1 femur*, 2 tibiae (prox), 1 fibula, 1 metatarsal, all broken	Ig256, leg bones,; Ig262-269, leg bones; Ig273, rib; Ig 282, leg bones	2	metatarsals of *Dysalotosaurus*	No
Bamboo corset "Ig 277, 279, 284"	5 clay jackets	*Dysalotosaurus*	Tibia	Ig 277, leg (shoulder); Ig 279, legs (together with Ig 278, 280); Ig 284, leg bones	1	Material of *Kentrosaurus*	No
		Kentrosaurus	1 right scapula and humerus, 1 left scapula prox.				
Bamboo corset "Ig 281"	4 clay jackets, 8 bone fragments in sediment	*Dysalotosaurus*	1 dentary fragment, 1 distal femur, 2 dorsal vertebral centra, undetermined bone fragments	Ig281, vertebra	1	Fragmentary dentary of *Dysalotosaurus*, sauropod vertebra material	No
		Sauropoda indet.	Presumable dorsal vertebral fragments and pneumatic transverse process				
Bamboo corset "Ig 291, 291"	3 clay jackets	*Dysalotosaurus*	1 femur* in three parts and with sediment matrix, 1 small rib	IG 291, ?	2	Contains sediment for screen washing	No

TABLE 1 (continued).

Container and Labelling	Conservation type	Taxa	Bone elements (number) and preservation	Mention in Field catalogue of Janensch, 1909-1911	PPL 1/2/0	Rationale for PPL Scores 1 and 2	Preservation in original condition preferred?
Bamboo corset "Ig 298, 300, 301, 302, 303, 304"	10 clay jackets, 2 bone fragments with matrix	*Dysalotosaurus*	1 femur, 2 fibulae, 1 metatarsal, 4 dorsal ribs, some undetermined long bone fragments	Ig 297-319, ?	2	Dorsal ribs of *Dysalotosaurus*, contains sediment for screen washing	No
Bamboo corset "Ig 305, 303, 307, 310, 317, 318, 319"	10 clay jackets	*Dysalotosaurus*	1 ilium (anterior part broken), 1 femur proximal, 1 tibia , 1 metatarsal, 2 dorsal ribs fragments, long bone fragments	Ig 297-319, ?	1	*Kentrosaurus* vertebra	No
		Kentrosaurus	1 caudal vertebral centrum with base of neural arch				
Bamboo corset "Ig 310, 311, 312, 313, 314"	9 clay jackets	*Dysalotosaurus*	2 femora (1 large, 1 small), 1 tibia, 5 metatarsals	Ig 297-319, ?	1	Sauropod material	No
		Sauropoda indet.	Pneumatic transverse process of dorsal vertebra				
Bamboo corset "Ig 320, 322, 329, 344, 348, 349, 357, 358"	3 clay jackets, 20 isolated bone fragments	*Dysalotosaurus*	2 complete femora in parts, metapodial fragments, dorsal rib fragments, other unidentified bone fragments	No reference	2	Dorsal ribs and metapodials of *Dysalotosaurus*	No
Bamboo corset "Ig 323, 327, 333, 334, 337, 341, 362, 364 (?)"	9 clay jackets, 12 single bone fragments in savanna grass, another strongly broken bone part	*Dysalotosaurus*	Fragments of one ilium, 2 femora, 2 tibiae, 2 fibulae, all of two different sizes; 1 unidentified long bone	Ig 321-332, diverse (together); Ig 333-342, diverse (together); Ig 359-367, diverse (together)	0	Preservation because of clay jacket, savanna grass wrapping	Yes
Bamboo corset "Ig 329, 323, 361, 362, 363, 356"	6 tin cans filled with bones, 1 clay jacket	*Dysalotosaurus*	1 caudal vertebral centrum, lots of small long bone fragments and ribs	Ig 321-332, diverse (together); Ig 333-342, diverse (together); Ig 359-367, diverse (together)	2	Large collection of unidentified small bones	No
Bamboo corset "Ig 330, 339, 347, 349 350, 351, 352, 356, 360, 346, 366"	7 tin cans, 4 clusters of bone fragments	*Dysalotosaurus*	Small vertebrae, long bone fragments, other flat bone fragments	Ig 321-332, diverse (together); Ig 333-342, diverse (together); Ig 359-367, diverse (together)	2	Large collection of unidentified small bones	No
Bamboo corset "Ig 335, 336, 338, 368"	5 clay jackets, 1 head of a femur, at least 7 slabs of sediment matrix with bone fragments	*Dysalotosaurus*	1 humerus, 1 femur*, tibia and fibula all prox. Half, bone shaft fragments	Ig 321-332, diverse (together); Ig 333-342, diverse (together); Ig 359-367, diverse (together)	2	Humerus of *Dysalotosaurus* and sediment for screen washing	No
Bamboo corset "Ig 343, 346, 354, 359, 366, 383"	6 cluster of bone parts, at least 4 clay jackets	*Dysalotosaurus*		Ig 343-357, diverse (together); Ig 359-367, diverse (together); Ig382-385, leg bones	2	Ilium of *Dysalotosaurus*	No
Bamboo corset "Ig 379, 382, 383, 385, 386, 388"	10 clay jackets	*Dysalotosaurus*	Ilium, ischium, 2 dorsal ribs, 2 femora (1 large, 1 small), 2 metatarsals, bone fragments	Ig 382-385, leg bones; Ig 386-388, ?	2	Ilium, ischium and metatarsals of *Dysalotosaurus*	No
Bamboo corset "Ig 400, 412, 482, 483, 485"	13 clay jackets	*Dysalotosaurus*	1 prox. Femur, 1 ilium fragment, fragments of dorsal ribs, undetermined long bone fragments	Ig 399-411, 412-413, Ig 416-496, diverse, found together	0		No

TABLE 1 (continued).

Container and Labelling	Conservation type	Taxa	Bone elements (number) and preservation	Mention in Field catalogue of Janensch, 1909-1911	PPL 1/2/0	Rationale for PPL Scores 1 and 2	Preservation in original condition preferred?
Bamboo corset "Ig 401, 415, 416, 417, 472, 475"	15 clay jackets	*Dysalotosaurus*	1 well preserved ilium, 1 prox. Fibula, at least 2 metatarsals, long bone fragments	Ig 399-411, Ig 416-496, diverse, found together; Ig415, *Brachiosaurus* left Mt I (note that a specimen with this field number is already in collection as MB.R.2393)	1	supposed material of *Giraffatitan*, MtII	No
		Giraffatitan brancai	Left metatarsal II				
Bamboo corset "Ig 402, 403, 406, 413, 414"	11 clay jackets	*Dysalotosaurus*	2 femora** in parts, 2 metatarsals in parts	Ig 399-411, 412-413, diverse, found together	2	Metatarsals of *Dysalotosaurus*	No
Bamboo corset "Ig 420, 439, 453, 512"	12 clay jackets	*Dysalotosaurus*	1 complete femur* in pieces, 1 distal femur, 1 small tibia, 1 larger and 1 smaller part of proximal ischium	Ig 416-496, Ig511-515, diverse, found together	2	Partial ischium of *Dysalotosaurus*	No
Bamboo corset "Ig 425, 473, 476, 477, 484"	7 clay jackets	*Dysalotosaurus*	2 femora, at least 2 metatarsals, long bone fragments in large sediment slab	Ig 416-496, diverse, found together	2	Metatarsals of *Dysalotosaurus*	No
Bamboo corset "Ig 428, 459, 501, 504, 506, 508, 509, 514, 520, 526"	14 clay jackets	*Dysalotosaurus*	1 ilium, at least 5 dorsal ribs (one of them complete), 1 humerus, 1 ulna & radius, 3 metapodium fragments	Ig 416-496, 499-515, 517-537, diverse, found together	2	Forelimb elements, ilium and dorsal ribs of *Dysalotosaurus*	No
Bamboo corset "Ig 440, 443, 444, 434, 432, 442"	9 clay jackets	*Dysalotosaurus*	1 tibia in 4 pieces, 1 metatarsal in 5 pieces, 1 phalanx, 1 ilium fragment, undetermined long bone remains	Ig 416-496, diverse, found together	2	Ilium and autopodial elements of *Dysalotosaurus*	No
Bamboo corset "Ig 446, 447, 448, 450, 460, 467"	11 clay jackets	*Dysalotosaurus*	1 femur, 1 tibia in fragments, at least 5 metatarsals, ?autopodial elements	Ig 416-496, diverse, found together	1	Preservation priority level 1 because of possible autopodial bone	No
Bamboo corset "Ig 498"	3 clay jackets	Sauropoda: Titanosauriformes	Neural arch with hyposphene and neural spine, some more fragments in 3 clay jackets	Ig497-498, cervical vertebra sauropod	1	Vertebral material of sauropods	No
Bamboo corset "Ig 522, 527, 528, 539, 543, 544"	10 clay jackets, single bone fragments	*Dysalotosaurus*	1 large tibia & fibula, 1 large ulna, 1 small tibia & fibula, metatarsal, dorsal rib body	Ig517-537, 538-570, diverse, found together	2	Ulna and metatarsal of *Dysalotosaurus*	No
Bamboo corset "Ig 537, 540, 547, 549, 562"	3 clay jackets, lot of small unprepared bones and vertebral centra in matrix	*Dysalotosaurus*	At least 5 vertebral centra, 2 neural arches, 1 coracoid, 1 distal femur*, metatarsal, long bone fragments	Ig517-537, 538-570, diverse, found together	2	Coracoid, neural arches and metatarsal of *Dysalotosaurus*	No
Bamboo corset "Ig 590, 597, 599, 603, 605"	10 clay jackets	*Dysalotosaurus*	3 tibiae in several parts	Ig580-607, diverse, found together	1	*Kentrosaurus* material	No
		Kentrosaurus aethiopicus	1 haemapophysis				
Bamboo corset "Ig_NN1" (No Ig numbers outside)	One larger and one smaller cluster of vertebral centra and small bone fragments	*Dysalotosaurus*	More than 30 single vertebral centra (dorsal, sacral and caudal region), small long bone fragments	No reference	0		No

TABLE 1 (continued).

Container and Labelling	Conservation type	Taxa	Bone elements (number) and preservation	Mention in Field catalogue of Janensch, 1909-1911	PPL 1/2/0	Rationale for PPL Scores 1 and 2	Preservation in original condition preferred?
Bamboo corset “Ig_NN2” (No Ig numbers outside)	9 cluster of vertebral centra and bone fragments	*Dysalotosaurus*	1 sacral vertebral centrum, 37 other vertebral centra, undetermined bone fragments	No reference	0		No
Bamboo corset “Ig_NN3” (No Ig numbers outside)	9 cluster of vertebral centra and bone fragments	*Dysalotosaurus*	At least 55 vertebral centra, some of them from dorsal and caudal region, ?phalanges, ?small dorsal rib fragments, bone fragments	No reference	2	Potential phalanges and undetermined bone fragments of *Dysalotosaurus*	No
Bamboo corset “Ig_NN4” (No Ig numbers outside)	3 big clusters of vertebral centra	*Dysalotosaurus*	Estimated 66 vertebral centra from dorsal and caudal region	No reference	0	Preservation because of clusters of vertebrae	Yes
Bamboo corset “Ig_NN5” (No Ig numbers outside)	2 clay jackets and bone fragments in matrix	*Dysalotosaurus*	1 femur in several parts,1 tibia in parts, 2 metatarsals	No reference	2	Metatarsals of *Dysalotosaurus*	0
Bamboo corset “Ig_NN6“ (No Ig numbers outside)	3 tin cans (2 of them composed by different cans), 1 cluster of vertebral centra	*Dysalotosaurus*	29 vertebra, some of them from sacral and caudal region, small bone fragments in tin cans	No reference	2	Tin cans with undetermined bone fragments	yes
Crate “Ig_2011_1” (Ig 140, 143, 156, 158, 165, 184, 208, 210, 215, 218, 221, 228)	Bone fragments with sediment packed in 8 Savanna grass bundles and 4 bamboo stalks	*Dysalotosaurus*	At least 1 femur, 2 tibiae, 2 fibulae, 2 metatarsals, other long bone fragments	Ig 125-243, leg bones	1	Material of *Kentrosaurus*; but also only example of bamboo stalks	yes
		Kentrosaurus	Ulna				
Crate Ig_2011_2 (Ig 261)	5 clay jackets	*Dysalotosaurus*	At least 2 femora, 1 fibula, 1 metatarsal, other long bone fragments	Ig 261, cervical vertebra sauropod - no sauropod material detected!	1	Material of *Kentrosaurus*	No
		Kentrosaurus	Proximal ilium fragment				
Crate Ig_2011_3 (Ig 1009)	7 clay jackets	*Dysalotosaurus*	3 femora in pieces	No reference	0	0	No
Crate Ig_2011_4 (No Ig numbers outside)	2 sediment blocks with densely packed bones	*Dysalotosaurus*	1 complete dorsal vertebra, 1 fibula, other long bones and vertebrae that cannot be visualized individually	No reference	2	Sediment blocks for screen washing	No
Crate Ig_2011_5 (No Ig numbers outside)	Large collection of vertebral centra and single long bone fragments	*Dysalotosaurus*	Sacral and dorsal vertebral centra, 1 proximal femur, 1 metatarsal, few long bone fragments	No reference	2	Metatarsals of *Dysalotosaurus* and undetermined bone fragments	No
Crate Ig_2011_6 (No Ig numbers outside)	9 clay jackets	*Dysalotosaurus*	2 femora, 1 tibia, 1 fibula in pieces	No reference	0	Preservation as an example for clay jackets and packing in a crate	Yes

they come from) have been included in the sample composition.

Bones of other taxa, in particular *Kentrosaurus aethiopicus, Giraffatitan brancai,* and undetermined sauropod remains, were identified based on the distinctive morphology of these elements.

RESULTS

Packing Mode, Content and Documentation of Field Practice

Fossil material in the bamboo corsets and crates was found to be packed either in clay jackets (Figure 3A, 4), as single bones (with or without sediment) wrapped in savanna grass (Figure 4), as clusters of bones wrapped in savanna grass (Fig-

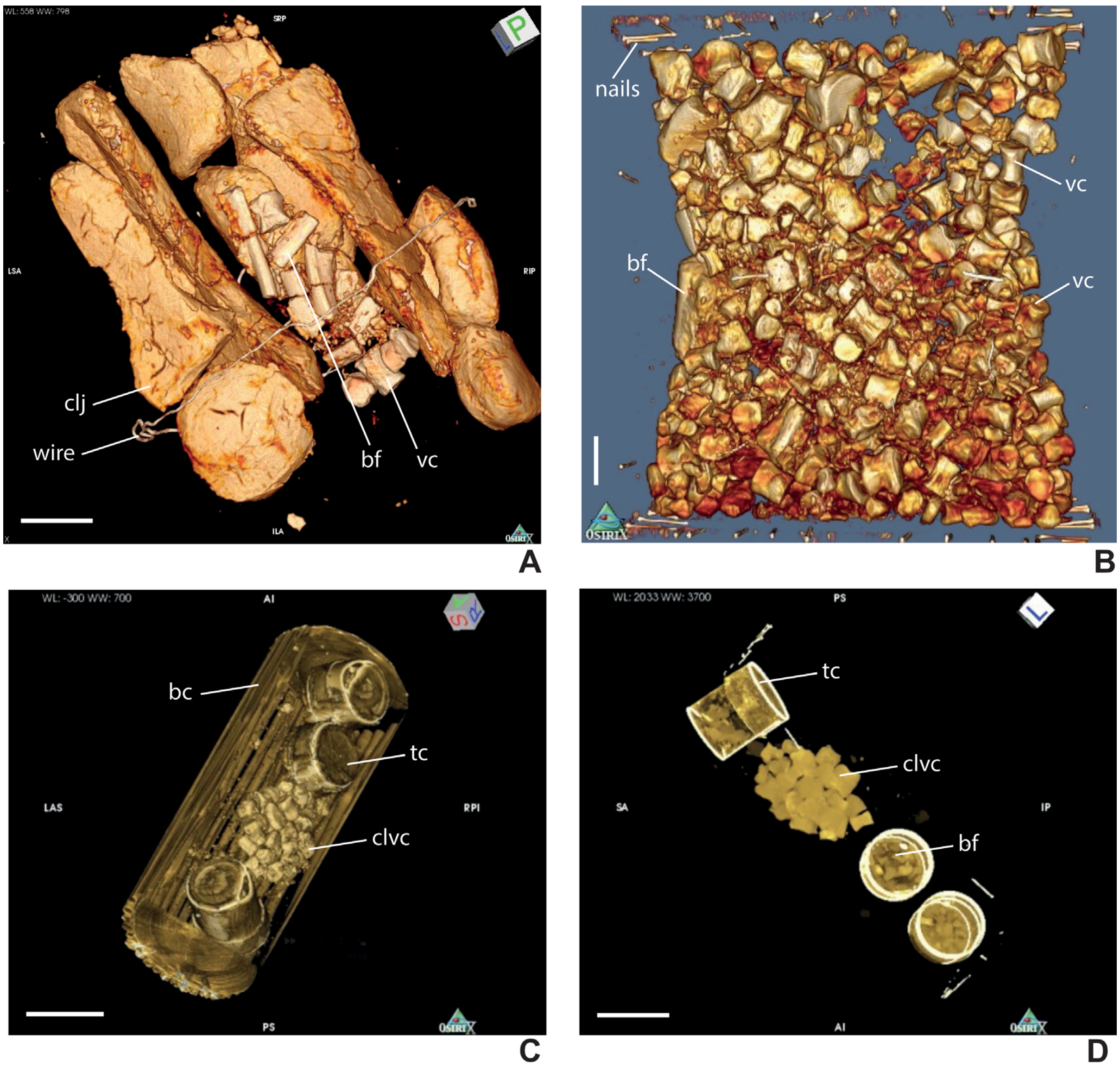

FIGURE 3. 3D visualization images of containers, showing different content types, link to corresponding movies. **A)** "Ig88", clay jackets and bones; **B)** "Ig_2011_5", crate with an accumulation of vertebrae and some other bones. Scale bars in A) and B) are 50 mm. "Ig_NN6", tin cans and small bones in bamboo corset, 3D MIP videos, **C)** with bamboo corset and surface visualized, **D)** with content of tin cans visualized. Scale bars in C) and D) are 100 mm. Abbreviations: bc, 3D visualized bamboo corset; bf, bone fragment; clvc, cluster of vertebral centra; clj, clay jacket; tc, tin can; vc, vertebral corpus.
Videos of A), B), C) and D) available at the PE You Tube channel (https://www.youtube.com/channel/UCF6IBDiGbut-DrVada60Izyg).

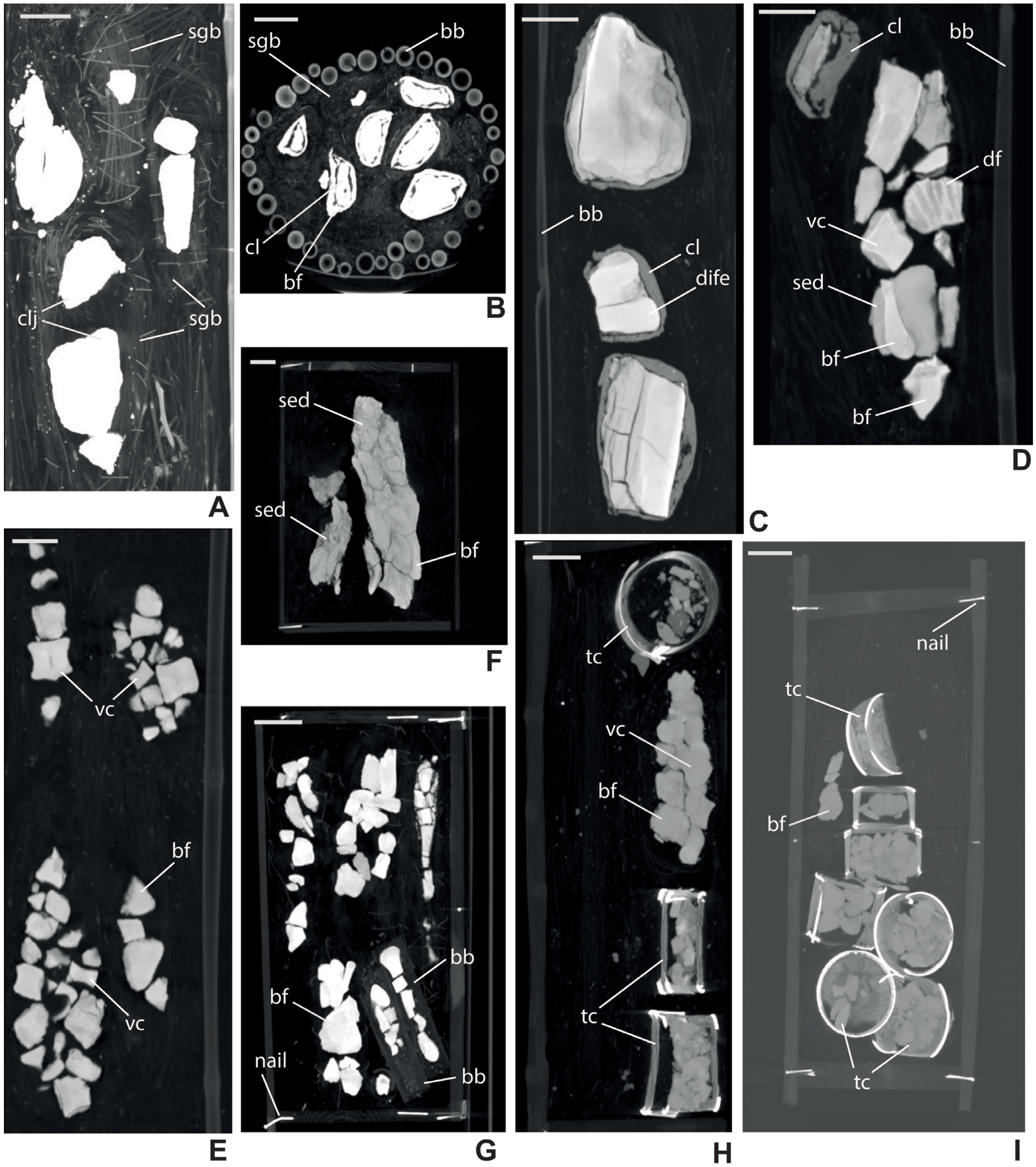

FIGURE 4. Packing types of fossil specimens as visible in the CT images **A)** “Ig 420, 439, 453, 512”, longitudinal section (MIP mode and CT-pulmonary filters set) showing wrapping of specimens in savanna grass, **B)** “Ig88” cross-section showing wrapping of fossils in savanna grass and tight stuffing of bamboo corsets, **C)** “Ig291, 291”, longitudinal section of the typical clay jackets, showing a femur of *Dysalotosaurus* in pieces with protection cover of clay, **D)** “Ig281”, partial longitudinal section showing clay jackets and single bone fragments with and without sediment, **E)** “Ig 122, 124, 266, 267, 269, 270, 272, 276”, longitudinal section showing clusters of vertebrae and bone fragments in the bamboo corset, **F)** “Ig_2011_4”, crate with two large sediment slabs with fossil bones, **G)** “Ig_2011_1”, crate with bamboo stalks filled with fossil bones and bones wrapped in savanna grass, **H)** “Ig_NN6”, bamboo corset in longitudinal section (MIP mode) showing tin cans and bone cluster in between (see also Figure 4C-D), **I)** “Ig 330, 339, 347, 349 350, 351, 352, 356, 360, 346, 366”, bamboo corset in longitudinal section (MIP mode) showing several tin cans and some additional loose bones. Scale bar is 50 mm. Abbreviations: bb, bamboo stalk; bf, bone fragment; cl, clay cover of bone; clj, clay jacket; df, dentary fragment; dife, distal femur; sed, sediment; sgb, savanna grass bundle; vc, vertebral centrum.

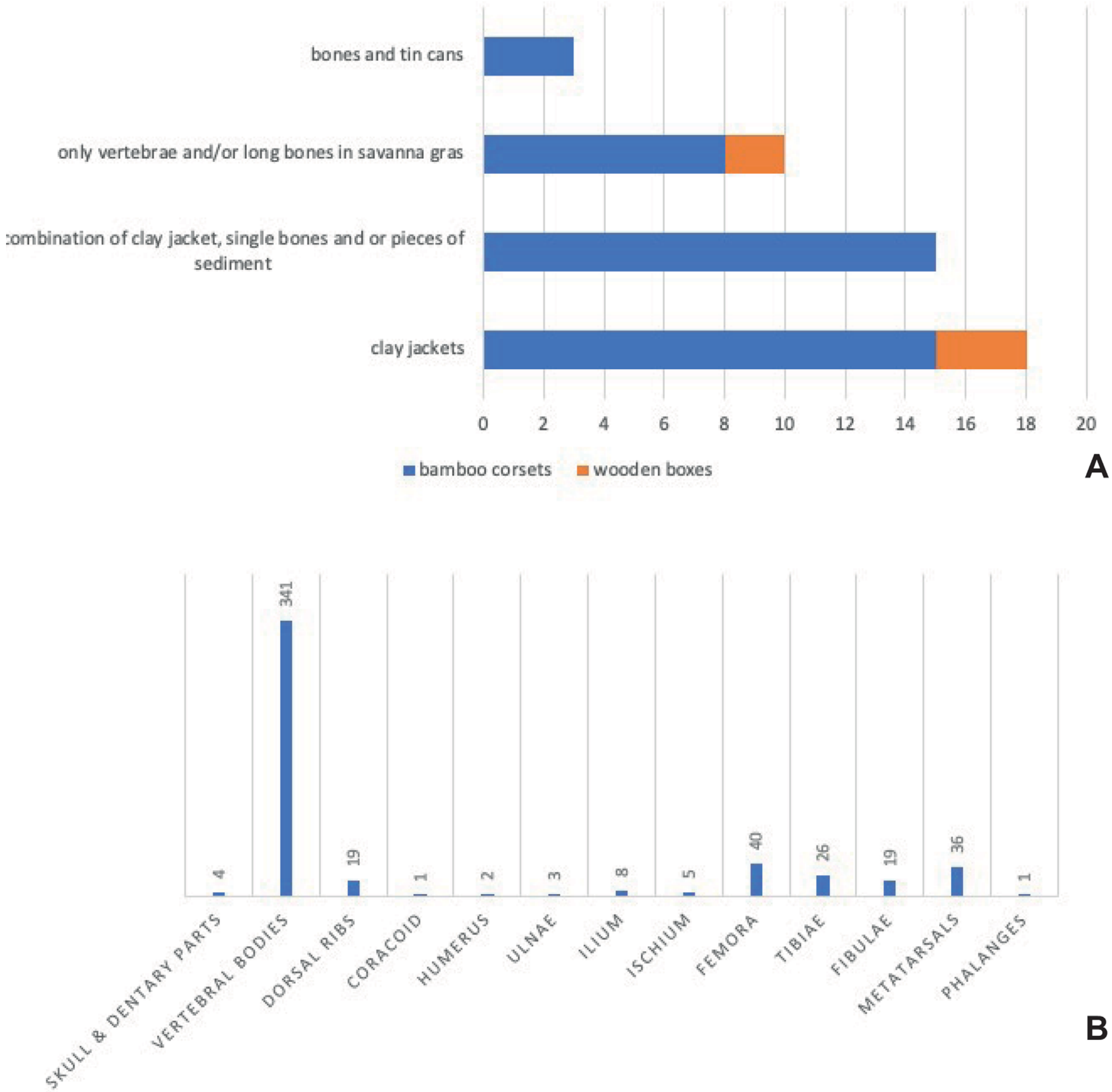

FIGURE 5. Diagrams showing **A)** the distribution of clay jackets, unprepared bones and tin cans in the bamboo corsets and crates, **B)** Frequency of different bone elements of *Dysalotosaurus lettowvorbecki* in the bamboo corsets and crates. The unidentified bone fragments of *Dysalotosaurus* are not incorporated in this count. Isolated vertebral centra have been counted without determination of their corresponding body region (i.e., cervical, dorsal, sacral, or caudal).

ure 3B-D, 4), as sediment blocks with multiple bones wrapped in savanna grass (Figure 4F), or in tin cans containing multiple smaller bones and bone fragments (Figure 3C, D, 4, 5A, Table 1). The field numbers assigned to the bamboo corsets and crates often do not exactly match the number of bones, clusters, and clay jackets they contain. In contrast to the usual field practice during the GTE of assigning and labeling one single bone with one field number (for labelled specimens see for example Janensch, 1909-1911; Janensch, 1929; Heinrich, 1999a), the field numbers in the studied sample often were assigned to sediment slabs or whole containers. One example, bamboo corset “Ig122, 124, 266, 267, 269, 270, 272, 276” (Figure 4E and Table 1), contains five clusters of varying numbers of bones but is assigned with eight field numbers. An exception is specimen “Ig 291, 291” (Figure 4C and Table 1), which contains three pieces of a single femur labelled under one field number.

Clay jackets. The most common contents were unprepared single bones in clay jackets: 15 bamboo corsets contained a combination of clay jackets and single bones with or without sediment or sediment blocks (Table 1, Figures 3A, 4D), and 15 bamboo corsets plus three crates contained only clay jackets (Figure 4A, C). Single long bone fragments, vertebral centra and sediment blocks were wrapped in savanna grass and packed together with clay jackets (e.g., in Ig 88, Figure 3A), presumably to optimize the available space and weight. The respective bamboo corsets and crates were all labelled with single field numbers referring to the single clay jackets and were listed in the GTE field catalogue of Janensch (Table 1; Figure 1; Janensch, 1909-1911). There is only one exception, a crate labelled only as “Ig”. The number of clay jackets in the bamboo corsets ranged from three (e.g., in “Ig 291, 291”) to ten (e.g., in “Ig428, Ig459, Ig501, Ig504, Ig506, Ig508, Ig509, Ig514, Ig520, Ig526”). Most of the bamboo corsets and crates contained five to seven clay jackets. In some cases, larger bones were found packed in pieces in several clay jackets (see example of bamboo corset “Ig 291, 291” above, also Figure 4C).

Single bones and bones in matrix. Clusters of loose bones, bone fragments, and sediment slabs containing one or multiple unprepared bones were also common in the bamboo corsets and crates. Of the 40 bamboo corsets and six crates, seven bamboo corsets and three crates contained only clusters of vertebrae (Table 1, Figures 3B, 4E, 5A) and unprepared sediment slabs with bone material (Figure 4F). Three bamboo corsets housed a combination of unprepared and unwrapped material and tin cans (Figure 3C-D, 4H-I). Some of these bamboo corsets containing single bones and bones in matrix were labelled with specific field numbers (e.g., “Ig 248, Ig 249, Ig 250, Ig 253, Ig 254”), but of the five bamboo corsets labelled only as “Ig”, four contained bones in matrix. In these unlabeled containers, appendicular bones of *Dysalotosaurus* were packed as fragments without clay cover. Larger numbers of vertebral centra were assembled in separate clusters of more than 50 specimens within the bamboo corsets and crates, as in “Ig_2011_5” (crate, Figure 3B) and “Ig 122, 124, 266, 267, 269, 270, 272, 276” (bamboo corset, Figure 4E). These vertebral clusters seem to have been sorted by size and probably kept separate from other small bone elements that remained undetermined in the field.

Tin cans and bamboo stalks. Empty tin cans from the provisions of the camp have been documented in three of the bamboo corsets (Table 1, Figures 3C-D, 4H-I, 5A) and were used as containers for small bones and bone fragments (presumably phalanges, metapodials, rib fragments etc.). The tin cans were either sealed with their lids, or two tin cans were joined to contain the bones. The tin cans were usually combined in the bamboo corsets with unpacked smaller bones, or single clay jackets (Figure 4H-I). In the crate “Ig_2011_1”, four bamboo stalks filled with small bones were visible (Figure 4G). From previously opened bamboo corsets, we know fruit capsules of the baobab tree and bamboo stalks were also used as containers for small bones (see Introduction and Heinrich and Schultka, 2007).

Taxa and Elements, Size Distribution

The size spectrum of the specimens is naturally limited by the size of the bamboo corsets. We have detected no material larger than 20 cm in the samples. Small bones of 0.5 to 3 cm are frequent in the samples, for example the vertebral bodies and material in the tin cans (Figure 4E-I). Except for “Ig 498”, all other 39 bamboo corsets and six crates contained bones of *Dysalotosaurus* (Table 1). It is most likely that the tin cans filled with smaller bones also contain material of *Dysalotosaurus*, although the resolution of the CT images is too low to allow a more precise identification (see Material and Methods) (Figures 3C-D, 4H-I).

In “Ig 189, 211, 213” a dentary and two other undetermined skull fragments of *Dysalotosaurus* were identified (Figure 6A), “Ig 281” contained another dentary fragment (Figures 4D). The majority of identified elements from *Dysalotosaurus* are from the postcranial skeleton. Of those, most are vertebral centra (Figures 3, 4, 6) with hind limb elements being the second most common (femora, tibiae, fibulae, and metatarsals) (Figure 6A-F). Other elements occurring were fragmentary dorsal ribs (Figure 6A, F), a coracoid (Figure 6E), humeri (Figure 6D) and ulnae (Figure 6F), ilia, ischia (Figure 6A-C), and a phalanx. In “Ig 537, 540, 547, 549, 562”, two isolated neural arches were found that may belong to the vertebral centra of the same container (Figure 6E).

Six bamboo corsets and two crates contained bones of *Kentrosaurus*, packed together with bones of *Dysalotosaurus*. Bamboo corset “Ig 88 etc” (Figure 7A) is a good example of a mixed

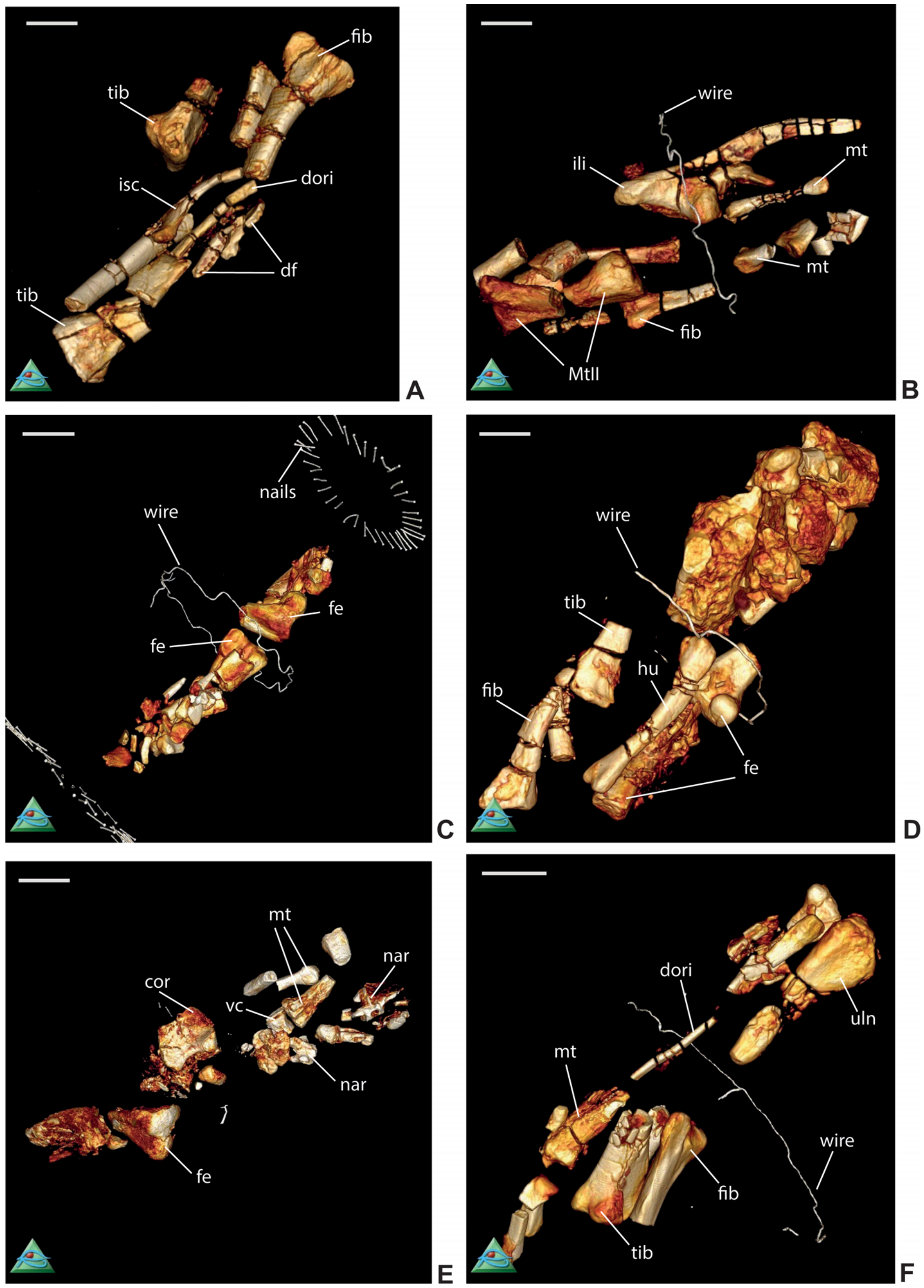

FIGURE 6. Examples of bone elements from *Dysalotosaurus lettowvorbecki* as found in the bamboo corsets, link to corresponding movies. **A)** "Ig 189, 211, 213", bamboo corset with dentary fragments, dorsal rib shaft, tibia remains, a proximal fibula and some other bone fragments; **B)** "Ig 401, 415, 416, 417, 472, 475", bamboo corset with well-preserved ilium, proximal fibula, at least two metatarsals and other long bone fragments, as well as a presumed MtII of *Giraffatitan brancai* in 2 parts; **C)** "Ig 343, 346, 354, 359, 366, 383", bamboo corset with femur in 3 parts, fragments of ilium and some bone fragments; **D)** "Ig 335, 336, 338, 368", bamboo corset with 1 humerus, 1 femur, tibia and fibula as proximal parts and other bone fragments; **E)** "Ig 537, 540, 547, 549, 562", bamboo corset with vertebral centra, 2 isolated neural arches, a coracoid, a distal femur, a metatarsal and other bone fragments; **F)** "Ig 522, 527, 528, 539, 543, 544", bamboo corset with tibia and fibula, ulna and other bone fragments. Scale bar is 50 mm. Abbreviations: cor, coracoid; df, dentary fragment; dori, dorsal rib; fe, femur; fib, fibula; hu, humerus; ili, ilium; isc, ischium; MtII, second metatarsal of *Giraffatitan*; mt, metatarsal (of *Dysalotosaurus*); nar, neural arch; tib, tibia; uln, ulna; vc, vertebral centrum.
Videos of A) to F) available at the PE You Tube channel (https://www.youtube.com/channel/UCF6IBDiGbut-DrVada60Izyg)

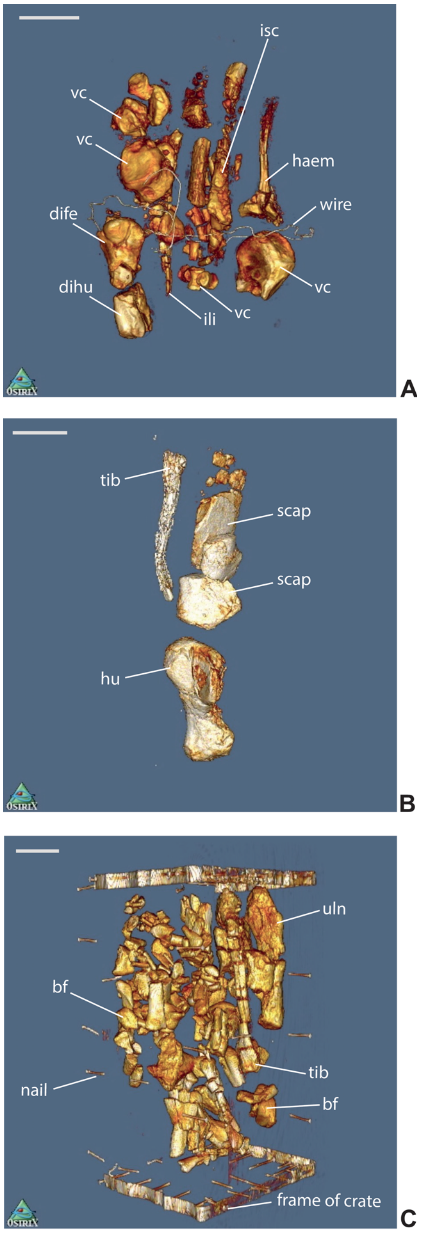

FIGURE 7. Examples of bone elements from *Kentrosaurus aethiopicus* as found in the bamboo corsets link to corresponding movies. **A)** “Ig88”, bamboo corset with two caudal vertebral centra (one of them with separate neural arch), a haemapophysis, a distal part of humerus, femur and ilium and ischium fragments of *Kentrosaurus*, and vertebral centra of *Dysalotosaurus*; **B)** “Ig 277, 279, 284”, remains of one right scapula and humerus and proximal part of left scapula, and tibia of *Dysalotosaurus*; **C)** Crate “Ig_2011_1”, ulna of *Kentrosaurus*, and several long bones and bone fragments of *Dysalotosaurus*. Scale bar is 100 mm. Abbreviations: bf, bone fragment; dife, distal femur; dihu, distal humerus; haem, haemapophysis; hu, humerus; ili, ilium; isc, ischium; scap, scapula; uln, ulna; vc, vertebral centrum.
Videos of A) to C) available at the PE You Tube channel (https://www.youtube.com/channel/UCF6IBDiGbut-DrVada60Izyg)

ensemble, it contains a cluster of small bones belonging to *Dysalotosaurus* and larger identified as *Kentrosaurus* based on their size and morphology. *Kentrosaurus* was represented by partial caudal vertebrae (Figure 7A), haemapophyses (Figure 7A), two scapulae (Figure 7B), humerus fragments (Figure 7A), an ulna (Figure 7C), and fragments of ilium, ischium (Figure 7A), and a distal part of a femur (Figure 7A).

Sauropod bones were found together with remains of *Dysalotosaurus* in four of the 40 bamboo corsets. “Ig 230” contained a large cervical rib with a complete but fragmented costal body and nine separate narrow, rodlike fragments packed close to it (Figure 8A). Undamaged, this cervical rib would have expanded caudally into a very long, narrow, and rodlike process that slightly and continuously tapers towards its end, corresponding unambiguously to morphology of the cervical ribs of *Giraffatitan* as preserved in the collection of the MfN (Janensch, 1950). “Ig 281” (Figure 8B) and “Ig 310, 311, 312, 313, 314” (Figure 8C) both contained parts of a pneumatic transverse process and dorsal vertebral fragments, which because of their visible skeletal pneumatic features and morphology are determined to belong to a sauropod dinosaur. “Ig 498” (Figure 8D) contained two clay jackets with a vertebral neural arch, including a clearly visible hyposphene and neural spine of a titanosauriform sauropod. The bamboo corset “Ig 401, 415, 416, 417, 472, 475” contained a left MtII of *Giraffatitan brancai* (Janensch 1961; Figure 8E, F). Interestingly, the field notes list under Ig 415 a MtI of *G. brancai*, which has been catalogued under MB.R.2329 in the collection of fossil vertebrates.

Preservation of Material

The overall condition of the specimens in the bamboo corsets and crates was good. Some specimens were preserved in their sediment, as they have been taken out as slabs of the bonebeds (see Introduction). Single bones packed individually have been taken out and freed from sediment, but not fully prepared. All the bones were preserved three-dimensionally and neither compressed nor distorted, which allowed many of the bones to be identified directly from the 3D visualizations. The appendicular bones were in most cases complete and not missing their articular ends or processes; however, they were often fractured and therefore packed as several parts (Figures 3, 4, 6). Vertebrae of *Dysalotosaurus* were present mostly as vertebral centra (Figures 4B, 5). However, rare

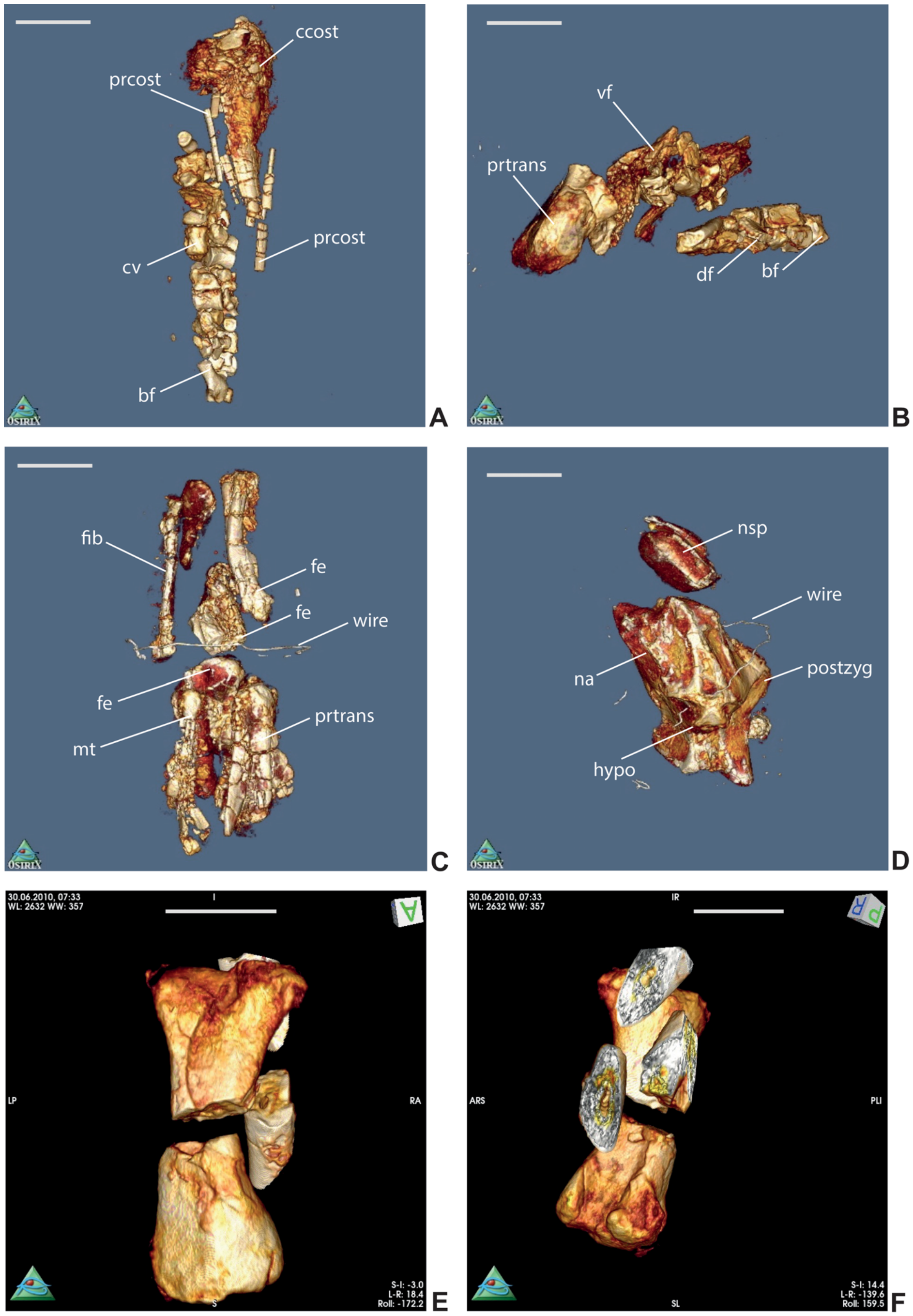

FIGURE 8. Examples of bone elements from sauropod dinosaurs found in the bamboo corsets, link to corresponding movies. **A)** “Ig 230”, cervical rib of *Giraffatitan brancai*, and cluster of vertebrae and bone fragments of *Dysalotosaurus*; **B)** “Ig 281”, presumable dorsal vertebral fragments and pneumatic transverse process of a sauropod (this bamboo corset contains also a dentary remain of *Dysalotosaurus*); **C)** “Ig 310, 311, 312, 313, 314”, pneumatic transverse process of dorsal vertebra; **D)** “Ig 498”, neural arch with clearly visible hyposphene and broken neural spine of titanosauriform sauropod. Close-up of visualization of isolated MtII of *Giraffatitan*, **E)** in dorsal view **F)** in plantar view. Scale bar in A-D is 100 mm, in E-F it is 50 mm. Abbreviations: bf, bone fragment; ccost, corpus of cervical rib (of *Giraffatitan*); df, dentary fragment (of *Dysalotosaurus*); hypo, hyposphene; mt, metatarsal; na, neural arch; nsp, neural spine; prcost, caudal process of cervical rib (of *Giraffatitan*); postzyg, postzygapophysis; prtrans, transverse process of vertebra; tib,tibia; vc, vertebral centrum; vf, vertebral fragment.
Videos of A) to D) available at the PE You Tube channel (https://www.youtube.com/channel/UCF6IBDiGbut-DrVada60Izyg)

exceptions such as in bamboo corset “Ig 537, 540, 547, 549, 562” (Figure 6E), show the possibility of detecting additional neural arches in some of the unidentified bone clusters or the tin cans. Although appendicular bones and more sturdy bones like vertebrae seem to have been more frequently used for packing in the bamboo corsets and crates, there were also some more fragile and plate-like bones, such as ilia, present. These blade-like ilia and ischia were either complete (Figure 6B), preserved with their more delicate processes broken, or packed as incomplete remains. In most cases, only the shafts of the dorsal ribs of *Dysalotosaurus* were preserved, though rarely complete specimens were identified (e.g., in “Ig 428, 459, 501, 504, 506, 508, 509, 514, 520, 526”). *Kentrosaurus* vertebrae were incomplete but well preserved (Figure 7A). From the sauropod vertebrae, only neural spines and fragments were packed here and appeared to be undamaged (Figure 8B-D). Size of packed specimens was limited due to size of the containers but corresponds to the size spectrum of material known from Quarry Ig/WJ (Hübner et al., 2021).

DISCUSSION

Fossil Contents of the Containers and Historical Field Practices

The visualizations from the tomographic data of the unopened bamboo corsets and wooden crates document the different ways of packing fossil specimens that are already known from the Tendaguru area generally, and from Quarry Ig/WJ in particular (e.g., Maier, 2003; Heinrich and Schultka, 2007; Hübner et al., 2021). Most of the label numbers on the bamboo corsets are listed in the GTE field catalogue (Janensch, 1909-1911, Table 1), details of the content are not always given. For example, “Ig 498” lists remains of a sauropod vertebra, whereas in other cases, single field numbers are together referred to as “Ig382-385 – leg bones” or “Ig399-411 diverse bones found together” (Table 1, Figure 1B). The poor preparation status of the specimens in the field and the huge number of individual bones that were so quickly excavated at Quarry Ig/WJ made it impossible for Janensch and Hennig to observe and list each of the specimens for scientific determination before packing (see also introduction).

The lack of specific field numbers on some of the crates and corsets means it is not possible to refer to where specifically in Quarry Ig/WJ the material was collected from. Specimens in these unlabeled containers were packed together based on similarity of object types, and we consider it possible that the material has been collected from all over Quarry Ig/WJ. In contrast, the packing of the samples with field numbers is in roughly subsequent order. Occasionally some field numbers are missing in between or found in other bamboo corsets. We could not figure out the location of the specimens with these numbers, as they are not listed in any inventory of the dinosaur remains from Tendaguru of the MfN.

During the GTE, packing of loads was directed by Janensch and Hennig themselves, who partly kept track of the loads that went to the coast in their field notes (Janensch 1909-1911). It is assumed that, while the numbering of the jackets served as a first criterion to pack them together, the packing order of the clay jackets was also determined by size and in particular weight of the specimens. For example, the numbers “Ig279” and “Ig 291” are listed for two different bamboo corsets (Table 1) but refer to different pieces of the same bone packed in two containers due to space constraints. The preservation of all fossil material in the bamboo corsets and wooden crates, showing fractures and cracks, being mostly preserved in pieces or broken but generally undistorted and uncompressed, corresponds to that known and described from Quarry Ig/WJ (Heinrich, 1999a; Hübner et al., 2021).

Whereas the collection of the MfN houses a number of well-preserved and complete vertebrae of *Dysalotosaurus lettowvorbecki*, complete vertebrae of this taxon are absent from the sample here. Most plausibly, these rarer well-preserved vertebrae of *Dysalotosaurus* were transported separately and regarded to be of higher scientific value, as they were planned to be used for the scientific description and skeletal mount of the specimen (Maier, 2003; Hübner et al., 2021). Similarly, skull bones are rare in the unopened containers, but records from collections of the MfN, Stuttgart, and Munich demonstrate that Quarry Ig/WJ yielded articulated skulls and a fair number of isolated skull bones of *Dysalotosaurus* (Hübner and Rauhut, 2010; Hübner et al., 2021). Vertebral centra are the most frequently preserved element, as is usual in the collections of the MfN, Tübingen, and Göttingen (see Hübner, 2001: table 4). Comparably frequent in this sample are femora, tibiae, and metatarsals, but in contrast to the other collections shoulder and pelvic girdle elements and humeri are rare in the containers. Of course, the studied sample comprises only a tiny amount of the material of

Dysalotosaurus and comes from an early excavation period of the GTE. Together with the fact that it was not possible to determine all the material that is preserved in these containers, it can be concluded that the sample of *Dysalotosaurus* bones identified in this study gives only a limited and possibly skewed account of the total diversity of bones preserved in Quarry Ig/WJ.

Most of the non-*Dysalotosaurus* bone material from Quarry Ig/WJ is attributed to the basal thyreophoran *Kentrosaurus aethiopicus* (Hübner et al., 2021). Sauropod remains from Quarry Ig/WJ are limited and currently, there is only one metatarsal of *Giraffatitan* (MB.R.2393) from that quarry listed in the collection of the MfN. The presence of more sauropod material from Quarry Ig/WJ is interesting and important for further researching into its taphonomy and taxonomic content, although it can neither be excluded nor verified that these other remains also belong to *Giraffatitan*. The vertebra of the theropod dinosaur *Elaphrosaurus bambergi* and the manual theropod phalanx mentioned by Janensch (1925b) seem to be lost (Rauhut and Carrano, 2016). The collection catalogues of the MfN lists theropod teeth referred to *Elaphrosaurus* (Janensch, 1925b), but in the absence of skull remains of this taxon, this referral is uncertain, and these elements might be better identified as belonging to undetermined theropod dinosaurs. Presumably, such larger teeth were packed and transported separately, whereas smaller ones might have been stored in the tin cans together with other small material. In general, the taxonomic distribution of macroscopic finds in the bamboo corsets and crates, dominated by many differently sized bones of *Dysalotosaurus* and only few finds of thyreophorans and sauropods, is in line with what is known from Quarry Ig/WJ (Hennig, 1936; Janensch 1914b, 1925, 1955; Heinrich, 2001; Maier, 2003).

Beyond these macroscopic fossils, screen-washing of sediment samples from Quarry Ig/WJ by Dr. Wolf-Dieter Heinrich in the 1990s revealed a rich microvertebrate fauna, ranging from the remains of pterosaurs, crocodylomorphs, and lizards to three genera of mammals (Broschinski, 1999; Unwin and Heinrich, 1999; Heinrich 1998, 1999b, 2001). This hidden richness emphasizes the potential value of preserved sediment within the bamboo corsets, which may hold more of the microvertebrates waiting to be uncovered. Since there is no record of non-dinosaurian material from Quarry Ig/WJ in the field notes of Janensch (1909-1911), it remains speculative as to whether, for example, the tin cans also contain some microvertebrate remains.

Preparation Priorities and Handling of Data for Collection Management

As all the material is in good condition and none of the containers show signs of decay, from a conservational viewpoint there is no actual need to prepare the content of the bamboo corsets and wooden boxes soon. Therefore, only scientific arguments for and against opening and preparation of the containers need be considered when creating the criteria for prioritization of this work. These arguments are outlined below:

a. The occurrence of rare and/or nicely preserved bone elements in the sample compared to bones in the collection of MfN is the most important argument for priority preparation. As mentioned before, prepared and unprepared material of *Dysalotosaurus lettowvorbecki* is fortunately also preserved in other German collections, in particular in Munich (BSPG), Stuttgart (SMNS), Tübingen (GPIT), and Göttingen (GZG) (i.e., Hübner and Rauhut, 2010; Hübner, 2018; Hübner et al., 2021). However, rareness of single elements in the “core collection” from the GTE at the MfN Berlin should be used as a driver for priority preparation.

In case of *Dysalotosaurus*, skull elements, forelimb elements, and those of the shoulder and pelvic girdle are rare in the vertebrate paleontology collection of the MfN, and their presence in the studied sample would warrant priority preparation. Because manus bones of *Dysalotosaurus* are still unknown (Hübner, 2018; Hübner et al., 2021), it would be auspicious to screen bone accumulations in the tin cans specifically for these autopodial bones.

Due to the rarity of non-*Dysalotosaurus* material known from Quarry Ig/WJ, any record of other dinosaurs in the sample is important. Due to their high taxonomic and taphonomic value, the remains of *Kentrosaurus* and sauropods in some of the containers have high priority for preparation.

b) As described above, it is possible that close examination of the tin cans and fruit capsules from Quarry Ig/WJ may yield some non-dinosaurian material among the bones. Screen washing sediment from the quarry is one method that may reveal microvertebrate remains. This technique has been applied very successfully by Dr. W.-D. Heinrich for isolated sediment slabs from Quarry Ig/WJ (e.g., Heinrich, 1999b; Heinrich, 2001; see also above).

Therefore, both tin cans and fruit capsules containing sediment, and sediment slabs from Quarry Ig/WJ are suggested to have a high preparation priority.

c) Another scientific aspect is the conservation of old preparation techniques and in situ documentation of old field practices. As preserved, the containers serve as an original account and physical documentation of field practices and handling of paleontological specimens at an excavation in a remote area from the beginning of the twentieth century. Preservation of some of the containers in their original condition is favorable as a part of the historical documentation from the GTE. They also have value as objects in future exhibitions. The containers chosen to remain in their original condition should ideally comprise material of all the different kinds of packing and preservation documented above: clay jackets, clusters of vertebrae, filled tin cans and fruit capsules and/or stalks, single bones packed in savannah grass, loose sediment slabs, and one of the six originally packed crates.

With the help of the above arguments **a)** (fossil preservation, rare elements and taxa) and **b)** (sediment available for screen washing), each container is scored for a "Preparation Priority Level" (PPL) (see Table 1 for scores), defined as following:

PPL 1 = The highest priority level for unpacking of containers and preparation of bones is applied to bamboo corsets and crates with material determined as *Kentrosaurus* or sauropods, and cranial and mandibular bones of *Dysalotosaurus*. PPL 1 is assigned to the bamboo corsets "Ig 88", "Ig 189, 211, 213", "Ig 230", "Ig 88", "Ig 277, 279, 284", "Ig281", "Ig 305, 303, 307, 310, 317, 318, 319", "Ig 310, 311, 312, 313, 314", "Ig 401, 415, 416, 417, 472, 475", "Ig 498", and "Ig 590, 597, 599, 603, 605"; and to the crates "Ig_2011_1" (but see below) and "Ig_2011_2".

PPL 2 = Containers scored with the second priority level should be unpacked in the progress of preparation of the remaining Tendaguru material, but only after containers scored with PPL 1. PPL 2 comprises rarer complete bones of *Dysalotosaurus* from shoulder girdle, forelimb, pelvic girdle and autopodium, as well as assemblages of small bones in tin cans that cannot be determined without opening, and sediment slabs that would be suitable for screen washing. Tin cans and fruit capsules could be easily opened, and the bones preliminarily determined without much preparation necessary before, as they are preserved with minimal sediment sticking to them (Personal Observation from already opened containers by DS). PPL 2 is assigned to the bamboo corsets "Ig 133, 151, 152, 191", "Ig 233, 279, 299, 306, 315, 321, 325, 326, 328", "Ig 256, 262, 264, 273, 282", "Ig 291, 291", "Ig 320, 322, 329, 344, 348, 349, 357, 358", „"Ig 329, 323, 361, 362, 363, 356", "Ig 330, 339, 347, 349, 350, 351, 352, 356, 360, 346, 366", "Ig 335, 336, 338, 368", "Ig 343, 346, 354, 359, 366, 383", "Ig 379, 382, 383, 385, 386, 388", "Ig 402, 403, 406, 413, 414", "Ig420, 439, 453, 512", "Ig 425, 473, 476, 477, 484", "Ig 428, 459, 501, 504, 506, 508, 509, 514, 520, 526", "Ig 440, 443, 444, 434, 432, 442", "Ig 522, 527, 528,539, 543, 544", "Ig 537, 540, 547, 549, 562", "Ig_NN3", "Ig_NN5" and "Ig_NN6"; and to the crates "Ig_2011_4", "Ig_2011_5". s

PPL 0 = Containers assigned as PPL 0 are not considered to have any priority for preparation and therefore can be processed in the future and after those containers with PPL 1 and 2 or be preserved as original samples (see directly below). PPL 0 is scored for the bamboo corsets "Ig 122, 124, 266, 267, 269, 270, 272 276", "Ig 202, 203, 204, 212, 214, 231", "Ig 323, 327, 333, 334, 337, 341, 362, 364 (?)", "Ig400, 412, 482, 483, 485", "Ig_NN1", "Ig_NN2" and "Ig_NN4"; and for the crates "Ig2011_3" and "Ig_2011_6".

The following containers, chosen mostly from the category "PPL 0" are suggested for preservation under original condition, representing the whole sample of different packing techniques:

- Bamboo corset "Ig 122, 124, 266, 267, 269, 270, 272, 276" (PPL 0) contains clusters of vertebral centra and some hindlimb bone fragments of *Dysalotosaurus* wrapped in Savanna grass
- Bamboo corset "Ig 323, 327, 333, 334, 337, 341, 362, 364 (?)" (PPL 0) contains the typical clay jackets plus some bone fragments in savanna grass, all material of *Dysalotosaurus*,.
- Bamboo corset "Ig_NN4" (PPL 0) contains three big clusters of vertebral centra packed in savanna grass and has no field numbers assigned.
- Crate "Ig_2011_6" (PPL 0) is chosen as an example for an originally packed crate, containing clay jackets and single hind limb bones of Dysalotosaurus, but having neither

field numbers nor reference in the field catalogue, PPL 0.

- Bamboo corset "Ig_NN6" (PPL 2) contains three fossil-filled tin cans and a cluster of vertebral centra. All containers with tin cans are assigned PPL 2, because they should be screened for autopodial elements of *Dysalotosaurus*. This bamboo corset has been chosen because it has no field numbers assigned and so is not listed in the field catalogue, and it contains the least amount of tin cans.
- Crate "Ig_2011_1" (PPL 1) has several bone fragments with sediment that are packed in Savanna grass bundles and additionally contains four bamboo stalks. The container was assigned PPL 1, because it contains an ulna of *Kentrosaurus*, but as this is the only container with bamboo stalks it is strongly suggested that this crate be kept in its original condition if possible. Alternatively, the crate could be opened, the material of *Kentrosaurus* could be removed, and the rest be left in its original packing condition. In any case, careful consideration is required before opening this crate.

Cataloguing of New Specimens

The collection practice of referring to specimens from the GTE under their respective field numbers in the past (see Introduction) makes it necessary to maintain the original field number together with the specific MfN collection number (MB.R.xxxx). It is important to ensure that each catalogued specimen can be explicitly identified either by the collection number, with reference to the historic field number, and/or a combination of both numbers, as historical GTE field numbers were also used in scientific publications of the past. With the information retrieved from the CT data here, accessioning of unpacked materials with MfN specific collection numbers plus a GTE field number is possible in those cases where field numbers are assigned to determined specimens (see Table 1 and Janensch, 1909-1911). To match the field numbers on the containers to the other specimens, as well as when several bones are assembled under one field number, there is no other way than to unpack the respective container and look up the field numbers painted onto the clay jackets or on the specimens themselves. Additional assignment of MfN specific NURIs (Uniform Resource Identifier, MfN term) for object identification, a practice that has been used at the MfN for collection objects for some years, will allow tracking of the specimen and collecting corresponding information in all databases (the NURI does not replace the collection number, but runs parallel to it). Before unpacking any of the bamboo corsets, NURIs need to be given to them to serve as a primary identifier for those units that can also be referred to in scientific publications.

Further Use of the CT Data

The visualization and interpretation of the CT data in this work yielded 3D volume data that allows the identification and record of bones larger than ca. 5 cm in length from the unopened containers of the GTE, as well as digital measurements of some of them (Hübner et al., 2021). In contrast, smaller specimens and clusters of bones could not be individually identified, mostly because the resolution is too low to distinguish single bones clustered together tightly and/or partly stored in tin cans. Segmentation of smaller bones from the sample for 3D visualization (either as 3D volume or surface data) would mean a large amount of time-consuming work. In contrast, simply unpacking these bones to directly study and digitize them requires significantly less time.

Volumetric data can be used for a range of scientific questions, including digital measuring of bone dimensions (Hübner et al. 2021) and 3D reconstruction and printing of unprepared bones (Schilling et al., 2014). The resolution of the medical CT scans however is not good enough for approaches that require a high resolution of extracted 3D surface polygon models, such as FEA and kinematic modelling applications. This is likely because the scans are not focusing on single bones but record in each sample a large number of bones packed together. Segmentation of single larger bones is required before further processing, but producing a mesh of sufficient quality would require additional work to improve the models. Therefore, research that requires models of a higher resolution would be better collecting 3D surface data of the fully prepared original specimens from the collections (usually either photogrammetry or structured light scanners, see Díez-Díaz et al., 2021).

The data quality allows an overview of the contents of these containers, a certain level of 3D digitization, and it provides a long-lasting information source and documentation of these old GTE containers. Being aware that costly computer programs are not available to all scientists and can easily create another barrier to global accessibility, it is advisable to share data that can be visualized and studied in freeware computer programs. The original CT data in DICOM format as provided for download (https://doi.org/10.7479/d1pq-2g96) can be viewed and reconstructed in several DICOM viewers that are available either as freeware or have a smaller freeware version (e.g., OsiriX™, Horos, ImageJ or MicroDicom). Automated segmentation and export of the volume data into surface models (e.g., obj. or stl. format) is possible (e.g., in 3D Slicer), for improvement or visualization of the resulting surface meshes the freeware programs MeshMaker and MeshLab (among other programs) would be suitable.

The provided data also has the potential to be used in museum displays, interactive exhibitions, and for other museological purposes. The documentation of this sample and the global availability of the virtual data allows its future use for studies beyond paleontology, especially regarding the colonial context of the sample. The materials described and documented here are both the results of and the historical evidence of hard and substantial excavation work of many local people from the Tendaguru area. It also serves as an example of historical collection, preparation, and field practices of the GTE. As such, the data provides/gives the opportunity for scientists to study these well documented historical field practices under colonial conditions and supplement current research on this topic (e.g., Heumann et al., 2018). The context of the digital data, as has been provided in this paper, is of particular importance considering this colonial background.

CONCLUSIONS

The last unopened bamboo corsets and wooden crates from Quarry Ig/WJ of the Tendaguru area in southern Tanzania were originally regarded as a kind of “leftover” material from that quarry. The bamboo corsets and crates seem to have been packed to contain specimens regarded to be less scientifically valuable, whereas the “better” specimens were treated separately. Apparently, Janensch and Hennig, the responsible scientists from the MfN for the field work in the Tendaguru area between 1909 and 1911, sorted out these “better” specimens directly in the field for priority transport. Given that the field numbers from these boxes are low, it can be presumed that this happened soon after it became clear that the bonebeds in Quarry Ig/WJ were going to deliver a huge amount of material, and that there was the need to distinguish between material deemed important and that which was of less use. Yet, the destruction of lots of material of *Dysalotosaurus* from Quarry Ig/WJ during WWII and the presence of originally packed containers from an expedition more than 100 years ago proves the scientific importance of these bamboo corsets and crates today. In fact, the existence of originally packed and untouched specimens is a fortunate circumstance, as it allows both studies with a paleontological focus as well as studies of historical context, giving life to documentation of old preparation and field practices from one of the most famous paleontological expeditions worldwide.

This paper also wants to serve as an example of a virtual study of unpacked material, demonstrating rapid assessment of information about large amounts of historical fossil material that is used not only for paleontological research questions, but also to enhance studies of the historical contexts of the GTE. Preparation of the materials without careful virtual documentation could dilute the connection between sampled specimens and the aspects of the historical collection. Physical unpacking of these bamboo corsets requires meticulous documentation to capture all available information. By scanning the unopened containers, criteria for prioritizing the opening of the containers were able to be produced. Containers with bones that supplement missing skeletal elements of *Dysalotosaurus* and those that contain bones from species underrepresented in Quarry Ig/WJ are assigned the highest priority for unpacking and preparation. Additionally, those that contain original sediment matrix were assigned a high priority as the preserved sediment allows the study of the original bonebeds deposit (Heinrich, 1999a; Hübner et al., 2021), the taphonomy of the environment, and has the potential to yield more elements of microvertebrate fauna.

By defining criteria for specimens that need to be prepared in the near future it is also possible to determine which containers can be left unopened to remain as original collection samples from the GTE. In its original state of preservation, this whole suite of containers stands as a living document and evidence of the hard and substantial excavation work of many local people from the Tendaguru area (Maier, 2003; Heinrich and Schultka, 2007; Heumann et al. 2018), who spent several months saving this valuable material, from which new discoveries are being made even over a century later. The publication of not only the data on the specimens contained in these crates, but also of the historical context under which it was collected and packed, makes it useful beyond the scope of paleontology and allows researchers from a wide range of disciplines to make use of it. It plays a part in contributing to the understanding and preservation of the history and natural heritage of the Tendaguru locality and preserves the memory of the colonial practices that went into the collection of, and cannot be decoupled from, these important specimens.

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