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VARIATION IN TIME AVERAGING AND TAPHONOMIC CHARACTER OF SHELL BEDS IN LAKE TANGANYIKA, AFRICA: PALEOENVIRONMENTAL AND STRATIGRAPHIC IMPLICATIONS OF SHELL BEDS IN RIFT LAKES

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VARIATION IN TIME AVERAGING AND TAPHONOMIC CHARACTER OF SHELL BEDS IN LAKE TANGANYIKA, AFRICA: PALEOENVIRONMENTAL AND STRATIGRAPHIC IMPLICATIONS OF SHELL BEDS IN RIFT LAKES

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Abstract

Large regions of the littoral lake bottom along structural platforms in Lake Tanganyika, Africa, are carpeted with shell beds of late Holocene age. The viviparous gastropod *Neothauma tanganyicense (Neothauma)* is the lead contributor to these accumulations but the snail itself is rarely found living on or adjacent to the shell accumulations (poor live-dead agreement), which makes it difficult to develop a model for the process(es) of shell accumulation and consequent community structuring of those organisms that occupy the shell beds.

In this study, time averaging and taphonomy of shell beds located in Kungwe Bay, Lake Tanganyika are examined to better understand paleoecology, paleoclimate, and the processes that lead to the formation of the shell beds. Radiocarbon dating indicates that *Neothauma* deposits in the region are time averaged over the last ~3300 years. Young shells are primarily located in shallow water, older shells are located in deep water, and temporal mixing varies based on the slope of river deltas. Taphonomic results indicate that water depth and siliciclastic deltaic input both influence the degree of *Neothauma* shell abrasion and encrustation. Shells coated with a black coating and reddish-orange oxidation patinas show signs of exposure, burial, and microbial activity. The shell beds accumulate as lake-level fluctuation impacts and reworks the river deltas where *Neothauma* live. The results from this study build a framework for climate, lake-level fluctuation, and deltaic depositional processes which play unique roles in the distribution and accumulation of shell beds in Lake Tanganyika, and can be used to interpret paleoenvironment in the geologic record.

Introduction

Lake Tanganyika is the largest tropical lake and the second deepest lake in the world (McGlue et al., 2010). Located in the East African Rift Valley, the lake is bordered by Burundi, the Democratic Republic of the Congo, Tanzania, and Zambia (Fig. 1). Because of Lake Tanganyika's ancient age and environmental variability, a number of endemic taxon have evolved (Coulter, 1991) and the lake has been the subject of numerous evolutionary biology and ecology studies (e.g. West et al., 1991; Koblmüller et al., 2007; Michel et al., 2007; Marijnissen et al., 2009). Further, Cohen and Thouin (1987) suggest that the lake's diverse carbonate facies are "unparalleled among modern lakes worldwide," and form an analogue for many carbonate-rich lake deposits in the geologic record. Extensive shell beds form one of these carbonate depositional environments in Lake Tanganyika. These shell beds form a crucial interface between the bio- and geosystems of the lake (McGlue et al., 2010) as they record environmental and ecologic change and may have fostered evolution of endemic species that occupy the shell beds.

The shell beds are primarily found along deltaic platforms and consist of siliciclastic gravel, sand, gastropod shells, bivalve shells and shell fragments (Fig. 2; Soreghan and Cohen, 1996; McGlue et al., 2006; McGlue et al., 2010; Jordan, 2012) which blanket shallow platforms opposite of half-graben-forming normal faults. Whole shell and shell fragments from the bivalve, *Coelatura burtoni,* and the gastropods *Neothauma tanganyicense* and *Paramelania* form the majority of the bioclasts within the shell beds (Cohen and Thouin, 1987; Soreghan and Cohen, 1996; McGlue et al.,

2010) and the shells serve as a habitat for a group of endemic mollusks, sponges, crabs, and cichlid fish (Coulter, 1991).

The snail, *Neothauma tanganyicense (*hereafter, *Neothauma)*, a viviparous gastropod, is the largest bioclast of the death assemblages and is poorly understood ecologically (McGlue et al., 2010). *Neothauma* is rarely found living on or adjacent to the shell accumulations (poor live-dead agreement), which makes it difficult to develop a model for the process(es) of shell accumulation and consequent community structuring of those organisms that occupy the shell beds. Nonetheless, examining the time averaging and taphonomy of the shells can provide the data to develop a model for the accumulation of the vast deposits of shells throughout the littoral environments of Lake Tanganyika.

Taphonomy and analysis of time averaging of bioclasts are powerful tools that can be used to reconstruct paleoecology and paleoenvironmental changes (Kidwell et al., 1986; Kidwell and Bosence, 1991, Fürsich and Aberhan, 1990). Although studies investigating time averaging and taphonomy in lacustrine systems are less common than studies in marine systems, several recent studies of the shell beds in Lake Tanganyika suggest spatial variation and sedimentologic differences in shell composition and sediment texture related to variations in depth and geographic location (Cohen, 1989; Soreghan and Cohen, 1996; McGlue et al., 2010; Jordan, 2012; Soreghan, 2016). This study of shell beds in Kungwe Bay, Lake Tanganyika integrates time averaging and taphonomy to determine the paleoecology of *Neothauma tanganyicense,* the processes that led to the development of extensive accumulations of the shells, and the influence deltaic sedimentation has on taphonomy and time averaging. The results of this study will lead to a better understanding of the genesis of the shell accumulations in this and other tropical lakes and provide a measure of recent ecological and environmental change recorded by the time-averaging of the shells. Because this study is the first of its kind for Kungwe Bay, it also improves the understanding of the distribution, spatial variability, and depositional environment of the shell beds, and provides important constraints on the formation and variability of shell accumulations for ancient lacustrine deposits.

Background

Geology and Limnology of Lake Tanganyika

Rifting in East Africa began in the Miocene as the African plate migrated northwest and the Somalian plate migrated southeast, forming a series of N-S trending basins (Chorowicz, 2005; Macgregor, 2015). The Tanganyika basin is estimated to have developed between 9 and 12 Ma (Cohen et al., 1993) and forms a series of half-graben basins bounded by high-angle faults along which the polarity of the footwall alternates (Fig. 1; Chorowicz, 2005). The Tanganyika basin is 700 km long, up to 70 km wide, and contains 4,000-5,000 m of sediment fill (Chorowicz, 2005). The lake reaches maximum water depth of approximately 1,470 m in the southern basin (Rosendahl, 1988; McGlue et al., 2008). The bedrock within the lake's watershed is predominantly Proterozoic metamorphic and igneous rocks, late Paleozoic-early Mesozoic Karroo sedimentary rocks, and volcanic rocks of late Tertiary age (Cohen et al., 1997).

Lake Tanganyika's water chemistry results in the development of unique carbonate environments (Cohen and Thouin, 1987; Haberyan and Hecky, 1987; Cohen et al., 1997; McManus et al., 2015). The water chemistry of Lake Tanganyika appears to be strongly controlled by variations in the Ruzizi River's (Fig. 1) discharge into Lake Tanganyika as it transports water from Lake Kivu. The two lakes have been hydrologically intermittently connected since 10.6 ka (Felton et al., 2007), but carbonate production increased ~2.2 ka when Lake Kivu's input increased (Craig et al., 1974; Cohen et al., 1997; Stager et al., 2009). Lake Kivu, a volcanic lake, is a major source of alkalinity, resulting in Lake Tanganyika's supersaturation with respect to calcite, aragonite, and magnesium calcite (Cohen et al., 1997; Brucker et al., 2011). Lake Tanganyika has a high Mg/Ca ratio, is mildly alkaline, and has a pH of ~8.5 (Cohen and Thouin, 1987; Edmond et al., 1993). With an average transparency of 8.7-12.8 m, the lake's clear waters allow photosynthetic algae to grow in relatively deep water (Plisnier et al., 1999). The oxycline of the lake lies at a depth of roughly 150 m and the majority of the lake's water volume is anoxic (Hecky and Degens, 1973; Coulter and Spiegel, 1991). A warm, non-windy season occurs from October-April and a cool, dry, windy season lasts from May-September (O'Reilly et al., 2003). The oxycline fluctuates seasonally, and during the dry season differential cooling of the lake and stronger winds promotes upwelling of nutrient-rich anoxic waters into the epilimnion, though this process has been modified by higher temperatures in the recent past (Verburg et al., 2011; Cohen et al., 2016).

Shell Beds and Neothauma tanganyicense of Lake Tanganyika

The shell beds of Lake Tanganyika form semi-continuous deposits in ~9-30 m of water for as much as 10 km along low-gradient platforms of the lake's littoral zone (Fig. 1; Cohen and Thouin, 1987). There is an association between the location of the shell beds and river deltas as the majority of documented shell beds and studies examining them have been performed along river deltas (Soreghan and Cohen, 1996; McGlue et al., 2006; McGlue et al., 2010; Jordan, 2012). The association between shell beds and river deltas has also been documented in Lake Edward where gastropod and bivalve shells and shell hashes are found over clinoform reflections (McGlue et al., 2006). The shell beds consist of the gastropod species *Neothauma,* several snails of the genus *Paramelania,* and the bivalve *Coelatura burtoni,* along with siliciclastic mud and sand (Fig. 2; Cohen and Thouin, 1987; Soreghan and Cohen, 1996; McGlue et al., 2010). The individual shells exhibit varying levels of taphonomic overprinting, including fragmentation, abrasion, encrustation and/or exhibit a black coating associated with oxidation and reduction (McGlue et al., 2010). The composition of the shell beds varies depending on water depth and coastline morphology (McGlue et al., 2010). Along embayments and headlands, coquinas consist of gravel-rich mollusk hash (McGlue et al., 2010), whereas along deltaic platforms coquinas are sandy to silty mollusk hash or pure mollusk hash (McGlue et al., 2010). All the surficial hashes and shells are unconsolidated, but cemented coquinas have been observed in outcrops along the upper deltaic plain of the Ruzizi River (Soreghan and Cohen, 1996).

Neothauma tanganyicense is the target taxon of this study. *Neothauma* is endemic to Lake Tanganyika and is distinguishable by a smooth, obtuse protoconch and thick shell (Van Damme and Pickford, 1999) composed of aragonite. *Neothauma* likely has a life span of ~2-4 years (E. Michel, pers. comm.) Phylogenetic studies suggest *Neothauma* existed in Africa since the early to middle Miocene and were widespread in East African lakes until 4.5 Ma, when climate change or tectonic activity resulted in regional extinction but left an isolated *Neothauma* population in Lake Tanganyika (Sengupta et al., 2009). Edgar Smith first documented *Neothauma* in 1880; however, their ecology and life history have remained poorly understood since live specimens are extremely rare (McGlue et al., 2010; Soreghan, 2016). In 1946-47 Eugene Leloup surveyed benthic organisms in Lake Tanganyika by dredging and recorded live *Neothauma* at 17 sites (Table 1). Live *Neothauma* are observed to inhabit shallow, clear waters with sandy and silty substrates (Moore, 1903; Leloup, 1953; McGlue et al.,

2010) and do not live on the shell beds. *Neothauma* likely live on the surface of sediment and use a proboscis to feed on endobenthic organisms (Van Damme and Pickford, 1999). Juvenile snails have been observed burying themselves 3-10 cm deep in soft substrate to avoid predators (West et al., 1991), but adult African viviparids do not burrow (Van Damme and Pickford, 1999).

Neothauma are long lived in Lake Tanganyika, serving as a key component in the littoral ecosystem. But today, dead *Neothauma* shells outnumber live snails, indicating poor live-dead agreement. Disagreements between live and death assemblages have been attributed to anthropogenic stresses, specifically eutrophication (Kidwell, 2013). Studies from Lake Tanganyika document anthropogenic-induced sedimentation resulting in decreased diversity of fish, ostracods, and mollusks (Alin et al., 1999; Alin et al., 2002; Donohue et al., 2003; Donohue and Irvine, 2004; McIntyre et al., 2005). Busch (2017) documented land-use change and consequent impacts to modern sediment cover within the study area, however, it is not clear if human-induced change to the littoral ecosystem or natural basin-wide environmental changes is the primary driver for the live-dead disagreement of *Neothauma.*

Environmental Changes in Lake Tanganyika

Lake Tanganyika has undergone significant environmental changes since its formation. During the late Pleistocene and early Holocene, sub-Milankovitch scale changes in precipitation-aridity and the migration of the Intertropical Convergence Zone (ITCZ) were the main forcings controlling climate of East Africa (Gasse, 2000; Tierney et al., 2008). Lake Tanganyika is susceptible to changes in climate to the extent that lake level is estimated to have fallen ~260 m during the Last Glacial Maximum (32-14 ka) (McGlue et al., 2008).

Holocene climate has been controlled by changes in regional climate caused by migration of the ITCZ and the elevation of the lake's outlet (Tierney et al., 2008; McManus et al., 2015). Cohen et al. (1997) suggested lake-level fluctuations of 20 m over the past 2,800 years based on stable isotope records derived from stromatolites within the lake. Holocene climatic changes of Lake Tanganyika are not fully documented because shallow-water cores are rare and commonly stratigraphically incomplete, whereas deep-water cores often overpenetrate the uppermost sediment column or are insensitive to low-amplitude lake fluctuations. However, sediment core data collected from Lake Tanganyika indicate variable dry and wet periods during the Holocene (Stager et al., 2009). The most recent significant fluctuation in lake level occurred during the latter half of the Little Ice Age (LIA, ~1550-1850 CE) when the lake dropped ~10 m as climate became drier (Alin and Cohen, 2003). After the LIA, precipitation in the area increased and lake level reached a maximum around 1878 and has since decreased to its present-day level of 773 m above sea level (Alin and Cohen, 2003).

Previous studies suggest that climatic change may impact the formation and distribution of shell beds in Lake Tanganyika through winnowing during lowstands in lake level (Cohen, 1989), or by transgressive reworking (McGlue et al., 2010) as lake level rises. The volume and texture of sediment delivered to the nearshore environment also varies with rainfall variability, and deltaic morphology is impacted by both lake level changes and variations in sediment discharge. And the most recent environmental impact on Lake Tanganyika is anthropogenic land-use change and changes in lake mixing due to global warming (Cohen et al., 2016). Examining the taphonomy and time-averaging of the shells should shed light on the relative importance of these climatically linked processes in forming the shell beds of Lake Tanganyika.

Methods

The fieldwork for this study was carried out in July-August of 2015 and 2016 from the Tuungane field station near Buhingu, Tanzania in Kungwe Bay on Lake Tanganyika (Fig. 1). Field and laboratory data collection methods are outlined below.

Field Methods

Sampling Transects

Within the Kungwe Bay study area, shells were collected at 9, 12, 15, and 20 m along eight sampling transects perpendicular to the shoreline (Fig. 3). At each transect a name was assigned to the sample, e.g. MT2016-T9-9, MT indicates the Kungwe Bay location, 2016 indicates the year, T9 indicates the transect, and 9 indicates the water depth in meters. All samples follow this nomenclature.

Shell Sample Collection

Bulk shell samples were collected along 8 transects (Transect 1-9, there is not a transect 8) perpendicular to the shoreline at 9, 12, 15, and 20 meters water depth (Fig. 3). The distance offshore to 9 meters of water depth averages 520 m. Navigation along transects via GPS was recorded with a Lowrance HDS-5 sonar unit. At each sampling location depth, a GPS point was determined and using SCUBA, the researchers would drop directly below the boat to the lake floor. Where shells were present, researchers would place a 50 cm x 50 cm quadrat on the lake floor and scrape all the shells within that quadrat into a mesh sampling bag. In the absence of surficial shells, the researchers would dig to 5 cm into the substrate to collect buried shells; however, at MT2015-T2 at 9 m and 12 m there were no shells within the upper 5 cm of sediment. Back at the field station, shells would be set out to dry in the sun and placed in a labeled 1-gallon Ziploc bag. The sample size of *Neothauma* shells varied from 5-232 shells among the sampled sites. The shells were packaged carefully and wrapped in bubble wrap to prevent any further taphonomic damage, specifically fragmentation, and transported to the United States.

Laboratory Methods

Geochronology

Time averaging is the process of non-contemporaneous individuals accumulating into a single death assemblage (Kidwell and Tomasovych, 2013) and the extent of time averaging in recent accumulations can be determined using radiocarbon dating. The degree of time averaging in Kungwe Bay was determined using rapid method radiocarbon dating (Bush et al., 2013) on 60 *Neothauma* shells, and then dating live-caught *Neothauma* shells to access the impact of the reservoir effect of old carbon (discussed below).

Rapid method radiocarbon dating was performed on 60 *Neothauma* shells, 15 shells from 9 m and 15 shells from 20 m at a northern transect, MT2016-T4, and 15 shells from 9 m and 15 shells from 20 m at the most southern transect MT2016-T9 (Fig. 3). MT2016-T5 is the northernmost transect in Kungwe Bay, but the transect did not have enough shells at the targeted depth to date for consistency. The 15 shells from each locality and depth were randomly selected and included adult and juvenile size snails. Several shells from each locality were encrusted. A Dremel 7000 was used to grind away the encrustation until pristine shell was observed, and then a square centimeter fragment was cut from the sixth whorl of each shell to be dated. Rapid method radiocarbon dating was performed following the methods described by Bush et al. (2013), which are modified from Longworth et al. (2013) by using an iron catalyst rather than a titanium catalyst. The rapid method ^{14}C analysis produces carbon ions directly from carbonate and does not require samples to be transformed into graphite, decreasing the chance for contamination (Longworth et al., 2013). Shell fragments were prepped for rapid method radiocarbon dating at the Amino Acid Geochronology Laboratory at Northern Arizona University (NAU). At NAU, each sample was rinsed with water and debris was removed by sonication. The outer ~33% of the shell was removed with 2 M HCl. The samples were ground into a fine powder with an agate mortar and pestle and mixed with ~5 mg of Sigma Aldrich -400 mesh Fe powder. The samples and Fe mix were placed into a target cartridge and 400 psi was applied to the target to compact the powder. Rapid method radiocarbon dating was completed at the Accelerator Mass Spectrometry (AMS) laboratory at the University of California, Irvine (UCI). Each sample was analyzed four times for 150 seconds. Radiocarbon dates were calibrated and converted to calendar years using CalPal (Weninger et al., 2008).

Five live-caught *Neothauma* shells were radiocarbon dated to determine the presence and magnitude of the old-carbon reservoir effect in Kungwe Bay. A one-centimeter rectangular fragment from the sixth whorl near the lip was removed from each shell. Radiocarbon dating on the shell fragments was performed at the Center for Accelerator Mass Spectrometry at the Lawrence Livermore National Laboratory.

Taphonomic Analysis

The taphonomic analysis examines the post mortem damage state of *Neothauma* shells, in order to interpret the origin and depositional history of shell beds and potential transport mechanisms (Kidwell et al., 1986; Kidwell et al., 2001). By examining the taphonomic character of *Neothauma* shells, we can begin to understand the sedimentological and environmental processes contributing to the formation of the shell beds, which has implications for stratal development of analogous shelly deposits in ancient settings. Prior to analysis, the shells were soaked in bleach to remove recent algal growth. The taphonomic variables analyzed were abrasion, fragmentation, encrustation, black coating, and oxidation patina (Table 2). A qualitative 3-pt scoring of the degree of each taphonomic attribute was applied to each shell (0 = no damage, 1 = low damage, 2 = high damage; Fig. 4). The results were calibrated to a pristine dead *Neothauma* shell as a reference. 2,022 specimens were evaluated by a single evaluator to maintain consistency. Average values were calculated by taking the mean of individual scores of each taphonomic character at each dive site. Ternary diagrams and graphs were created to analyze trends in the taphonomic character with depth and position across the bay. Samples were divided into shallow water (9 and 12 m) and deep water (15 and 20 m) for analysis of the ternary diagrams.

X-ray Diffraction of Encrustation and Black Coating

X-Ray Diffraction (XRD) was utilized to determine the mineralogical composition of the encrustation and black coating on the shells. The encrusted shell came from transect MT2015-T6-12. The shell with the black coating came from transect MT2015-T2-20. The encrustation and black coating were removed using a Dremel 7000 and crushed into a fine power with a mortar and pestle. Random mounts of powdered encrustation and black coating were prepared with standard glass holders.

Samples were analyzed with a Rigaku Ultima IV XRD with Cu radiation source and a graphite monochromator using the Bragg-Brentano method (2-70° 2θ angle interval). The analyses were run with 0.02° step size and 2 seconds counting time using variable slits. The sample's spectrum was examined using the MDI-Jade Software Program that matched the resultant spectrum to known mineral spectrums.

Scanning Electron Microscope and Energy Dispersive X-ray Spectroscopy of Encrustation and Black Coating

A scanning electron microscope (SEM) equipped with energy dispersive X-ray spectroscopy (EDS) was used in addition to XRD to determine the composition of encrustation and the black coating. A one-centimeter fragment was removed from an encrusted *Neothauma* shell from transect MT2015-T6-12 and a *Neothauma* shell with black coating from MT2015-T2-20.

Results

Time Averaging

Results of radiocarbon dating reveal late Holocene ages across the Kungwe Bay shell beds, and no very young or modern shells within the deposits, confirming prior observations of poor-live-dead agreement within the shell beds. The radiocarbon dating results of the five live-caught *Neothauma* shells reveal modern calibrated ages in 4 out of 5 shells (Table 3). The live-caught shell that was not modern was collected in ~20 m of water which is deeper than the other live-caught snails and yielded an age of 147 ± 97 yrs BP. Rapid method radiocarbon dating calibrated ages range from 370 yrs BP to 3340 yrs BP (Table 3; Fig. 5A). The average age of *Neothauma* shells is ~1250 yrs BP at MT2015-T4-9, ~2550 yrs BP at MT2015-T4-20, ~1070 yrs BP from MT2016-T9-9 and ~1580 yrs BP at MT2016-T9-20. The data indicate a mixed temporal range spanning more than ~3300 yrs BP at the two-sigma level. Samples from MT2015-T4 exhibit the greatest range in ages. MT2016-T9 shows the greatest temporal mixing and contains the youngest sample dated to 372 ± 58 yrs BP. Results from a Mann-Whitney U-test using the Paleontological Statistics software package (PAST) indicate that shells from MT2015-T4-20 are statistically significantly older than the shells from MT2016-T9-20 with a U-value of 10 and a p-value of 0.0001; the age differences in samples from the same transects at 9 m are not significantly different with a U-value of 94.5 and p-value of 0.4693 (Table 4; Hammer et al., 2016). The age difference between shells in deep and shallow water from the same transect are significantly different (Table 4). The ages appear to cluster between ~3000-2000 yrs BP and ~1500-900 yrs BP with

~500 yr BP gap between the two clusters; there is only one shell with an age less than 400 yrs BP (Fig. 5B).

Taphonomy

The rank of the five taphonomic variables (Table 2) evaluated vary with water depth and proximity to modern river deltas. Ternary diagrams (Fig. 6-10) provide perspective on the range in damage states among the different samples and graphical representations of taphonomic averages (Fig. 11) provide information on the lateral variation of taphonomy across the study site.

Abrasion. Averages of samples range from 0 to 1.5; samples collected at 9 m depth exhibit the highest average abrasion score (Fig. 11). The ternary diagram for abrasion indicates that shallow-water samples (9 and 12 m depths) show higher degrees of abrasion, whereas deeper-water samples (15 and 20 m depths) are more variable, with some samples showing moderate levels of abrasion and others showing none (Fig. 6). Shells are more abraded in front of the delta-front slopes, peaking laterally at transects MT2015-T2, MT2015-T5, and MT2016-T9, which are all located in front of river deltas (Fig. 11).

Fragmentation. Fragmentation scores range from to 0.6-2.0 and the highest average score is at transect MT2015-T7 (Fig. 11). Overall, the taphonomic average scores are the highest at transects MT2015-T1 and MT2015-T7 and the lowest at transects MT2015-T4 and MT2015-T6 (Fig. 11). Large overlap and wide scatter occurs among samples in terms of shallow-water versus deep-water samples, and there does not appear to be a strong depth or lateral trend in the data (Fig. 7 and 11).

Encrustation. Encrustation scores range from 0.7-2.0 and is the lowest at transect MT2016-T9-9 (Fig. 11). Shallow-water samples exhibit less encrustation than deep-water samples, but variability exists with both shallow- and deep-water samples ranging from high to moderate levels of encrustation (Fig. 8). Laterally, the average scores for encrustation decrease at transects MT2015-T2, MT2015-T5, and MT2016-T9 (Fig. 11). These transects are adjacent to river deltas, indicating a relationship between river deltas and the degree of encrustation. However, even in deeper water, shells nearer to the deltas are less encrusted, even at similar water depths.

Black Coating. Black coating scores range from 0-1.5 with the highest average at transect MT2015-T7 (Fig. 11). Overall, the occurrence of black coating is relatively low. Shallow-water samples tend to exhibit lower degrees of black coating compared to deeper-water samples; there is a large degree of variability (Fig. 9). Laterally, the averages for black coating at each transect are greater in deeper waters than in shallow waters (Fig. 11). Despite deep-water samples having greater degree of black coating, there does not appears to be no distinct lateral trend within the deeper-water samples (Fig. 11).

Oxidation Patina. Oxidation patina averages range from 0-0.9 (Fig. 11). Oxidation patina is more prominent in shallow-water samples than deep-water samples but there is a large overlap between shallow- and deep-water samples (Fig. 10). Overall, the occurrence of oxidation patina is relatively low and exhibits low variability laterally (Fig. 11).

Overall, abrasion and encrustation exhibit a moderate relationship between water depth and taphonomic damage and a strong relationship between the degree of taphonomic damage and the proximity to river deltas, even in deeper water. Fragmentation levels are moderate to high among the samples but show little relationship to water depth or position along the platform. Finally, black coating and oxidation patina exhibit relatively lower taphonomic scores overall with the level of black coating exhibiting a weak relationship with water depth, but oxidation patina showing none.

Mineralogic and Elemental Composition of Shell Encrustation and Black Coating

X-Ray Diffraction (XRD) results from the encrustation indicate the mineralogical composition consists of 53% calcite, 38% aragonite, 8% kutnohorite (carbonate mineral), and 1% quartz (Fig. 12). The large percentage of kutnohorite is surprising. The peak for kutnohorite is very close to dolomite, so there is a possibility that it is dolomite, however, the kutnohorite peak matched the data better. The mineralogic composition of the black coating is 83% calcite, 7% quartz, 4% Fe containing minerals, 1% siderite and the remainder is variations in silicon oxides (Fig. 12). Energy dispersive X-ray spectroscopy (EDS) analysis confirmed that the encrustation is an Mg-bearing calcite. Scanning electron microscope (SEM) imaging of the encrusted shell showed a biofilm layer composed of diatoms, filamentous bacteria, possible cyanobacteria, and coccus of cyanobacterial cells (Fig. 13 A and B). SEM imaging of the black coating showed an irregular surface not resembling biologic structures (Fig. 13 C and D). However, major peaks obtained by EDS show the presence of Si, O, and Al in addition to a relatively smaller peak of Fe, potentially the source of the dark color. Si may come from the fragments of diatoms observed on the carbonate encrustation.

Discussion

This study's approach makes use of radiocarbon dating of individual shells coupled with taphonomic analysis of bulk *Neothauma* samples to determine the time averaging and post-mortem accumulation mechanisms of the shell beds in Kungwe Bay, north of the Mahale Mountains in Lake Tanganyika. Results indicate that *Neothauma tanganyicense* dominated shell beds are late Holocene in age and their formation is linked to the complex interplay between deltaic processes and water depth changes as discussed below.

One of the challenges to placing the time-averaging and taphonomic results into context is the lack of information on the life history and habitat preference of *Neothauma* itself. Our observations are that *Neothauma* live in shallow, clear water along sandy and silty substrates mostly in water depths of less than 10 m, although one live snail was recovered in a grab sample in 20 m of water. Leloup (1953) reported that the snails live in habitats as deep as 50 m which has been cited by other researchers; however, this result comes primarily from Leloup's (1953) expedition in which he recorded live snails collected by dredging out to 50 m of water, so the snails could have been living in shallower water and dragged by the dredge to deeper water. The discussion here assumes that the *Neothauma* live along delta slopes in shallow, sandy substrates in up to 20 m of water, which is most consistent with live collection made in the vicinity of Kungwe Bay.

Age distributions of shells and time averaging of shell deposits

Calibrated ages of *Neothauma* shells from Kungwe Bay range from modern to

3340 yrs BP, indicating ~3300 yrs BP of temporal mixing (Table 3; Fig. 5A). This study's results represent an even older and longer period of mixing than the ~1600 years of temporal mixing documented from *Neothauma* shells collected by McGlue et al. (2010) at a site (Luiche River; Fig. 1) farther north in Lake Tanganyika. The radiocarbon dates from McGlue et al. (2010) were corrected for Lake Tanganyika's old carbon reservoir following a correction outlined by Felton et al. (2007). However, a similar correction for the reservoir effect for shells from Kungwe Bay was not made, because the 4 out of 5 live-caught *Neothauma* from the region yield modern ages, which suggests that *Neothauma* may not be strongly influenced by old carbon in the lake (Table 3). The live-caught *Neothauma* snails from Kungwe Bay are potentially not impacted by the reservoir effect since they inhabit shallow water platforms, beyond the reach of deep-water upwelling. Alternatively, *Neothauma* may be grazing on fragments of terrestrial vegetation that is in equilibrium with atmospheric ^{14}C. The one snail that was live-caught from 20 m yielded an age of 147 ± 97 yrs BP. This complicates the correction for the reservoir effect because shells from deeper water may be impacted and shells in shallow water may not. In addition to the support of modern ages from live-caught *Neothauma*, Cohen et al. (1997) obtained modern and ultramodern radiocarbon ages after correcting for the reservoir effect on live-caught *Paramelania* and *Neothauma* from Lake Tanganyika collected near Burundi and the Democratic Republic of Congo. Despite having a greater degree of time averaging, the ^{14}C ages from this study (Table 3) are similar to the non-reservoir corrected ages obtained by McGlue et al. (2010) if a reservoir correction is not applied.

Factors that lead to time averaging of shelly deposits include biological, sedimentological, and diagenetic processes (Fürsich and Aberhan, 1990). For example, biogenic reworking, bioturbation, current and wave action coupled with low sediment input, and compaction and dissolution of matrix all result in time-averaged death assemblages; time averaging frequently results from a combination of factors (Fürsich and Aberhan, 1990). Shell preservation depends on factors such as water agitation, bioturbation, and sedimentation rate (Hauser et al., 2008); however, the data reveal little correlation between the shell age and the degree of taphonomic degradation (Fig. 14).

The shell beds in Lake Tanganyika are time averaged, and calibrated ages of the individual shells from this study form two clusters: the first ~3000-2000 yrs BP, the second ~1500-900 yrs BP, and then a single outlier at ~400 yrs BP (Fig. 5B). Climate in East Africa fluctuated between wet and dry conditions during the time range of the shell ages; and the periods of time when no shells were being produced or present in the region appear to correlate to phases of increased precipitation and accompanying heavy river discharge (Fig. 15; Stager et al., 2009). Climate change on decadal- to century-scales causing sediment variations are known to affect population levels in ecosystems (Covich and Stuiver, 1974). From 1700 to 1400 yrs BP the climate of East Africa became exceptionally wet (Fig. 15) and heavy river discharge likely resulted in increased sedimentation, including mass wasting, and expansion of deltaic habitats (Stager et al., 2009). Donohue and Irvine (2004) performed experiments with live gastropods from Lake Tanganyika wherein they subjected the gastropods to varying degrees of sedimentation; although none of the gastropods were *Neothauma,* results indicated that mortality increased when the snails were subjected to increased sedimentation. Our dataset suggests that *Neothauma* prefer sandy habitats with clear water and sub-aquatic vegetation (Moore, 1903; Leloup, 1953; McGlue et al., 2010; pers. obs.); if true, the increased sediment discharge during high precipitation phases may have created more turbid, muddier delta-front environments. This may explain the gap in shell ages between ~2000-1500 yrs BP, as *Neothauma* may have migrated to sandier, more suitable environments outside the sampled area, hence their local disappearance in the delta front environments.

The second gap in ages of *Neothauma* occurs between ~900-400 yrs BP (Fig. 5B). This absence of *Neothauma* from Kungwe Bay again correlates with published studies that suggest extremely wet conditions from ~1100-900 yrs BP and 700-500 yrs BP (Alin and Cohen, 2003; Stager et al., 2009) and may again reflect increased sedimentation in the delta front environments and migration of *Neothauma* out of the environment (Fig. 15). The most recent occurrence of *Neothauma* contributing to the shell accumulations was dated to 1578 ± 58 CE (Table 3). From our data, no modern or sub-modern *Neothauma* occur within the death assemblages in Kungwe Bay, indicating the small population of live snails on the modern Katumbi delta front (Fig. 3) are not contributing to these extensive shell bed deposits farther offshore; this potentially is a consequence increased eutrophication and sedimentation of the littoral zones by anthropogenic land-use change since the late-18th to early-19th centuries (Alin et al., 2002; Cohen et al., 2005).

There also appears to be a spatial difference in age populations of the shells. Kungwe Bay is fed by the Lukoma River in the north, the Lagosa River in the center and the Katumbi (Katobelo) River in the south (Fig. 3). Although shell beds are prevalent across the entire region, the oldest dated shells occur in the north, near the

Lukoma River at transect MT2015-T4 and the youngest are in the south near the Katumbi River at transect MT2016-T9. Results from a Mann-Whitney U-test indicate that shells differ in age with statistical significance laterally at 20 m of water and shells from the same transect at 9 and 20 m are statistically different (Table 4). The Lukoma and Lagosa river deltas are muddy and gently sloping, attributable to large human settlements and accompanying high land-use disturbance, whereas the Katumbi River delta is sandier and steeply sloping because the region feeding the delta is more pristine and partially protected by the Mahale Mountains National Park (Busch, 2017). Across Kungwe Bay, younger and live *Neothauma* have only been observed near the Katumbi River delta likely because it is sandier than the other deltas. Calibrated ages indicate live *Neothauma* have not been present proximal to the Lukoma River delta for over a century (Fig. 5B). As climate became wetter and land-use changes began to alter the landscape and increase the input of muddy sediments, the area around the Lukoma River became uninhabitable for the snails and they either died or migrated to regions with sandier substrates. Although this study interprets the absence of *Neothauma* from Kungwe Bay to be controlled by climate, the production and accumulation of hardparts may also be a factor causing a negative taphonomic feedback (Behrensmeyer and Kidwell, 1985). For example, the mass accumulations of dead hardparts from *Neothauma* alter the substrate where live *Neothauma* prefer to live which prevents them from colonizing the shell covered environment; therefore, we may not document snail populations where large accumulation are present, creating a gap in the timeline.

Taphonomy

The taphonomic analysis provides additional insight to the sedimentologic, climatic, and biologic impacts that have occurred since the death of *Neothauma tanganyicense.* This study examined the degree of abrasion, fragmentation, encrustation, black coating, and oxidation patina to identify evidence for transportation, sedimentologic processes, and diagenesis.

Mechanical destruction of shells is commonly attributed to water depth, since shells in shallow waters are easily transported, fragmented, and abraded by wave action. The shells in Kungwe Bay occur between ~9 and 30 m of water, whereas the wave base of Lake Tanganyika lies at only ~5 m (O'Reilly, 2006). Therefore, the shell beds are not impacted by modern, fair-weather waves unless large storms occur or during times when lake level dropped at least 4 m. During periods of lower lake level, e.g. the Little Ice Age when the lake was ~10 m below present-day levels (Cohen et al., 1997), the shell beds may have been reworked and the shells fragmented and/or abraded. Although the shell accumulations currently lie below modern, fair-weather wave base, water depth does appear to influence the degree of abrasion, as shells that are more abraded occur in shallower water. The relationship between water depth and abrasion is complex, however, because abrasion is also high in deeper-water samples in positions of relatively steep delta-front slopes (Fig. 11). Overall, abrasion values are higher proximal to the river deltas and decrease with distance from the deltas (Fig. 11). The increase in abrasion near the deltas is likely attributable to the increased siliciclastic input in these regions, owing to the abrasive potential of siliciclastic grains. Shells in shallow and deep water that are proximal to deltas are also subject to abrasion by wave energy and reworking of river deltas during minor lake-level fluctuations. The degree of fragmentation among samples is much more variable, and moderate levels of fragmentation occur in both shallow- and deep-water samples (Fig. 7). This is puzzling because the degree of abrasion is strongly controlled by water-depth, and both mechanisms are generally caused by transport. Bioerosion by crabs, cichlid fish, and sponges that have adapted to the shell beds could be a source of fragmentation, but it is likely only a minor source of fragmentation. In addition, no intense predation has been documented against *Neothauma*, as the robustness of the shell makes them strongly resistant to predation (West et al., 1991). Overall, mechanical destruction is influenced by water depth controlling wave energy and proximity to deltas as sediment flux from the deltas abrades the shells.

Sedimentologic factors associated with the river deltas in Kungwe Bay play a unique role in the degree of taphonomic overprinting in regard to encrustation. Near the Lukoma, Lagosa, and Katumbi deltas, the level of encrustation in samples decreases, likely due to the increase in sedimentation input that buries shells and removes them from the mud-water interface (Fig. 11). This pattern has been documented in a marine environment in Belize, where bivalve and gastropod shells that were exposed to minimal sedimentation were more likely to be encrusted (Hauser et al., 2008). Shells are locally buried at a faster rate when proximal to the deltas, and removal from the taphonomically active zone prevents microbes from attaching and forming thick encrustations. Furthermore, in siliciclastic environments like Lake Tanganyika, sediment plumes from rivers limit the colonization and survival of encrusting microbes (Best and Kidwell, 2000). The pattern of lower degrees of encrustation near the deltas and greater degrees of encrustation away from deltas is more prominent at deeper water depths, as the transparency of the lake enables light penetration to relatively great depths, but only in the absence of the turbid sediment plumes. Highly encrusted shells have lower fragmentation and abrasion suggesting that encrustation forms a protective layer, increasing shell preservation. Thus, the river deltas play a unique role in the lateral variability of taphonomic overprinting of the shell beds.

Diagenetic processes have impacted the shell beds and can be proxies for lake level fluctuation and microbial activity. Oxidation patina and black coating do not show strong patterns with water depth or laterally along the study site (Fig. 9, 10, & 11). Shells in shallow and deep water exhibit variable levels of oxidation patina (Fig. 10), although black coating is somewhat greater on shells from deeper water (Fig. 9). Oxidation patina coats shells locally throughout Kungwe Bay and is the result of Fe-rich sediments being adhered to shells by a microbial, adhesive biofilm or extracellular polymetric substance (EPS) that cover the shell and trap sediment (Costerton et al., 1978; Riding, 2000). The Fe attached to the shell is then oxidized in an oxygenated environment. The black coatings on the shells was previously interpreted as manganese oxide and evidence for winnowing of shells to form accumulations (McGlue et al., 2010). However, XRD results of the black coating indicate the presence of calcite and EDS results show the presence of silicon, oxygen, aluminum, and iron, but no manganese. Sediments containing Si, O, Al, and Fe were likely adhered to the shells by a biofilm. If the shell is then buried, or even during rotting of microbial biofilms, a locally reducing micro-environment can form where the Fe on the coating of the shell is reduced, creating the dark color of the shells (Lange et al., 2018). The presence of these diagenetic features on shells in the Luiche delta region was interpreted to be the result of winnowing of sediments during lake level fluctuation (McGlue et al., 2010).

However, these diagenetic features are not pervasive on shells in Kungwe Bay, and show little spatial trends, therefore pervasive winnowing of buried shells cannot explain the vast accumulations of shells. Instead, it appears that the oxidation patina and dark black coating on the shells are local phenomena developed when both sedimentation of clastic mud and microbial carbonate growth occurs.

In summary, calibrated ages of *Neothauma* shells from Kungwe Bay range from ~400-3300 yrs BP with generally younger shells in shallow water and older shells in deeper water, although there is more mixing of ages of shells in the southern transect (MT2016-T9) near the Katumbi River (Fig. 5B). Taphonomy results indicate that taphonomic averages of black coating and oxidation patina have lower taphonomic scores, therefore, are less prevalent than abrasion, fragmentation and encrustation in Kungwe Bay. Water depth influences the degree of abrasion, encrustation, black coating, and oxidation patina. Shells from shallow water are more abraded, but less encrusted, and exhibit lower incidences of black coating. Fragmentation levels do not correlate to water depth. In addition to taphonomic correlations to water depth, the degrees of abrasion and encrustation correlate with proximity to modern river deltas. Proximal to deltas, abrasion is greater, whereas encrustation is lower. Fragmentation, black coating, and oxidation patina do not follow distinctive patterns in proximity to river deltas.

Models for the Kungwe Bay Shell Accumulations and Time Averaging

Time averaging and taphonomy results from Kungwe Bay lead to the interpretation that the shell beds form from a combination of lake level fluctuation, wave energy, and deltaic deposition. Calibrated ages of *Neothauma* shells form two distinct groups, ~3000-2000 yrs BP and ~1500-900 yrs BP with a single shell age around 400 yrs BP (Fig. 5A). During these periods of time, *Neothauma* lived on delta fronts of the Lukoma, Lagosa, and Katumbi Rivers and possibly the interdeltaic shoreface. Shells are present at the Lukoma delta dating back to ~3300 yrs BP, whereas at the Katumbi River delta the oldest shells are ~2400 yrs BP (Fig. 5B & 16A). The first cluster of shells around ~3000-2000 yrs BP existed during a time when lake level was lower than present, deltaic deposition was occurring through the Lukoma and Katubmi Rivers lakeward of the present shoreline, and *Neothauma* occupied the delta fronts and possibly the adjacent shorefaces (Fig. 16B). The shells in shallow water and proximal to the delta became abraded as wave energy agitated the sediment surface and clastic sediment input by the delta abraded the shells. Wave energy also acts to transport and concentrate shells away from the deltas (McGlue et al., 2010; Pan et al., 2012) and preferentially transports smaller shells because they are easier to move. Jordan (2012), in a pilot study of shells north of the Luiche River delta (Fig. 1) observed that shell size decreases away from the delta and attributed this to longshore movement that preferentially transported smaller shells. Finally, in this model, the shells that accumulated away from the delta became more heavily encrusted whereas shells proximal to the delta were locally buried by sediment, which prevents microbes from attaching and encrusting. The younger shells in this cluster died out about ~2000 yrs BP as humidity increased, and the region experienced an exceptionally wet period (Stager et al, 2009; Fig. 15). The increased precipitation would have created a rapid transgression and then a subsequent increase in deltaic sedimentation, which, in turn, muddied the river deltas, creating an environment unfavorable for *Neothauma* (Stager et al., 2009). McGlue et al. (2010) suggested the death assemblages accumulate by transgression and wave reworking of the nearshore sediments based on observations made near the Malagarasi River delta where at the base of a sediment core, a muddy transgressive surface was found, capped by sandy horizon and a molluscan hash. I suggest a similar overall sequence, however, the Kungwe Bay shell accumulations are not interpreted as transgressive lags, instead the transgression and attendant wind-driven waves acted to rework and flatten the submerged delta front and uppermost delta plain, isolating the older population of *Neothauma* in relatively deep water.

After the wet period and transgression, in which the limited age data indicate the *Neothauma* were not present in Kungwe Bay (~1500-900 yrs BP) the deltaic environments became conducive to support *Neothauma* and dead shells began to contribute to new shell accumulations in the delta front environment of the deltas and possibly the inter-delta shoreface, inshore from the previous shell accumulation (Fig. 16C). Taphonomic processes acted in similar ways on these shells as the shells near the delta became abraded and those shells farther away became encrusted. Again, an exceptionally wet phase occurred around 1100-900 yrs BP and 700-500 yrs BP (Stager et al., 2009; Fig. 15) and the deltas were again transgressed and *Neothauma* were reduced in population in Kungwe Bay. The accumulated shells near the delta would become abraded and/or locally buried by deltaic sedimentation from the back-stepped river, whereas shells farther from the delta would continue to become encrusted. Another regression occurred during the Little Ice Age (LIA), dropping lake level ~10 m (Cohen et al., 1997). During this regression sediment and shells from this inner band of shells would have been condensed and concentrated through wave reworking by the lowered wave base (Fig. 16D). The single shell age of ~400 yrs BP from the Katumbi River delta may indicate reworking of a reduced population of *Neouthauma*. This model is consistent with the overall structure of the shell ages, with younger shells in shallower water and older shells in deeper water (Fig. 16).

In addition to progradation and retrogradation of the deltas influencing the accumulation of shells, deltaic morphology and sedimentation impacts the differences in time averaging and taphonomy. The difference in modern deltaic sedimentation is attributed to a combination of recent land-use change in the watershed, but also to variation in slope and the size of the low-relief lower catchment of the rivers (Bush, 2017). The Lukoma River delta is muddier and has a shallower gradient than the sandy, steeply sloping Katumbi River delta (Bush, 2017). At the Lukoma River delta (MT2015-T4) the majority of shells at 9 m range from ~1000-1600 yrs BP with a single age ~2500 yrs BP, whereas shells at 20 m range from ~2400-3300 yrs BP with a single age at ~1500 yrs BP; neither sample contains young (<900 yr BP) shells (Fig. 5B). The two samples from the Katumbi River delta (MT2016-T9) show more mixing of ages. The sample from 20 m contains a sub-equal mix of shells that range from 2000-2400 yrs BP and ~1000-1400 yrs BP, whereas the sample from 9 m contains a similar sub-equal mix with slightly more shells in the younger group, and with a shell at ~400 yrs BP (Fig. 5B). Therefore, the degree of time averaging appears greater at transect MT2016-T9; however, this is a function of delta morphology, because along the relatively steep Katumbi delta, the shells are prone to transport down slope during increased river discharge, slumps, and gravity flows (Fig. 16). Periodic transport of shells down steep slopes was proposed by Cohen (1989) based on taphonomy of the gastropod *Paramelania* in Lake Tanganyika. In front of the Lagosa-Lukuma rivers, however, where gradients are less steep, there is less mixing of shell ages, with only a single "old" shell (~2500 yrs BP) located in 9 m water and the rest of the shells are 1000-1500 yrs BP (Fig. 5B). The opposite is true in deep water with a single "younger" shell (~1600 yrs BP) is mixed with remaining shells dated to >2000 yrs BP. A steeper gradient results in increased degree of time averaging, but more faithfully records the temporal range of *Neothauma* compared to the shell beds along the flatter gradient; the variation in recorded time-averaging between the two environments could have implications for observations made in ancient, time averaged, shelly deposits (Fig. 17).

Ideally, more radiocarbon data are necessary to solidify this model. If shells are transferred laterally resulting in the large accumulations during lake level fluctuations. Then one would expect to find even larger degree of temporal mixing in the interdeltaic regions. In addition to the need for more constraints on the age model, core data from Kungwe Bay dating back to ~4000 yrs BP would better constrain regional climate trends and the history of lake-level fluctuations in the region. Additionally, sedimentologic and geochemical data on the sediment core could provide evidence of changes in texture and composition of the sediment during the periods of time when *Neothauma* were absent. Although more data is desired the time averaging and taphonomy of *Neothauma* shells in Kungwe Bay provide a better understanding of the paleoecology and paleoenvironment of shell beds in Lake Tanganyika, which can be applied to examples in the geologic record. Patterns in abrasion and encrustation can provide evidence for ancient river deltas and the degree of temporal mixing provides information on the gradient where shelly deposits form. The results from this study also further the discussion that climate plays a key role in the timing of the accumulation of *Neothauma* shells in Kungwe Bay and provides insight on the impacts that modern land-use changes are having on the lake's littoral zone.

Conclusions

Lake Tanganyika is a natural wonder that has fostered the evolution of unique lacustrine carbonate environments. This study's analysis of time averaging and taphonomy of *Neothauma tanganyicense* from shell beds in Lake Tanganyika reveals an association between climate, lake level, water depth and deltaic deposition. Climate and lake level are closely intertwined as climate controls lake-level fluctuations, which in turn controls deltaic sedimentation and therefore the locations of snail colonization. Climate also plays a key role in the deposition of shells, which does not occur during exceptionally wet periods when the nearshore environment becomes muddier and uninhabitable for *Neothauma.* The snails likely locally died out locally or migrated to more suitable habitats. Lake-level fluctuations also act to rework and transport shells during transgressions and regressions. Lastly, water depth and deltaic deposition plays a significant role in the taphonomic signatures and the degree of time averaging. The amount of taphonomic degradation associated with abrasion, encrustation, and black coating are influenced by water depth. The taphonomic variables of abrasion and encrustation show distinct links between the degree of damage and proximity to river deltas, as abrasion increases proximal to deltas and encrustation decreases away from deltas. Time averaging is also related to water depth as shells in shallow water are younger than in deeper water. The degree of time averaging also depends on the slope of deltaic environments as the degree of temporal mixing increases in steeper deltaic environments.

In agreement with other studies, we suggest that lake level fluctuation plays a significant role in time averaging and the taphonomic character of shells beds, however, our results also complicate the utility of shell beds as an indicator of lake-level change and highlight the association of shell beds, climate, and deltaic deposition. Thus, patterns in taphonomy, and time averaging of *Neothauma tanganyicense* from shell beds in Lake Tanganyika can inform paleoenvironmental interpretations in the geologic record if factors such as slope are accounted for.

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Appendix A: Tables

Location Name	Latitude	Longitude
Katibili Bay	-6.08333º	29.3º
Kalemie Bay	-5.922340º	29.204280º
Rutuku Bay	-6.219672º	29.336073º
Tembwe Bay	-6.51618º	29.470401º
Karema Bay	-6.82839º	30.434808º
Bulombola Bay	-5.025554º	29.775855º
Ujiji Bay	-4.926948º	29.663302º
Ruzizi River	-3.364442º	29.275841º
Rumonge Bay	-3.97277º	29.429259º
Utinta Bay	-7.100651º	30.54061º
Kala Bay	-8.137315º	30.954709º
Sumbu Bay	-8.513039º	30.480142º
Mtossi Bay	-7.675307º	30.713349º
Kigoma Bay	-4.868823º	29.623018º
Burton Bay	-4.1975º	29.145278º
Karago Bay	-5.287104º	29.795144

Table 1 Data repository table of live *Neothauma tanganyicense* collected by dredging in 1946-47 by Eugene Leloup.

Variable	No damage (0)	Low damage (1)	High damage (2)	Remarks
Abrasion	None; original luster,	Dull luster	Chalky; no luster	Environmental energy indicator
Fragmentation	None	Minor chips to aperture lip whorl, or apex	Major chips to aperture lip whorl, or apex	Environmental energy indicator
Encrustation	0-10% encrustated	10-60% encrustated	>60% encrustated	Coverage by encrusting organisms
Black Coating	0-10% coated	10-30% coated	>30% coated	Burial or microbial activity
Oxidation Patina	0-5% oxidized	5-20% oxidized	>20% oxidized	Proxy for lake-bottom exposure

Table 2 Taphonomic variables and scoring system used in this study.

Site	^{14}C age	Error ^{14}C yrs	Calibrated age (yrs BP)	2 sigma range (yrs BP)	Calendar years CE
MT2016-T9-9	1200	40	1132 ± 53	1079-1185	818 ± 53
MT2016-T9-9	1400	60	1325 ± 39	1285-1364	625 ± 39
MT2016-T9-9	1230	60	1163 ± 77	1086-1240	787 ± 77
MT2016-T9-9	1155	45	1077 ± 68	1009-1145	873 ± 68
MT2016-T9-9	1080	60	1007 ± 55	951-1062	943 ± 55
MT2016-T9-9	1180	50	1103 ± 70	1032-1173	847 ± 70
MT2016-T9-9	1285	45	1225 ± 45	1179-1270	725 ± 45
MT2016-T9-9	290	40	372 ± 58	314-430	1578 ± 58
MT2016-T9-9	1210	60	1148 ± 78	1069-1226	802 ± 78
MT2016-T9-9	985	45	884 ± 55	828-939	1066 ± 55
MT2016-T9-9	1205	45	1146 ± 66	1079-1212	804 ± 66
MT2016-T9-9	1325	45	1246 ± 45	1201-1291	704 ± 45
MT2016-T9-9	1050	45	985 ± 46	938-1031	965 ± 46
MT2016-T9-9	1390	50	1317 ± 30	1286-1347	633 ± 30
MT2016-T9-9	1000	45	897 ± 57	839-954	1053 ± 57
MT2016-T9-20	2190	45	2222 ± 72	2150-2294	272 ± 72
MT2016-T9-20	1160	60	1087 ± 78	1008-1165	863 ± 78
MT2016-T9-20	2310	90	2347 ± 146	2201-2493	397 ± 146
MT2016-T9-20	1420	80	1344 ± 60	1283-1404	606 ± 60
MT2016-T9-20	2110	60	2116 ± 99	2017-2215	166 ± 99
MT2016-T9-20	1605	45	1487 ± 54	1433-1541	463 ± 54
MT2016-T9-20	2250	60	2251 ± 72	2178-2323	301 ± 72
MT2016-T9-20	1150	70	1081 ± 85	996-1166	869 ± 85
MT2016-T9-20	1150	60	1078 ± 78	1000-1156	872 ± 78
MT2016-T9-20	1995	45	1952 ± 47	1904-1999	2 ± 247
MT2016-T9-20	1500	60	1414 ± 70	1344-1484	536 ± 70
MT2016-T9-20	1150	45	1072 ± 67	1005-1139	878 ± 67
MT2016-T9-20	2120	60	2139 ± 112	2026-2251	189 ± 112
MT2016-T9-20	1070	60	999 ± 55	943-1054	951 ± 55
MT2016-T9-20	1195	45	1128 ± 58	1070-1186	822 ± 58
MT2015-T4-9	1150	45	1072 ± 67	1005-1139	878 ± 67
MT2015-T4-9	1085	40	1005 ± 42	962-1047	945 ± 42
MT2015-T4-9	990	70	891 ± 74	816-965	1059 ± 74
MT2015-T4-9	2420	70	2527 ± 132	2394-2659	577 ± 132
MT2015-T4-9	1140	70	1074 ± 84	990-1158	876 ± 84
MT2015-T4-9	1110	45	1023 ± 46	977-1069	927 ± 46
MT2015-T4-9	1370	45	1299 ± 28	1270-1327	651 ± 28
MT2015-T4-9	1190	60	1121 ± 85	1036-1206	829 ± 85
MT2015-T4-9	1115	45	1029 ± 49	980-1078	921 ± 49
MT2015-T4-9	1170	45	1092 ± 68	1023-1160	858 ± 68
MT2015-T4-9	1660	80	1566 ± 108	1458-1674	384 ± 108
MT2015-T4-9	1345	40	1265 ± 40	1229-1301	685 ± 36
MT2015-T4-9	1400	60	1325 ± 39	1285-1364	625 ± 39
MT2015-T4-9	1170	45	1092 ± 68	1023-1160	858 ± 68
MT2015-T4-9	1510	50	1420 ± 65	1355-1485	530 ± 65
MT2015-T4-20	2340	60	2399 ± 84	2314-2483	449 ± 84
MT2015-T4-20	2820	60	2946 ± 80	2866-3026	996 ± 80
MT2015-T4-20	2770	80	2899 ± 90	2808-2989	949 ± 90
MT2015-T4-20	2710	70	2839 ± 63	2776-2902	889 ± 63
MT2015-T4-20	2230	60	2240 ± 72	2167-2312	290 ± 72
MT2015-T4-20	3130	90	3338 ± 104	3233-3442	1388 ± 104
MT2015-T4-20	2410	60	2521 ± 132	2389-2653	571 ± 132
MT2015-T4-20	1620	60	1513 ± 76	1436-1589	437 ± 76
MT2015-T4-20	2540	80	2602 ± 120	2481-2722	652 ± 120
MT2015-T4-20	2370	60	2481 ± 122	2358-2603	531 ± 122
MT2015-T4-20	2440	70	2535 ± 130	2405-2665	585 ± 130
MT2015-T4-20	2450	80	2540 ± 131	2409-2671	590 ± 131
MT2015-T4-20	2780	50	2883 ± 62	2821-2945	933 ± 62
MT2015-T4-20	2270	70	2261 ± 80	2181-2341	311 ± 80
MT2015-T4-20	2260	60	2255 ± 73	2182-2328	305 ± 73
*MT2016-T8-20	110	30	147 ± 97	45-239	1808 ± 97
*MT2016-T11-12	modern	——	modern	———	1950
*MT2015-live Katumbi 1	modern	——	modern	———	1950
*MT2015-live Katumbi 2	modern	——	modern	———	1950
*MT2015-live Katumbi 3	modern	——	modern	———	1950

Table 3 Radiocarbon data from *Neothauma tanganyicense* shells collected in Kungwe Bay. *Indicates shells that were live-caught and dated at the Center for Accelerator Mass Spectrometry at the Lawrence Livermore National Laboratory. The remaining shells were dated at the Amino Acid Geochronology Laboratory at Northern Arizona University.

	Sites			
	MT2015-T4-9 & MT2015-T4-20	*MT2016-T9-9 & MT2016-T9-20*	*MT2015-T4-9 & MT2016-T9-9*	*MT2015-T4-20 & MT2016-T9-20*
Median	1092 & 2535	1132 & 1414	1092 & 1132	2535 & 1414
U	8	56	94.5	10
p	0.0001	0.0195	0.4693	0.0001

Table 4 Results of a Mann-Whitney U-test comparing water depth and lateral variation in age across Kungwe Bay. MT2015-T4-9 & MT2015-T4-20 and MT2016-T9-9 &MT2016-9-20 are analyzed based on water depth. MT2015-T4-9 & MT2016-T9-9 and MT2015-T4-20 & MT2016-T9-20 are analyzed laterally across Kungwe Bay.

Appendix B: Figures

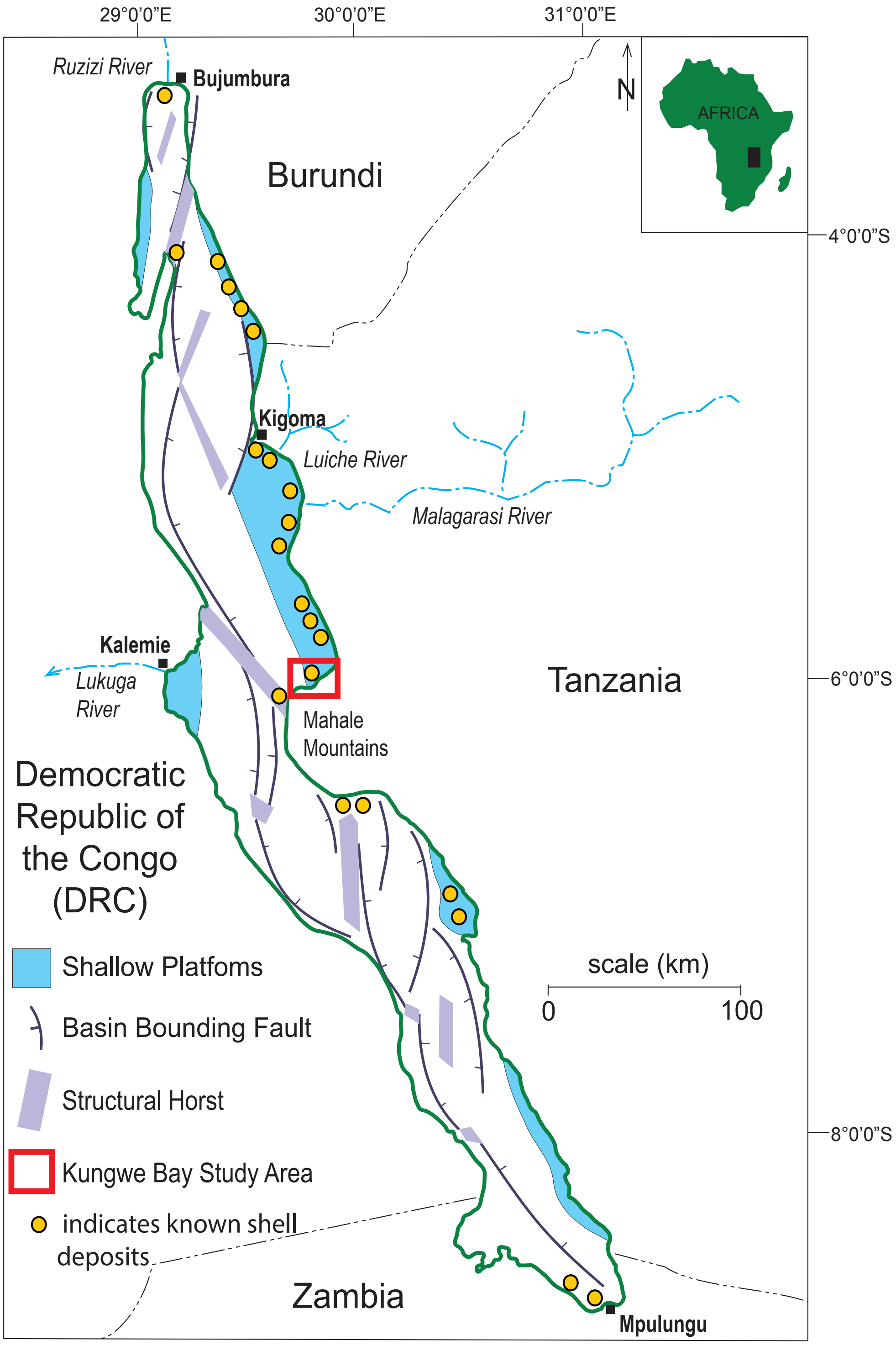

Figure 1 Location of Lake Tanganyika in Africa (inset) and the major structural features, location of shell assemblages, and study area. Modified from McGlue et al. (2010).

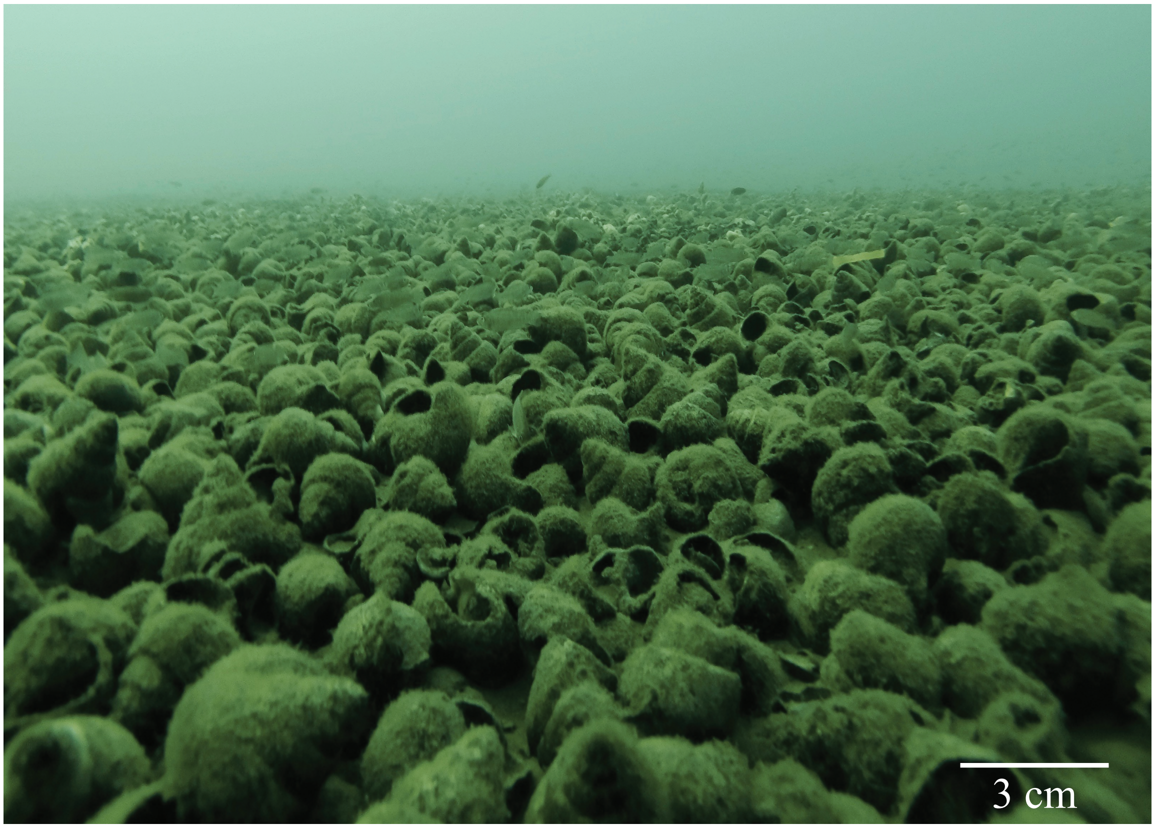

Figure 2 Photograph of shell beds in Kungwe Bay, Lake Tanganyika consisting of *Neothauma tanganyicence* shells.

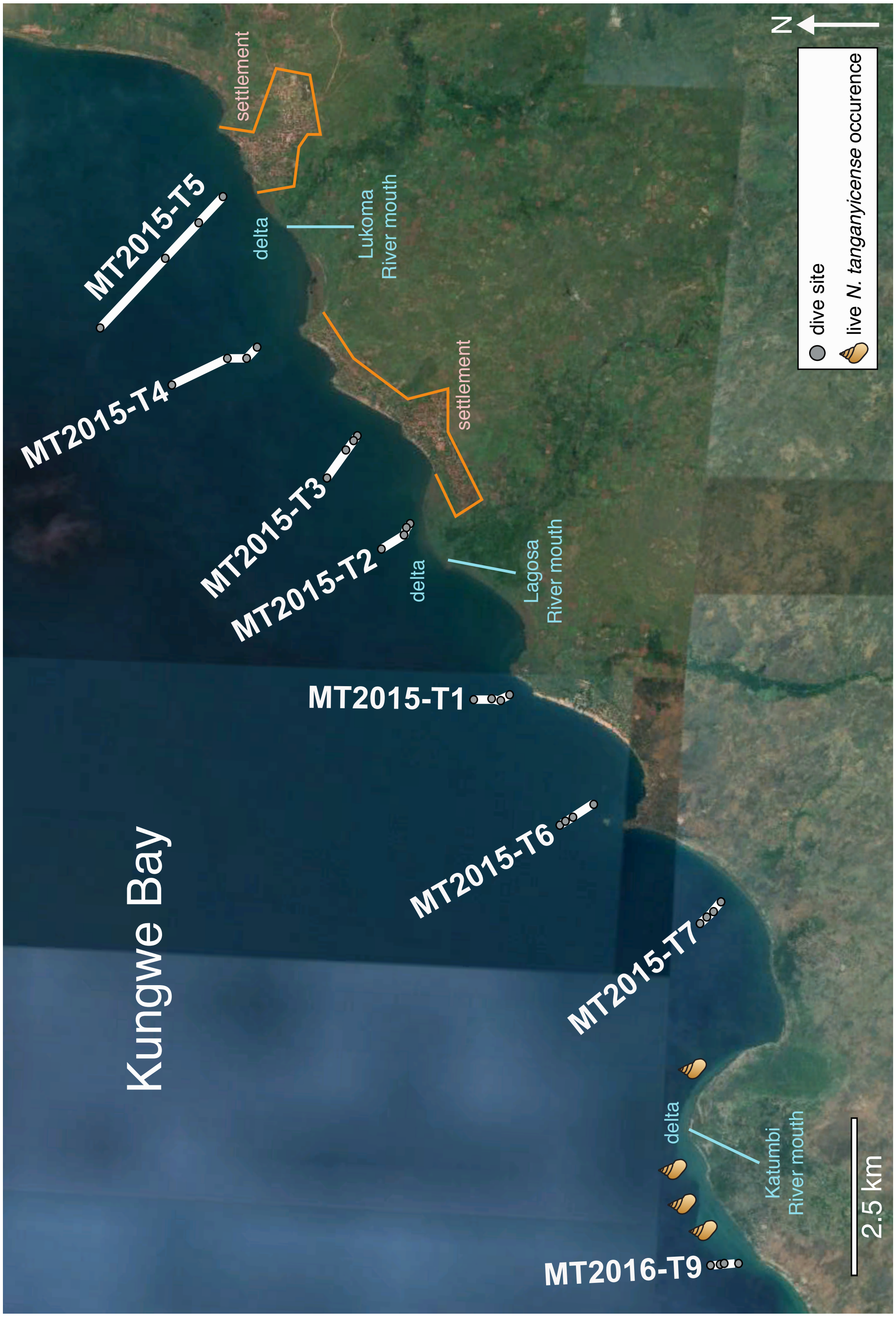

Figure 3 Map of Kungwe Bay highlighting settlements, rivers, deltas, locations of live *N. tanganyicense* and transect locations where samples were collected. Image courtesy of Google Earth.

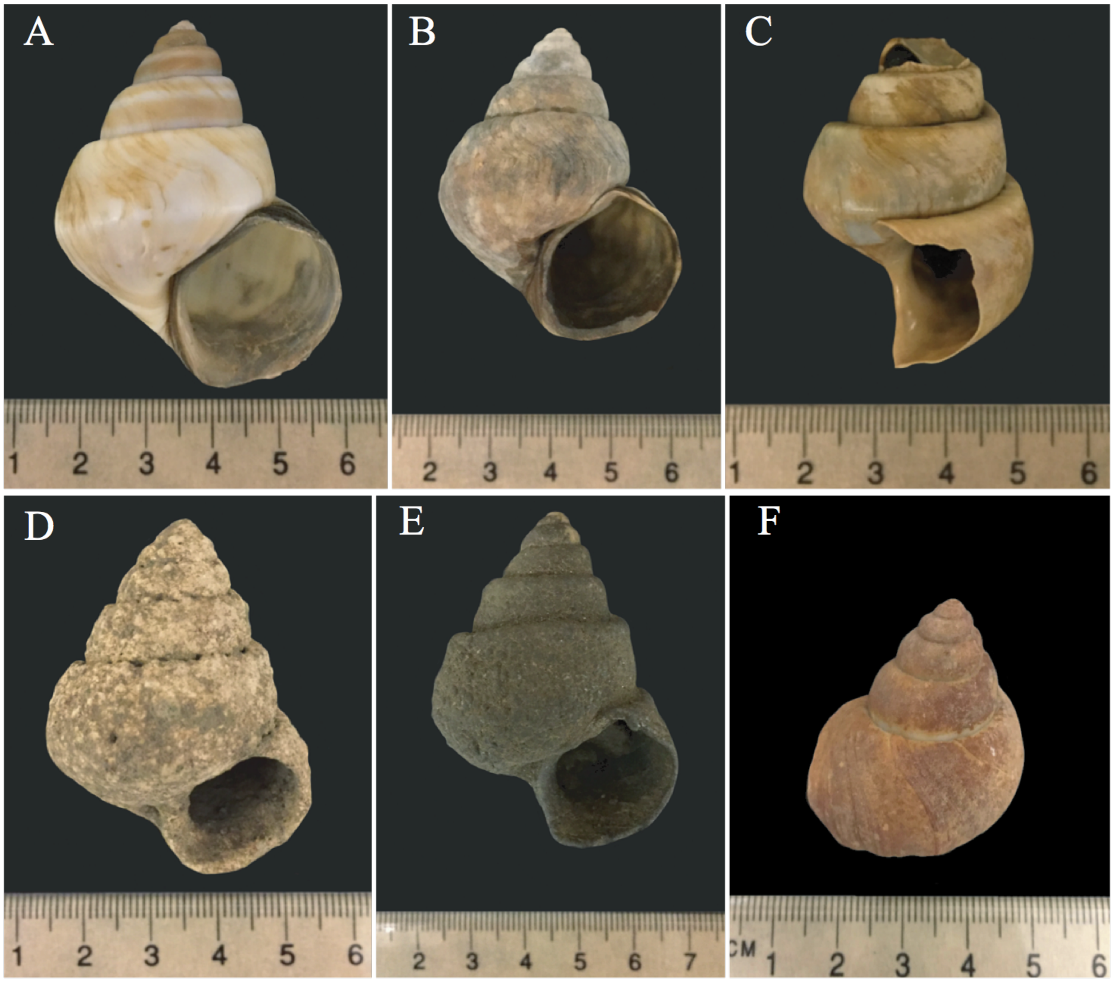

Figure 4 A.) *Neothauma tangnayicense.* Taphonomic score of 0. B.) *Neothauma tangnayicense.* Taphonomic score of 2 for abrasion. C.) *Neothauma tangnayicense.* Taphonomic score of 2 for fragmentation. D.) *Neothauma tangnayicense.* Taphonomic score of 2 for encrustation. E.) *Neothauma tangnayicense.* Taphonomic score of 2 for black coating. F.) *Neothauma tangnayicense.* Taphonomic score of 2 for oxidation patina. Scales are in centimeters.

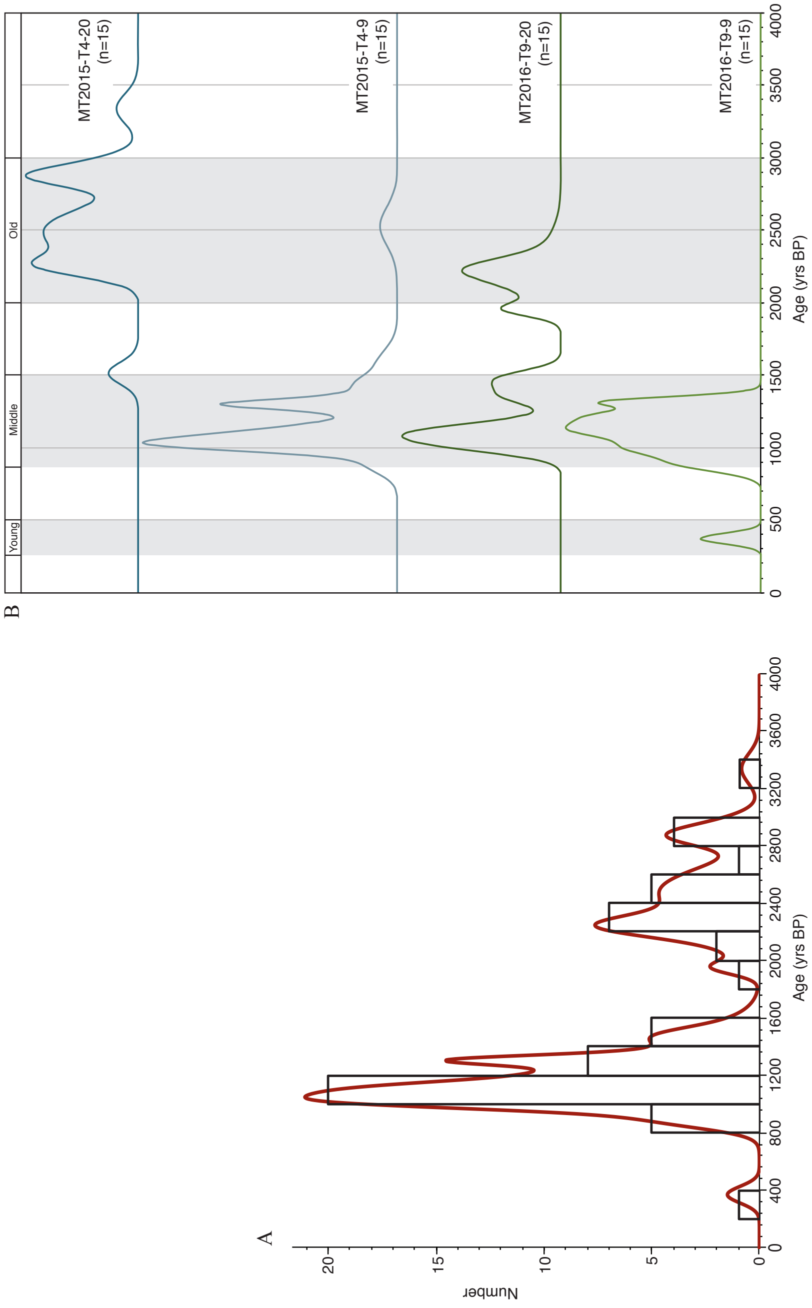

Figure 5 Cumulative probability plots of calibrated radiocarbon ages from *Neothauma tanganyicense* samples from Kungwe Bay. A.) Histogram (black) and cumulative probability plot (red) of shells dated in Kungwe Bay. B.) Cumulative probability plots of shell ages from transects MT2015-T4-20, MT2015-T4-9, MT2016-T9-20, and MT2016-T9-9. Area under each curve represents summed Gaussian distribution of individual ages and associated error for each shell.

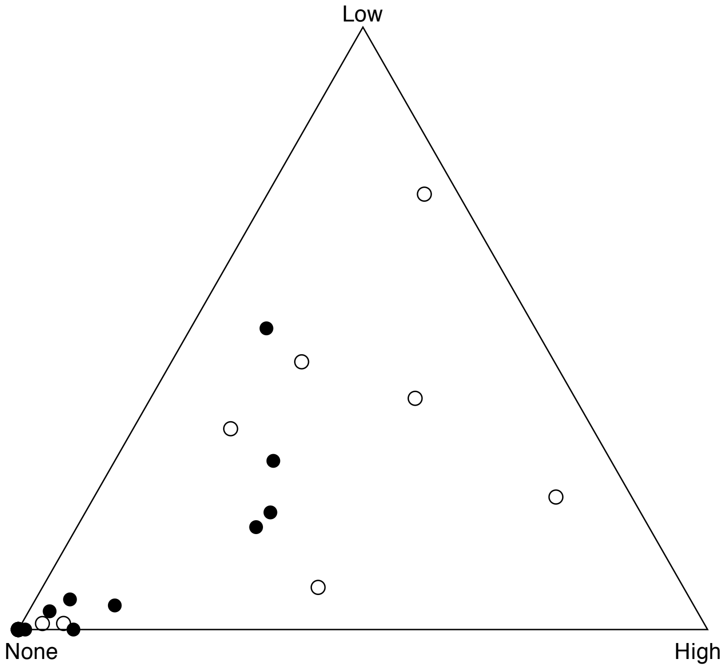

Figure 6 Ternary diagram of levels of abrasion for each sample. Open circles represent shallow-water (9 and 12 m) samples and closed circles represent deep-water (15 and 20 m) samples.

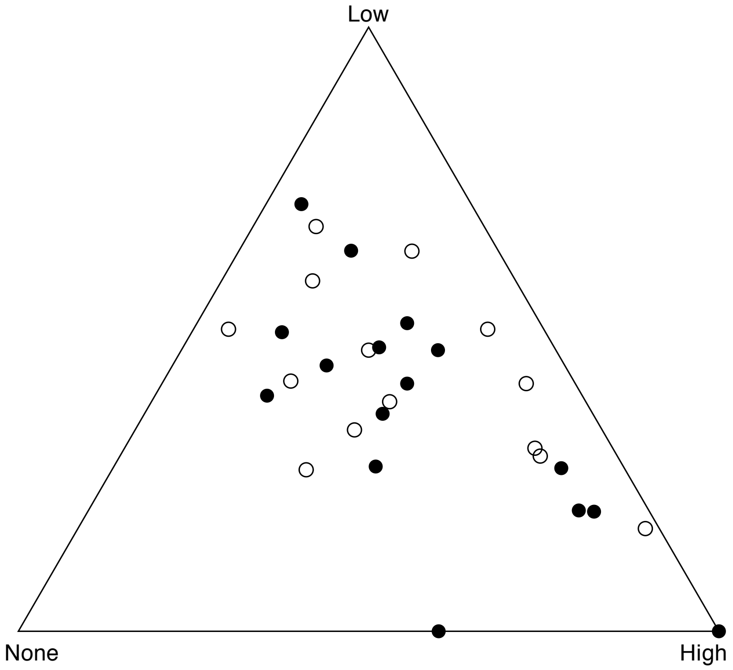

Figure 7 Ternary diagram of levels of fragmentation for each sample. Open circles represent shallow-water (9 and 12 m) samples and closed circles represent deep-water (15 and 20 m) samples.

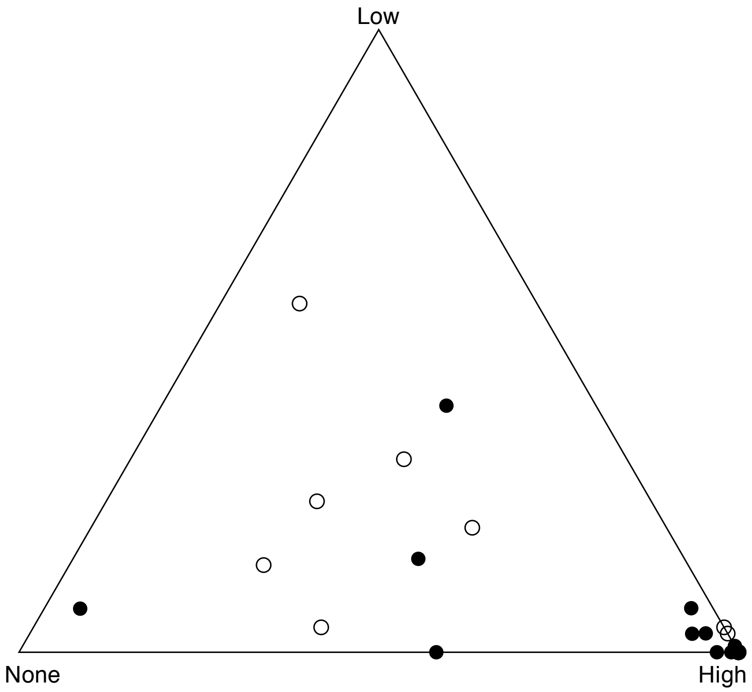

Figure 8 Ternary diagram of levels of encrustation for each sample. Open circles represent shallow-water (9 and 12 m) samples and closed circles represent deep-water (15 and 20 m) samples.

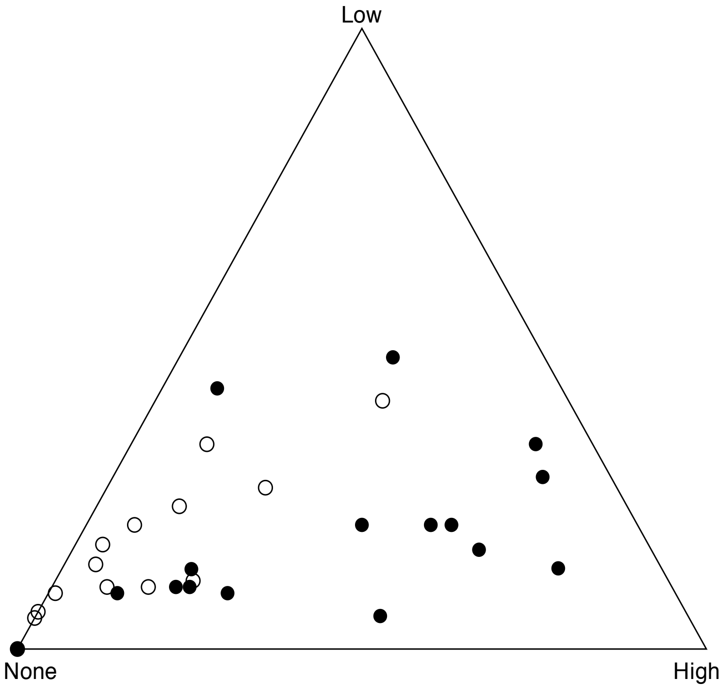

Figure 9 Ternary diagram of levels of black coating for each sample. Open circles represent shallow-water (9 and 12 m) samples and closed circles represent deep-water (15 and 20 m) samples.

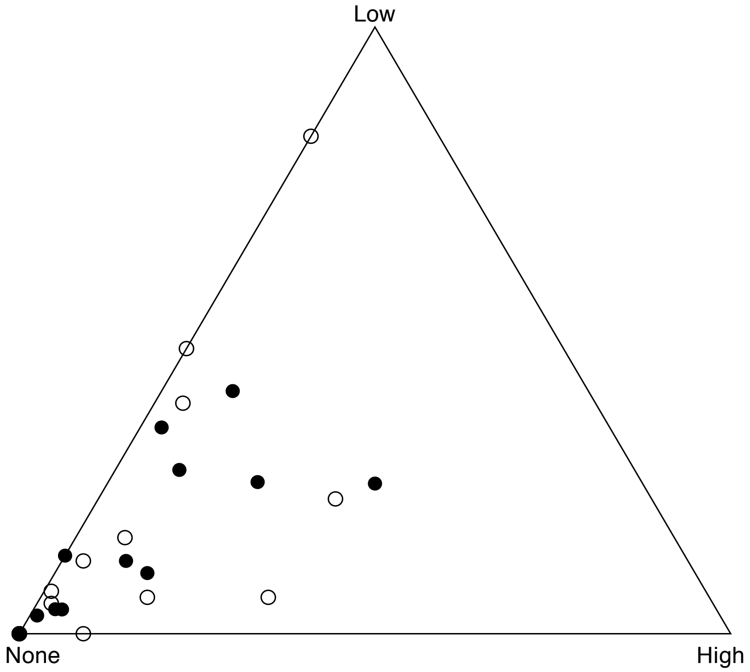

Figure 10 Ternary diagram of levels of oxidation patina for each sample. Open circles represent shallow-water (9 and 12 m) samples and closed circles represent deep-water (15 and 20 m) samples.

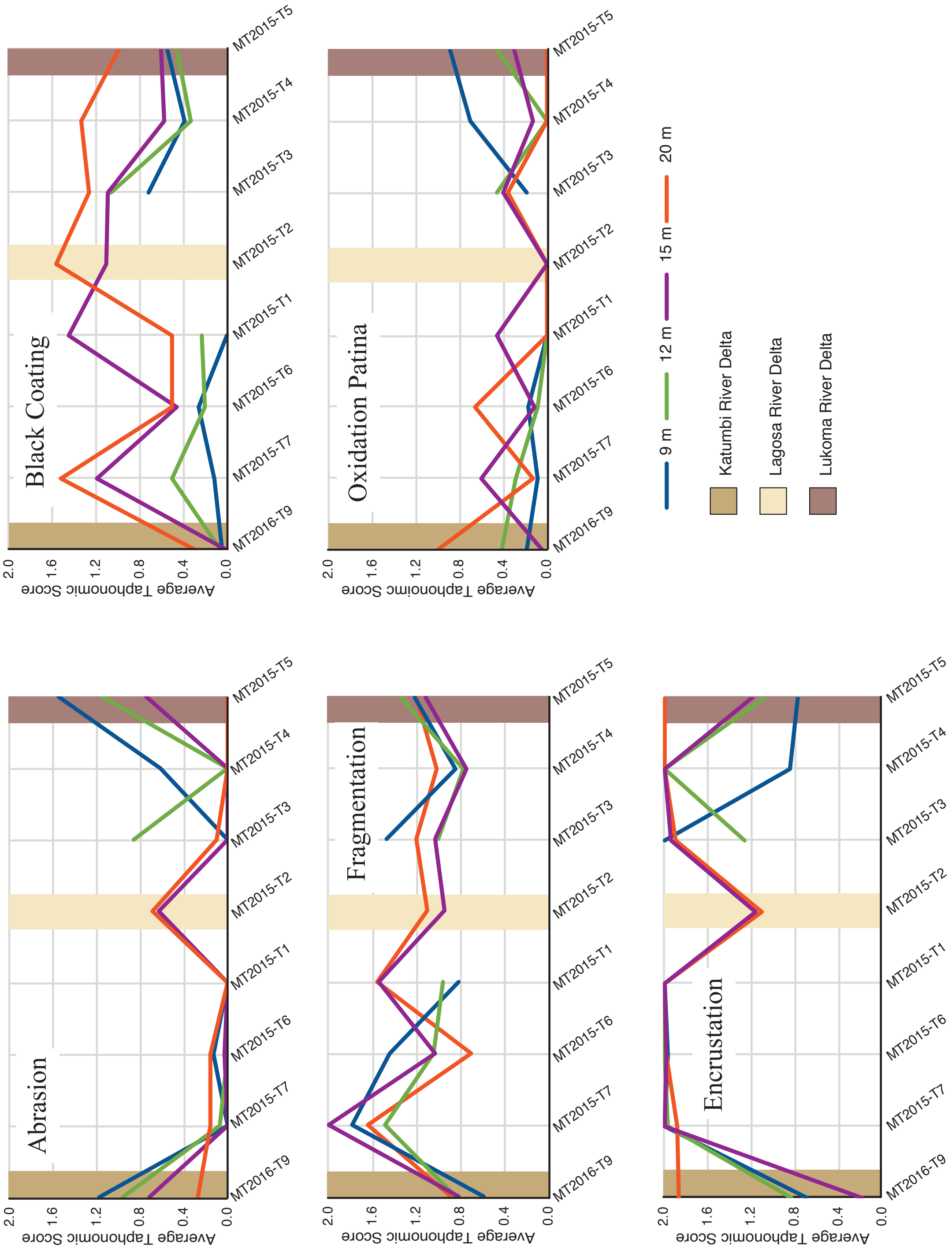

Figure 11 Graphical representations of the lateral variation in taphonomic scores of abrasion, fragmentation, encrustation, black coating, and oxidation patina. The modern river deltas are highlighted to show the association between taphonomic degredation and deltaic processes.

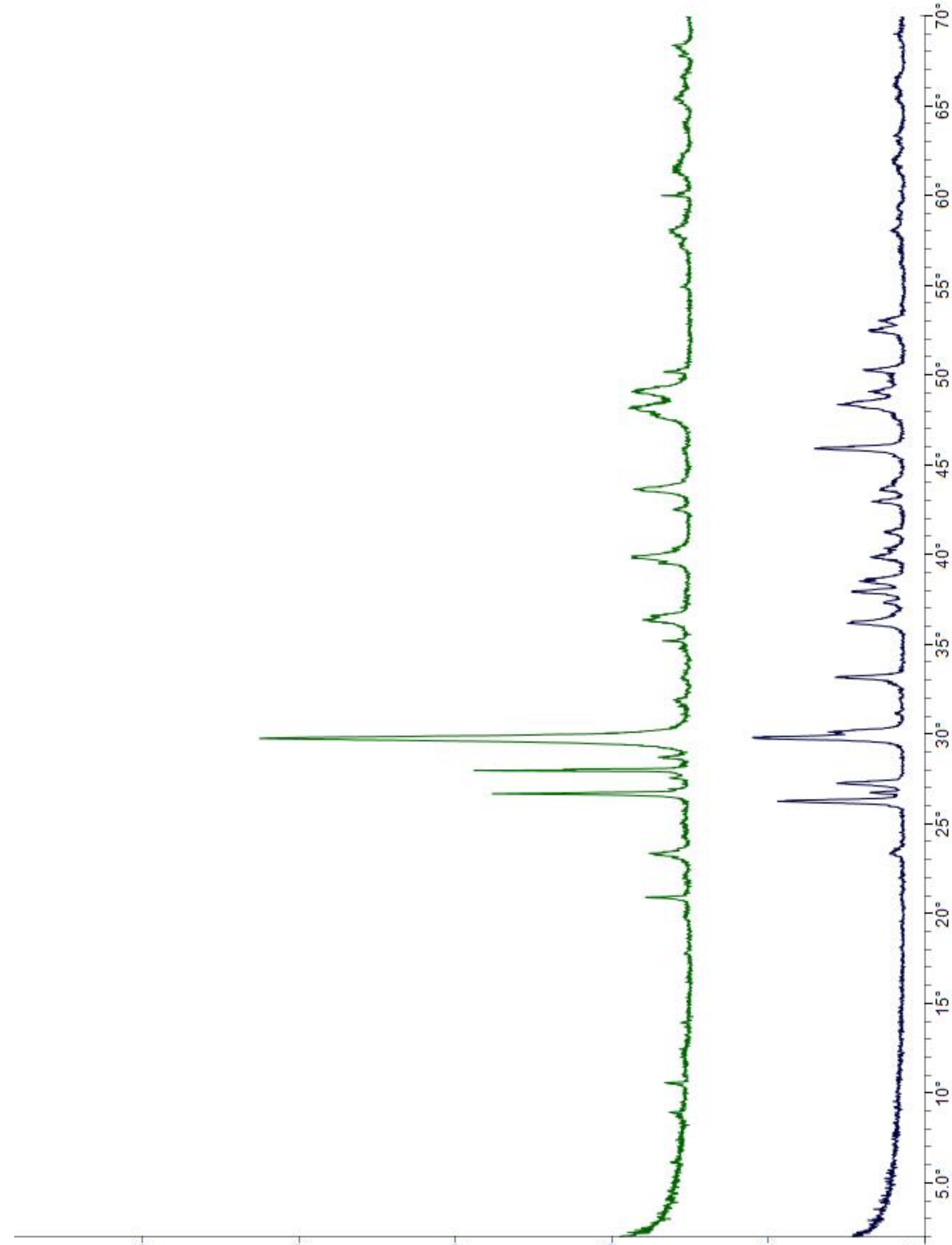

Figure 12 XRD results of the composition of the encrustation (blue line—lower) and the black coating (green line—upper).

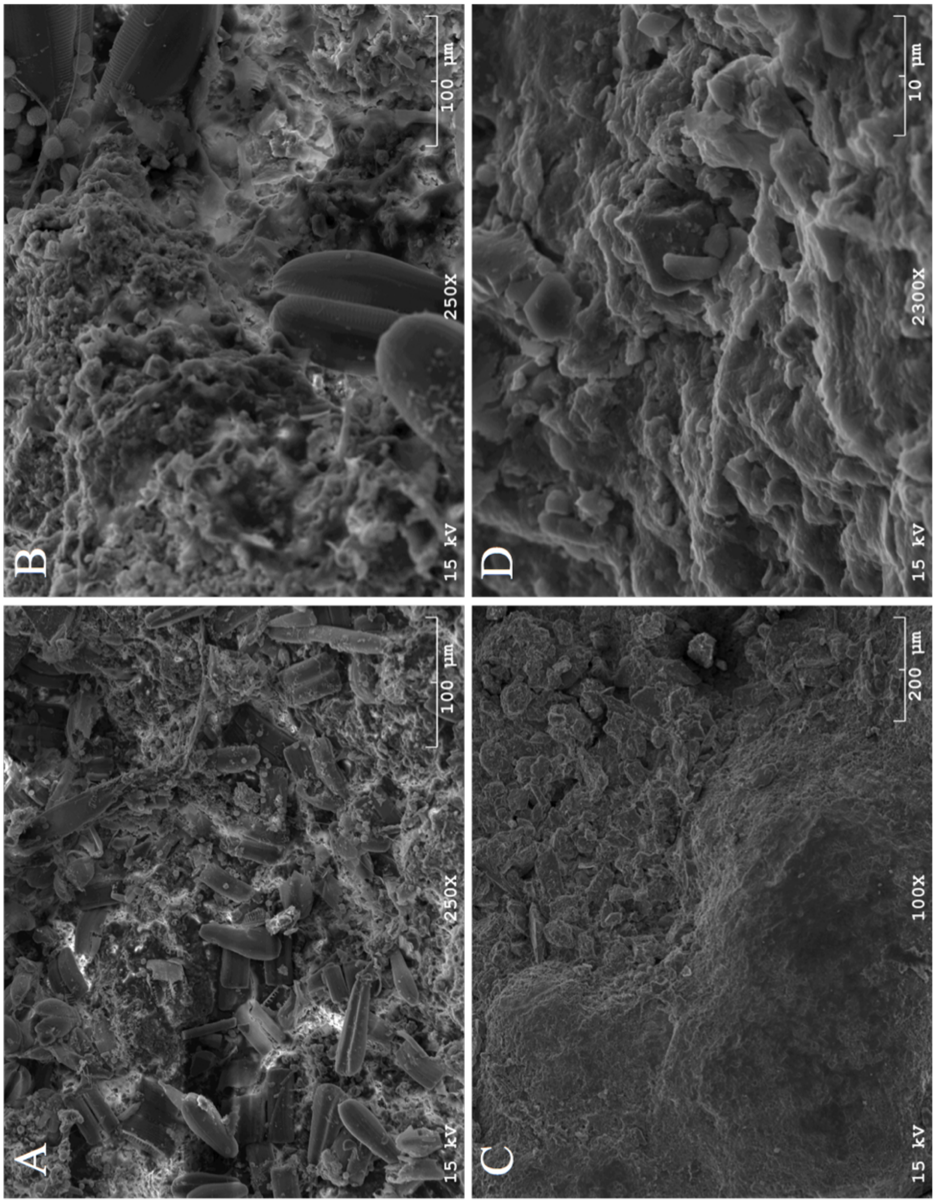

Figure 13 SEM images of encrustation and black coating found on *Neothauma tanganyicense* shells. A.) Image of an encrusted *Neothauma tanganyicense* shell showing a biofilm containing diatom fragments and cyanobacteria or algae. B.) Image of encrusted shell showing diatom fragments and cyanobacteria or algae. The round objects in the upper right corner of the images are coccus of cyanobacterial cells. C.) & D.) Images of the black coating consisting of a jumbled mixture of silica, Al, and Fe on *Neothauma tanganyicense* shells.

Figure 14 A.) *Neothauma* shells collected from transect MT2015-T4-9. The shells have an average age of 1253 yrs BP. B.) *Neothauma* shells collected from MT2015-T4-20. The shells have an average age of 2550 yrs BP. C.) *Neothauma* shells collected from MT2016-T9-9. The shells have an average age of 1068 yrs BP. D) *Neothauma* shells collected from MT2016-T9-20. The shells have an average age of 1581 yrs BP. The scales are in centimeters.

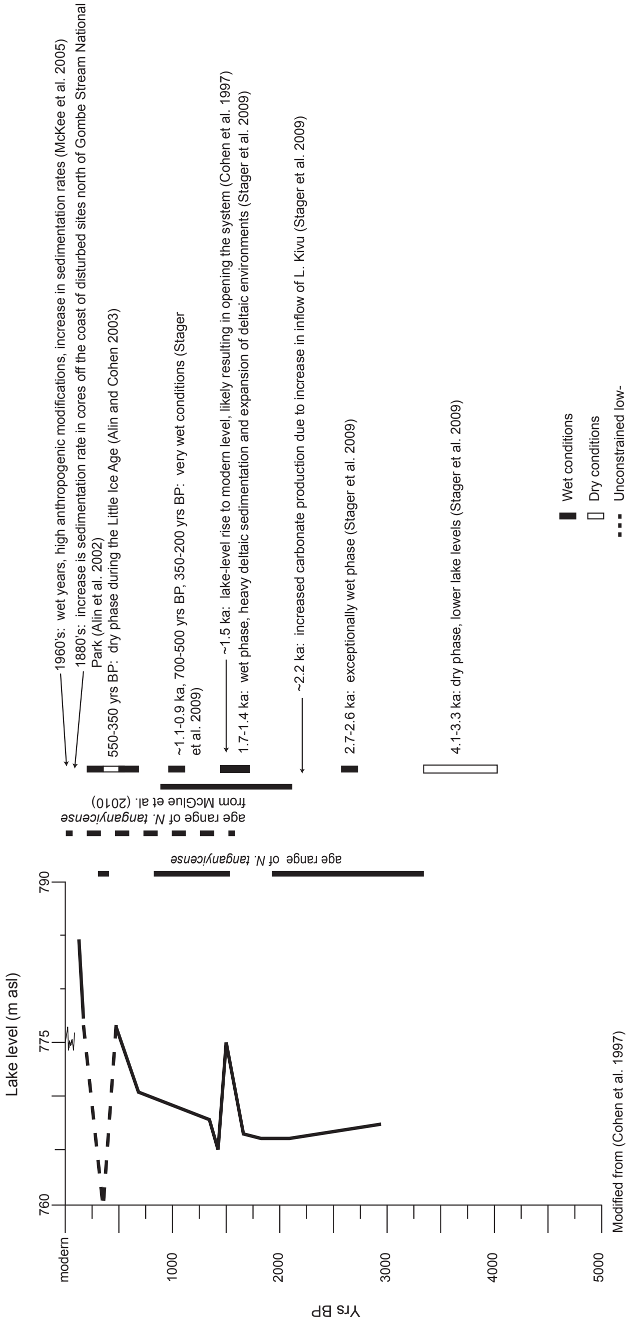

Figure 15 Curve summarizing inferred lake level fluctuations (in meters above sea level) up to ~2900 yrs BP (Cohen et al., 1997) and major climatic (wet-dry) events in Lake Tanganyika, mainly from Stager et al., (2009). *Neothauma tanganyicense* age clusters, represented by a solid black line, from this study are plotted against the time scale. McGlue et al. (2010) *Neothauma* ages are plotted with the dashed line.

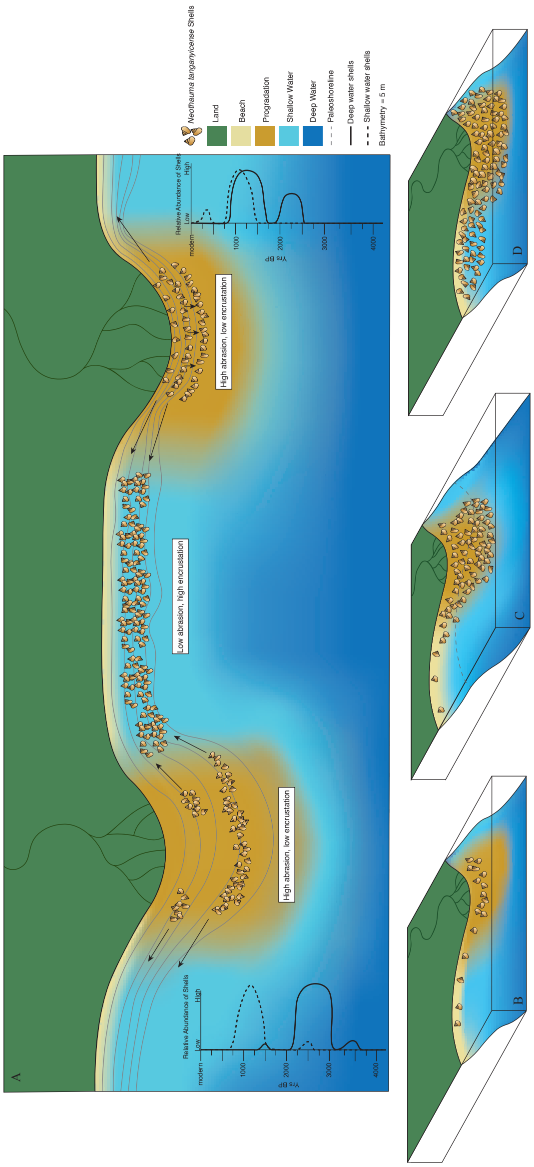

Figure 16 A.) Model depicting processes leading to shell-bed accumulations. Arrows indicate directions of transport for shells. Graphs representing time indicate the relative abundance of shells within specific age ranges. The dashed lines represent shallow water shells and the solid lines represent deep water shells. B.) Box diagram of the littoral zone around ~3000-2000 yrs BP when lake level was lower and *Neothaumas* lived along the river delta and tentatively along the inter deltaic shoreface, forming local populations. C.) Box diagram of the littoral zone around ~1500-900 yrs BP. *Neothauma* were absent from Kungwe Bay for ~500 years prior to this time as lake level rose and shell beds were reworked during transgression. At ~1500-900 years BP *Neothaumas* accumulated on the newly prograding delta and contributed to new (younger) death assemblages. D.) During the Little Ice Age (550-350 yrs BP) lake level decreased. Shell accumulations in shallow water were reworked by wave action. ~400 yrs BP *Neothaumas* began to live and contribute to the shell accumulations.

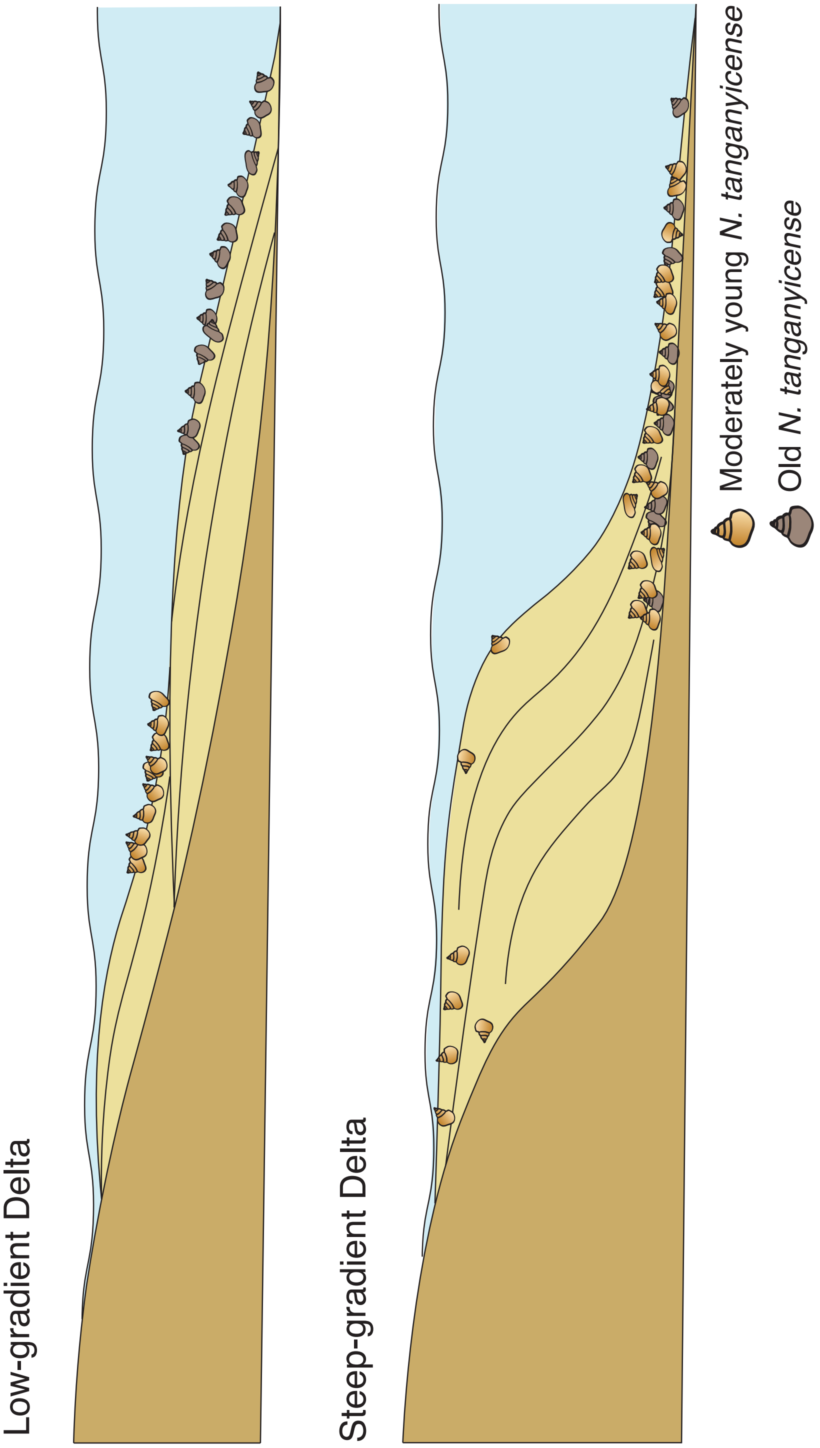

Figure 17 Variation in time averaging between low-gradient and steep-gradient river deltas. Mixing of young shells with older shells on the low-gradient delta does not occur or is less than the degree of mixing along a steep-gradient delta.

Appendix C: Taphonomic scores of individual *Neothauma tanganyicense* shells from each transect

MT2015-T1-9

Encrustation	*Abrasion*	*Fragmentation*	*Black Coating*	*Oxidation Patina*
2	0	0	0	0
2	0	0	0	0
2	0	0	0	0
2	0	1	0	0
2	0	1	0	0
2	0	1	0	0
2	0	0	0	0
2	0	0	0	0
2	0	0	0	0
2	0	1	0	0
2	0	2	0	0
2	0	0	0	0
2	0	1	0	0
2	0	1	0	0
2	0	2	0	0
2	0	0	0	0
2	0	1	0	0
2	0	0	0	0
2	0	0	0	0
2	0	1	0	0
2	0	1	0	0
2	0	1	0	0
2	0	0	0	0
2	0	2	0	0
2	0	0	0	0
2	0	0	0	0
2	0	1	0	0
2	0	1	0	0
2	0	1	0	0
2	0	0	0	0
2	0	0	0	0
2	0	2	0	0
2	0	2	0	0
2	0	0	0	0
2	0	0	0	0

2	0	0	0	0
2	0	2	0	0
2	0	2	0	0
2	0	0	0	0
2	0	2	0	0
2	0	1	0	0
2	0	0	0	0
2	0	0	0	0
2	0	0	0	0
2	0	0	0	0
2	0	1	0	0
2	0	1	0	0
2	0	0	0	0
2	0	0	0	0
2	0	0	0	0
2	0	1	0	0
2	0	1	0	0
2	0	0	0	0
2	0	0	0	0
2	0	0	0	0
2	0	0	0	0
2	0	2	0	0
2	0	1	0	0
2	0	2	0	0
2	0	0	0	0
2	0	1	0	0
2	0	0	0	0
2	0	0	0	0
2	0	0	0	0
2	0	0	0	0
2	0	2	0	0
2	0	1	0	0
2	0	0	0	0
2	0	0	0	0
2	0	0	0	0
2	0	0	0	0
2	0	0	0	0
2	0	0	0	0
2	0	0	0	0
2	0	0	0	0

2	0	0	0	0
2	0	1	0	0
2	0	2	0	0
2	0	1	0	0
2	0	0	0	0
2	0	2	0	0
2	0	2	0	0
2	0	0	0	0
2	0	0	0	0
2	0	1	0	0
2	0	0	0	0
2	0	2	0	0
2	0	2	0	0
2	0	0	0	0
2	0	2	0	0
2	0	1	0	0
2	0	1	0	0
2	0	1	0	0
2	0	0	0	0
2	0	2	0	0
2	0	1	0	0
2	0	2	0	0
2	0	2	0	0
2	0	2	0	0
2	0	1	0	0
2	0	2	0	0
2	0	2	0	0
2	0	2	0	0
2	0	2	0	0
2	0	2	0	0
2	0	2	0	0
2	0	2	0	0
2	0	2	0	0
2	0	2	0	0

MT2015-T1-12

Encrustation	*Abrasion*	*Fragmentation*	*Black Coating*	*Oxidation Patina*
2	0	0	0	0
2	0	1	0	0
2	0	1	0	0
2	0	1	0	0
2	0	1	0	0
2	0	0	0	0
2	0	0	0	0
2	0	2	0	0
2	0	0	0	0
2	0	2	2	0
2	0	1	0	0
2	0	1	0	0
2	0	2	2	0
2	0	0	1	0
2	0	0	0	0
2	0	2	0	0
2	0	1	0	0
2	0	0	0	0
2	0	0	0	0
2	0	1	1	0
2	0	0	0	0
2	0	0	1	0
2	0	1	0	0
2	0	0	0	0
2	0	0	0	0
2	0	0	0	0
2	0	2	1	0
2	0	2	0	0
2	0	2	0	0
2	0	2	0	0
2	0	1	0	0
2	0	1	0	0
2	0	1	0	0
2	0	1	1	0
2	0	1	1	0
2	0	1	0	0
2	0	0	0	0
2	0	2	0	0

2	0	1	0	0
2	0	0	1	0
2	0	2	0	0
2	0	0	0	0
2	0	0	0	0
2	0	0	0	0
2	0	1	1	0
2	0	2	0	0
2	0	2	0	0
2	0	0	0	0
2	0	2	1	0
2	0	2	0	0
2	0	2	0	0
2	0	1	0	0
2	0	2	0	0
2	0	2	0	0

MT2015-T1-15

Encrustation	*Abrasion*	*Fragmentation*	*Black Coating*	*Oxidation Patina*
2	0	1	2	1
2	0	0	2	0
2	0	2	2	0
2	0	2	1	2
2	0	1	2	0
2	0	1	2	0
2	0	2	0	0
2	0	2	2	0
2	0	2	1	1
2	0	2	1	1
2	0	2	1	0

MT2015-T1-20

Encrustation	*Abrasion*	*Fragmentation*	*Black Coating*	*Oxidation Patina*
2	0	1	0	0
2	0	2	2	0
2	0	2	0	0
2	0	2	0	0
2	0	1	0	0
2	0	2	0	0
2	0	0	2	0
2	0	2	0	0
2	0	2	0	0
2	0	2	1	0

MT2015-T2-15

Encrustation	*Abrasion*	*Fragmentation*	*Black Oxidation*	*Oxidation Patina*
2	0	0	2	0
2	0	0	0	0
2	0	2	2	0
2	0	2	2	0
2	0	1	0	0
2	0	0	2	0
2	0	2	2	0
2	0	1	2	0
0	1	1	0	0
0	2	1	0	0
0	2	1	0	0
0	2	1	2	0
0	1	1	0	0
0	2	1	0	0
0	1	1	0	0
0	1	0	2	0
2	0	1	2	0
2	0	1	2	0
2	0	1	1	0

MT2015-T2-20

Encrustation	*Abrasion*	*Fragmentation*	*Black Coating*	*Oxidation Patina*
2	0	0	2	0
2	0	1	2	0
2	0	2	2	0
2	0	1	2	0
2	0	1	2	0
2	0	0	2	0
2	0	1	2	0
2	0	0	2	0
2	0	0	2	0
1	0	0	2	0
2	0	1	2	0
2	0	2	2	0
0	0	0	2	0
0	2	2	1	0
0	2	0	0	0
0	1	1	2	0
2	0	0	2	0
0	1	1	0	0
0	0	1	2	0
2	0	0	2	0
2	0	1	2	0
0	1	1	2	0
0	2	2	1	0
0	2	1	0	0
0	1	1	2	0
2	0	2	2	0
2	0	2	2	0
2	0	2	2	0
1	2	2	2	0
1	1	1	2	0
1	1	0	2	0
1	2	1	2	0
1	0	2	2	0
0	2	1	1	0
1	1	1	0	0
0	2	0	0	0
0	2	1	1	0
0	1	1	1	0

2	0	2	2	0
2	0	2	2	0
2	0	2	2	0
2	0	2	2	0
0	2	2	1	0
2	0	2	2	0
0	2	1	0	0
0	2	2	0	0

MT2015-T3-9

Encrustation	*Abrasion*	*Fragmentation*	*Black Coating*	*Oxidation Patina*
2	0	2	1	1
2	0	0	0	0
2	0	2	0	0
2	0	2	0	0
2	0	0	0	0
2	0	1	1	1
2	0	2	0	0
2	0	2	0	0
2	0	1	1	1
2	0	1	0	0
2	0	2	0	0
2	0	2	0	1
2	0	2	2	0
2	0	1	1	0
2	0	2	0	1
2	0	0	0	0
2	0	0	1	0
2	0	1	2	0
2	0	0	2	0
2	0	1	0	0
2	0	1	0	0
2	0	2	0	0
2	0	2	0	1
2	0	2	0	0
2	0	2	1	0
2	0	2	0	0
2	0	0	2	0
2	0	2	2	0
2	0	2	1	0
2	0	2	0	0
2	0	1	0	1
2	0	1	2	0
2	0	1	0	1
2	0	1	0	1
2	0	1	1	0
2	0	2	0	0
2	0	2	0	0
2	0	2	1	0

2	0	1	1	0
2	0	0	2	0
2	0	2	0	0
2	0	2	0	0
2	0	2	2	0
2	0	2	0	1
2	0	2	0	0
2	0	2	1	0
2	0	1	1	0
2	0	2	0	0
2	0	2	0	1
2	0	2	0	0
2	0	0	1	0
2	0	0	0	0
2	0	0	0	0
2	0	2	0	0
2	0	1	2	0
2	0	2	0	0
2	0	2	0	0
2	0	2	2	0
2	0	2	0	0
2	0	1	1	0
2	0	1	1	0
2	0	2	1	0
2	0	1	1	0
2	0	2	2	0
2	0	1	1	0
2	0	2	2	0
2	0	2	2	0
2	0	1	2	0
2	0	2	0	0
2	0	1	2	0
2	0	1	2	0
2	0	2	0	0
2	0	0	2	0
2	0	2	1	0
2	0	1	2	1
2	0	2	0	0
2	0	1	2	0
2	0	2	2	0

2	0	2	1	0
2	0	2	0	0
2	0	2	1	1
2	0	2	1	1
2	0	2	2	0
2	0	1	2	0
2	0	2	2	0
2	0	2	1	0
2	0	2	1	1
2	0	2	1	0
2	0	1	2	0
2	0	1	2	0
2	0	1	0	0
2	0	1	0	0
2	0	2	0	0
2	0	0	0	1
2	0	2	1	0
2	0	2	2	0
2	0	2	2	0
2	0	2	0	0
2	0	2	0	0
2	0	2	0	0
2	0	2	1	1
2	0	1	0	0
2	0	1	1	0
2	0	1	0	1
2	0	1	0	0
2	0	1	0	0
2	0	0	1	0
2	0	1	0	0
2	0	2	0	1
2	0	2	1	0
2	0	2	0	0
2	0	2	0	1
2	0	1	1	0
2	0	2	0	0
2	0	1	0	0
2	0	0	2	0
2	0	2	0	1
2	0	2	0	0

2	0	2	0	1
2	0	2	0	0
2	0	2	1	0
2	0	2	0	0

MT2015-T3-12

Encrustation	*Abrasion*	*Fragmentation*	*Black Coating*	*Oxidation Patina*
0	2	0	0	1
1	2	1	0	0
1	2	1	0	0
2	0	2	2	1
2	0	1	2	0
0	2	0	2	0
2	0	0	1	1
2	0	2	1	1
0	2	1	1	0
2	0	1	1	1
0	1	2	0	0
1	2	1	1	0
2	0	0	2	1
2	0	1	2	0
2	0	2	1	1

MT2015-T3-15

Encrustation	*Abrasion*	*Fragmentation*	*Black Coating*	*Oxidation Patina*
0	0	2	0	0
2	0	0	2	0
2	0	0	2	0
2	0	1	1	1
2	0	1	0	0
2	0	2	1	1
2	0	1	1	0
2	0	0	1	0
2	0	2	0	0
2	0	0	2	0
2	0	1	2	0
2	0	2	2	0
2	0	0	0	1
2	0	1	0	0
2	0	1	1	1
2	0	1	1	1
2	0	2	1	0
2	0	1	2	0
2	0	1	2	0
2	0	1	1	0
2	0	0	1	0
2	0	1	2	1
2	0	2	1	0
2	0	2	1	0
2	0	1	2	1
2	0	1	1	0
2	0	1	1	1
2	0	0	0	2
2	0	0	0	1
2	0	2	2	1
2	0	2	1	1
2	0	1	1	0

MT2015-T3-20

Encrustation	*Abrasion*	*Fragmentation*	*Black Coating*	*Oxidation Patina*
2	0	1	0	1
2	0	1	1	2
2	0	1	2	0
2	0	1	0	2
2	0	1	2	0
2	0	0	2	0
1	1	1	2	0
2	0	0	2	0
2	0	0	1	0
2	0	1	2	0
2	0	2	1	0
2	0	1	2	0
2	0	1	0	0
2	0	2	1	0
2	0	0	2	0
2	0	1	0	1
2	0	1	0	0
2	0	2	0	2
2	0	2	2	0
2	0	0	2	0
2	0	2	2	0
2	0	2	2	0
2	0	2	1	1
2	0	2	2	0
2	0	2	2	0
2	0	1	1	0
2	0	1	2	0
2	0	2	2	0
2	0	1	0	2
0	2	2	0	0

MT2015-T4-9

Encrustation	*Abrasion*	*Fragmentation*	*Black Coating*	*Oxidation Patina*
0	1	0	0	0
0	1	0	0	1
0	2	1	0	0
0	0	1	0	2
0	2	1	0	2
2	0	2	2	0
0	2	0	0	2
0	2	0	0	2
0	1	0	0	2
0	2	1	2	0
2	0	1	1	2
1	2	0	2	0
0	0	0	2	0
2	0	2	0	0
0	2	1	0	2
0	2	1	1	2
0	1	0	0	2
2	0	1	0	2
0	1	1	0	0
2	0	1	2	0
2	2	0	0	0
0	1	1	0	0
0	1	1	0	1
2	0	1	2	0
0	1	2	2	0
2	0	1	1	1
2	0	1	1	2
0	1	0	0	0
2	0	0	2	2
1	1	1	0	0
0	1	1	1	2
2	0	1	0	0
2	0	1	0	0
2	0	1	0	0
0	2	0	2	2
2	0	2	0	0
0	0	1	0	0
0	0	1	0	0

2	0	1	2	0
2	0	1	0	2
2	0	1	0	2
0	1	1	0	2
0	1	0	0	0
0	1	1	0	0
2	0	2	1	0
0	0	1	0	2
0	1	1	1	2
2	0	1	0	2
2	0	1	0	2
0	0	1	0	0
2	0	0	0	0
2	0	1	1	2
0	1	1	0	2
0	1	1	1	0
0	1	0	0	0
0	1	0	0	0
2	0	1	2	2
0	1	1	0	0
2	0	0	0	0
2	0	0	0	0
2	0	1	0	0
0	1	1	0	0
0	1	0	0	2
0	0	1	0	0
0	1	0	0	0
2	0	1	0	0
0	1	1	0	2
0	1	1	0	0
1	2	1	0	0
1	0	1	0	0
2	0	1	0	1
2	0	1	0	2
2	0	1	0	0
2	0	2	0	2
2	0	1	0	0
0	0	1	0	0
0	1	1	0	0
2	0	1	0	0

2	0	2	0	0
0	1	1	0	0
2	0	2	2	0
0	1	1	0	0
0	2	0	0	2
0	1	1	2	0
0	1	0	0	0
2	0	1	0	1
0	2	1	0	0
0	0	1	0	0
0	0	1	0	0
0	0	1	0	0

MT2015-T4-12

Encrustation	*Abrasion*	*Fragmentation*	*Black Coating*	*Oxidation Patina*
2	0	1	0	0
2	0	1	0	0
2	0	1	0	0
2	0	1	0	0
2	0	1	0	0
2	0	0	0	0
2	0	0	0	0
2	0	0	0	0
2	0	1	1	0
2	0	1	1	0
2	0	0	0	0
2	0	1	1	0
2	0	1	0	0
2	0	0	0	0
2	0	2	0	0
2	0	0	2	0
2	0	1	2	0
2	0	1	0	0
2	0	0	0	0
2	0	0	2	0
2	0	0	1	0
2	0	0	0	0
2	0	1	0	0
2	0	0	0	0
2	0	1	0	0
2	0	2	1	0
2	0	0	0	0
2	0	2	2	0
2	0	0	0	0
2	0	1	1	0
2	0	1	0	0
2	0	0	0	0
2	0	1	0	0
2	0	0	1	0
2	0	1	0	0
2	0	1	0	0
2	0	2	0	0
2	0	1	1	0

2	0	0	0	0
2	0	0	0	0
2	0	2	0	0
2	0	1	0	0
2	0	1	2	0
2	0	0	0	0
2	0	0	0	0
2	0	0	2	0
2	0	0	0	0
2	0	0	0	0
2	0	0	0	0
2	0	2	0	0
2	0	2	0	0
2	0	0	0	0
2	0	2	0	0
2	0	2	0	0
2	0	2	0	0
2	0	1	0	0
2	0	0	1	0
2	0	1	0	0
2	0	0	0	0
2	0	1	0	0
2	0	1	0	0
2	0	1	0	0
2	0	0	0	0
2	0	0	1	0
2	0	2	0	0
2	0	1	1	0
2	0	0	0	0
2	0	1	0	0
2	0	2	0	0
2	0	2	1	0
2	0	0	0	0
2	0	0	0	0
2	0	0	0	1
2	0	0	0	0
2	0	0	0	0
2	0	2	0	0
2	0	2	1	0
2	0	2	0	0

2	0	1	0	0
2	0	0	0	0
2	0	1	0	0
2	0	1	0	0
2	0	0	2	0
2	0	0	0	0
2	0	1	1	0
2	0	2	0	0
2	0	2	0	0
2	0	1	0	0
2	0	1	0	0
2	0	0	0	0
2	0	1	1	0
2	0	0	2	0
2	0	1	2	0
2	0	1	1	0
2	0	0	2	0
2	0	1	0	0
2	0	1	0	0
2	0	1	0	0
2	0	2	0	0
2	0	0	1	0
2	0	1	1	0
2	0	0	0	0
2	0	0	0	0
2	0	1	0	0
2	0	0	2	0
2	0	2	0	0
2	0	0	0	0
2	0	2	0	0
2	0	2	1	0
2	0	1	0	0
2	0	2	0	0
2	0	1	0	0
2	0	1	0	0
2	0	1	0	0
2	0	2	0	0
2	0	0	0	0
2	0	0	1	0
2	0	0	0	0

2	0	1	0	0
2	0	0	0	0
2	0	2	0	0
2	0	0	0	0
2	0	0	0	0
2	0	1	1	0
2	0	1	1	0
2	0	0	0	0
2	0	2	0	0
2	0	0	0	0
2	0	1	0	0
2	0	1	0	0
2	0	0	0	0
2	0	1	0	0
2	0	0	0	0
2	0	1	0	0
2	0	0	0	0
2	0	2	1	0
2	0	0	0	0
2	0	0	1	0
2	0	0	0	0
2	0	2	0	0
2	0	0	1	0
2	0	1	0	0
2	0	0	0	0
2	0	0	0	0
2	0	1	0	0
2	0	0	1	0
2	0	0	0	0
2	0	1	0	0
2	0	0	0	0
2	0	1	0	0
2	0	1	1	0
2	0	1	0	0
2	0	1	1	0
2	0	0	1	0
2	0	0	0	0
2	0	2	2	0
2	0	0	0	0
2	0	1	0	0

2	0	1	1	0
2	0	0	0	0
2	0	1	0	0
2	0	1	0	0
2	0	1	0	0
2	0	1	0	0
2	0	1	0	0
2	0	1	1	0
2	0	2	0	0
2	0	1	0	0
2	0	2	1	0
2	0	0	0	0
2	0	2	0	0
2	0	1	1	0
2	0	1	1	0

MT2015-T4-15

Encrustation	*Abrasion*	*Fragmentation*	*Black Coating*	*Oxidation Patina*
2	0	0	0	0
2	0	1	1	0
2	0	1	0	0
2	0	1	1	0
2	0	1	2	0
2	0	0	1	0
2	0	0	1	0
2	0	0	0	1
2	0	2	1	0
2	0	1	2	0
2	0	1	0	0
2	0	0	1	0
2	0	1	0	0
2	0	1	0	0
2	0	0	0	0
2	0	2	1	0
2	0	1	0	0
2	0	0	1	0
2	0	1	0	0
2	0	0	0	0
2	0	1	1	0
2	0	1	0	2
2	0	2	1	0
2	0	0	0	0

MT2015-T4-20

Encrustation	*Abrasion*	*Fragmentation*	*Black Coating*	*Oxidation Patina*
2	0	0	0	0
2	0	2	0	0
2	0	2	2	0
2	0	1	0	0
2	0	1	2	0
2	0	0	2	0
2	0	2	2	0
2	0	2	0	0
2	0	2	0	0
2	0	1	2	0
2	0	0	2	0
2	0	0	0	0
2	0	2	2	0
2	0	1	2	0
2	0	1	2	0
2	0	0	2	0
2	0	1	2	0
2	0	2	0	0
2	0	0	2	0
2	0	0	2	0
2	0	2	2	0
2	0	2	2	0
2	0	2	0	0
2	0	1	2	0
2	0	1	1	0
2	0	1	2	0
2	0	1	2	0
2	0	2	1	0
2	0	0	2	0
2	0	0	2	0
2	0	0	2	0
2	0	1	1	0
2	0	2	2	0
2	0	0	1	0
2	0	0	1	0
2	0	0	2	0
2	0	1	2	0
2	0	0	2	0

2	0	1	1	0
2	0	0	0	0
2	0	0	2	0
2	0	2	0	0
2	0	2	1	0
2	0	2	2	0
2	0	0	0	0
2	0	0	2	0
2	0	2	2	0
2	0	1	1	0
2	0	2	2	0
2	0	2	0	0
2	0	2	0	0

MT2015-T5-9

Encrustation	*Abrasion*	*Fragmentation*	*Black Coating*	*Oxidation Patina*
0	2	1	0	0
1	2	1	0	0
0	2	2	0	0
1	1	0	1	2
2	0	1	0	2
1	2	2	2	2
0	2	1	1	0
1	2	1	1	1
1	1	2	0	1

MT2015-T5-12

Encrustation	*Abrasion*	*Fragmentation*	*Black Coating*	*Oxidation Patina*
2	0	2	2	0
1	1	2	0	1
0	2	2	0	0
0	1	1	1	0
1	1	0	1	1
2	0	1	0	1
2	0	2	2	0
1	1	1	0	0
1	1	1	0	1
2	0	0	2	0
0	1	1	0	0
0	2	2	0	0
0	2	1	0	0
2	1	2	0	2
0	1	1	0	0
1	2	2	0	1
0	2	1	1	1
1	2	1	0	0
2	2	2	0	0
2	0	2	1	0
2	0	2	0	1
0	2	1	0	0
1	1	1	1	1
2	1	1	1	1
2	2	1	0	0
1	2	2	0	1

MT2015-T5-15

Encrustation	*Abrasion*	*Fragmentation*	*Black Coating*	*Oxidation Patina*
2	0	2	2	0
2	0	2	2	0
2	0	2	2	0
2	0	1	2	0
1	2	2	2	0
0	1	1	1	1
2	0	2	2	0
2	0	1	0	0
0	0	1	0	0
1	1	0	0	0
0	2	1	0	0
2	0	2	2	0
1	1	1	0	0
2	0	2	2	0
0	1	1	0	0
1	1	0	0	2
1	2	1	0	0
1	2	1	0	0
2	0	1	2	0
1	1	1	1	0
2	0	1	2	0
1	0	2	0	0
2	0	1	0	0
0	2	1	0	0
1	0	1	0	1
2	0	2	0	0
2	0	1	0	0
1	2	1	0	0
1	1	0	0	0
1	2	0	0	2
1	0	2	0	2
1	2	0	0	0
2	0	2	0	1
2	0	1	2	0
0	2	1	0	0
1	1	1	1	1
2	0	2	0	2
0	1	2	0	0

1	1	0	0	0
0	2	0	0	0
1	1	1	1	0
2	0	1	0	1
0	1	0	0	0

MT2015-T5-20

Encrustation	*Abrasion*	*Fragmentation*	*Black Coating*	*Oxidation Patina*
2	0	0	2	0
2	0	0	1	0
2	0	2	0	0
2	0	2	0	0
2	0	2	2	0

MT2015-T6-9

Encrustation	*Abrasion*	*Fragmentation*	*Black Coating*	*Oxidation Patina*
2	0	2	0	0
2	0	2	0	0
2	0	1	0	0
2	2	1	0	0
2	0	1	0	0
2	0	2	0	0
2	0	1	2	0
2	0	2	0	0
2	0	1	0	0
2	0	2	0	0
2	0	1	1	0
2	1	1	1	1
2	0	0	0	0
2	0	1	0	0
2	0	2	0	0
2	0	2	0	1
2	0	2	0	0
2	0	2	2	0
2	0	2	0	0
2	0	2	0	0
2	0	1	0	0
2	0	1	2	0
2	0	0	0	0
2	0	0	1	0
2	2	2	0	1
1	2	1	0	0
2	0	2	0	0
2	0	0	0	0
2	0	1	1	0
2	0	0	2	0
2	0	2	0	1
2	0	1	0	0
1	2	2	0	2
2	0	1	2	0
2	0	2	0	0
2	0	2	0	0
2	0	2	0	0
2	0	1	0	0

2	0	2	0	0
2	0	1	0	0
2	0	1	0	0
2	0	1	0	0
2	0	2	0	1
1	2	2	1	0
2	0	1	0	0
2	0	2	0	0
2	0	2	0	0
2	0	1	2	0
2	0	2	0	0
2	0	2	0	0
2	0	1	0	0
2	0	2	0	1
2	0	1	0	0
2	0	2	0	2
2	0	2	0	0
2	0	1	0	0
2	0	1	0	2
2	0	0	0	0
2	0	1	0	0
2	0	2	0	0
2	0	1	0	0
2	0	2	0	0
2	0	2	0	0
2	0	0	1	0
2	0	1	0	0
2	0	2	0	1
2	0	2	0	0
2	0	2	0	0
2	0	2	2	0
2	0	1	0	1
2	0	1	0	0
2	0	2	0	0
2	0	1	0	0
2	0	1	1	0
2	0	1	1	0
2	0	2	0	0
2	0	1	0	0
2	0	1	0	1

2	0	2	1	1
2	0	2	0	0
2	0	2	0	0
2	0	2	0	0
2	0	1	0	0
2	0	1	0	0
2	0	1	0	0
2	0	1	2	0
2	0	2	1	0
2	0	2	0	0
2	0	1	0	0
2	0	2	0	0
2	0	2	0	1
2	0	2	0	0
2	0	2	0	0
2	0	2	0	0
2	0	2	0	0
2	0	2	0	0
2	0	1	0	0
2	0	2	0	0
2	2	1	0	1
2	0	2	0	0

MT2015-T6-12

Encrustation	*Abrasion*	*Fragmentation*	*Black Coating*	*Oxidation Patina*
2	0	2	0	0
2	0	0	0	0
2	0	1	0	0
2	0	1	0	0
2	0	2	0	1
2	0	2	0	0
2	0	2	0	0
2	0	0	0	0
2	0	1	0	0
2	0	0	0	2
2	0	2	0	0
2	0	2	0	0
2	0	2	0	0
2	0	1	0	0
2	0	0	0	0
2	0	1	0	0
2	0	1	0	0
2	0	2	0	0
2	0	2	0	0
2	0	1	1	0
2	0	2	0	0
2	0	1	0	0
2	0	0	0	0
2	0	1	0	0
2	0	0	0	0
2	0	2	0	0
2	0	2	1	0
2	0	1	1	0
2	0	1	2	0
2	0	2	0	0
2	0	0	0	0
2	0	0	2	0
2	0	1	0	0
2	0	2	0	0
2	0	1	0	0
2	0	2	0	0
2	0	1	2	1
2	0	0	1	1

2	0	0	0	0
2	0	1	0	0
2	0	2	0	0
2	0	1	0	0
2	0	1	0	0
2	0	2	0	2
2	0	1	0	0
2	0	2	0	0
2	0	2	0	0
2	0	1	1	0
2	0	2	0	0
2	0	0	0	0
2	0	0	0	0
2	0	1	2	1
2	0	1	0	0
2	0	0	1	0
2	0	1	1	0
2	0	1	0	0
2	0	2	0	0
2	0	1	0	0
2	0	2	0	0
2	0	2	0	0
2	0	2	0	0
2	0	0	0	0
2	0	0	0	0
2	0	2	0	0
2	0	0	0	0
2	0	1	0	0
2	0	1	1	1
2	0	1	0	0
2	0	2	1	0
2	0	2	0	0
2	0	1	0	0
2	0	1	0	0
2	0	1	0	0
2	0	0	0	0
2	0	2	0	0
2	0	2	0	0
2	0	1	0	0
2	0	0	0	0

2	0	0	1	0
2	0	0	1	0
2	0	1	0	0
2	0	1	0	0
2	0	1	0	0
2	0	0	0	0
2	0	0	0	0
2	0	0	0	0
2	0	0	0	0
2	0	0	0	0
2	0	1	0	0
2	0	1	0	0
2	0	1	0	0
2	0	2	0	0
2	0	0	0	0
2	0	0	1	0
2	0	0	1	0
2	0	2	0	0
2	0	0	0	0
2	0	2	1	0
2	0	0	0	0
2	0	0	0	0
2	0	1	0	0
2	0	0	0	0
2	0	2	0	0
2	0	1	0	0
2	0	2	0	0
2	0	2	0	0
2	0	1	0	0
2	0	1	2	0
2	0	2	0	0
2	0	2	0	0
2	0	1	0	1
2	0	1	0	0
2	0	2	0	0

MT2015-T6-15

Encrustation	*Abrasion*	*Fragmentation*	*Black Coating*	*Oxidation Patina*
2	0	1	2	0
0	2	0	2	0
2	0	2	0	0
2	0	1	0	0
2	0	1	0	0
2	0	1	1	0
2	0	1	0	0
2	0	0	0	0
2	0	0	0	0
2	0	0	0	0
2	0	1	2	1
2	0	2	2	0
2	0	2	0	0
2	0	0	0	0
2	0	0	0	0
2	0	0	2	0
2	0	1	0	0
2	0	1	0	0
2	0	0	0	0
2	0	1	0	0
2	0	0	0	0
2	0	2	0	1
2	0	1	0	0
2	0	0	0	0
2	0	2	0	0
2	0	0	0	0
2	0	2	2	0
2	0	1	0	0
2	0	0	0	0
2	0	0	2	0
2	0	0	0	0
2	0	2	2	0
2	0	2	0	0
2	0	1	0	0
2	0	0	0	0
2	0	2	2	0
2	0	1	0	0
2	0	0	0	0

2	0	0	0	2
2	0	2	0	0
2	0	2	0	0
2	0	2	2	0
2	0	0	0	2
2	0	0	0	0
2	0	2	2	0
2	0	1	2	0
2	0	0	1	0
2	0	0	0	0
2	0	0	0	0
2	0	2	0	0
2	0	1	0	0
2	0	2	2	0
2	0	2	0	0
2	0	1	0	0
2	0	2	0	0
2	0	1	0	0
2	0	2	0	0
2	0	2	0	0
2	0	1	0	0
2	0	2	0	0
2	0	0	0	0
2	0	1	0	0
2	0	1	1	0
2	0	1	1	0
2	0	2	0	0
2	0	1	0	0
2	0	0	0	0
2	0	2	0	0
2	0	2	1	0
2	0	2	2	1
2	0	1	0	0
2	0	1	2	0
2	0	0	0	0
2	0	1	0	0
2	0	1	0	2
2	0	2	1	0
2	0	0	0	0
2	0	1	2	0

2	0	1	2	0
2	0	1	0	0
2	0	1	0	0
2	0	2	1	1
2	0	2	0	0
2	0	1	0	0
2	0	2	0	0
2	0	2	0	0
2	0	2	0	0
2	0	1	1	0
2	0	0	0	0
2	0	1	1	0
2	0	2	0	0
2	0	0	0	0

MT2015-T6-20

Encrustation	*Abrasion*	*Fragmentation*	*Black Coating*	*Oxidation Patina*
2	0	1	0	0
2	0	1	0	0
2	0	2	0	0
2	0	1	0	0
2	0	0	0	0
2	0	1	0	0
2	0	0	0	0
2	0	0	0	0
2	0	0	0	0
2	0	0	0	0
2	0	0	0	0
2	0	0	0	1
2	0	2	0	0
2	0	0	0	0
2	0	0	0	0
2	0	0	0	0
2	0	0	0	0
2	2	0	0	0
2	0	0	0	0
2	0	0	0	0
2	0	0	2	0
2	0	0	0	0
2	0	0	0	0
2	0	0	0	0
2	0	2	2	0
2	0	1	0	0
2	0	0	0	0
2	0	1	0	0
2	0	1	0	0
2	0	1	0	1
2	0	0	0	1
2	0	0	0	1
2	0	1	2	0
2	2	0	1	1
2	0	1	1	2
2	0	1	2	0
2	0	1	0	0
2	0	0	2	0

2	0	2	0	0
2	0	0	0	0
2	0	2	2	0
2	0	0	2	0
2	0	2	1	2
2	0	0	0	1
2	0	0	0	1
2	0	1	0	0
2	0	0	0	0
2	2	0	0	1
2	0	1	1	1
2	0	0	0	0
2	0	2	2	0
2	0	1	2	0
2	0	1	2	0
2	0	2	2	0
2	0	2	2	1
2	0	0	0	2
2	0	0	0	2
2	0	0	0	0
2	0	0	0	0
2	0	1	0	1
2	0	0	0	2
2	0	1	0	0
2	0	0	0	0
2	0	1	0	1
2	0	1	0	2
2	0	2	0	0
2	0	1	2	1
2	0	1	0	2
2	0	1	2	0
2	0	1	0	0
2	0	1	0	0
2	0	0	0	0
2	0	1	0	0
2	0	0	0	1
2	0	1	0	1
2	2	1	0	2
2	0	0	0	0
2	0	2	2	0

2	0	0	1	2
2	0	2	2	0
2	0	2	2	0
2	0	0	0	0
2	0	1	0	2
2	0	1	0	0
2	0	2	0	1
2	0	2	1	2
2	0	1	0	0
2	0	0	1	0
2	0	0	0	2
2	0	2	2	1
2	0	1	0	0
2	0	1	1	0
2	0	2	2	0
2	0	1	0	0
2	0	0	0	0
2	0	0	0	1
2	0	0	1	2
2	0	1	1	1
2	0	0	2	0
2	0	0	0	1
2	0	0	0	2
2	0	1	0	0
2	2	1	2	1
2	0	0	1	1
2	0	0	0	1
2	0	0	0	0
2	0	1	0	1
2	0	2	0	2
2	2	1	0	2
2	0	0	0	0
2	0	0	1	2
2	0	2	2	0
2	0	2	2	0
2	0	1	1	1
2	0	1	2	1
2	0	0	0	2
2	0	2	0	1
2	0	0	0	2

2	0	0	0	2
2	0	1	1	1
2	0	1	0	0
2	0	1	0	2
2	0	1	0	2
2	0	0	0	0
2	2	1	1	0
0	2	1	1	1
1	2	1	0	2
2	2	0	2	1
2	0	2	2	0
2	0	1	0	1
2	0	1	0	1
2	0	1	0	2
2	0	1	2	1
2	0	1	0	1
2	0	1	0	0
2	0	2	2	0
1	2	1	0	2
2	0	2	0	0
2	0	1	0	1
2	0	0	0	0
2	0	1	0	0
2	0	1	0	2
2	0	1	0	2
2	0	0	0	2
2	0	0	1	1
2	0	1	0	1
2	2	0	0	0
2	0	1	1	2
2	0	0	0	0
2	0	0	0	2
2	0	2	1	0
2	0	0	0	2
2	0	0	1	1
2	0	0	0	1
2	0	0	0	2
2	0	0	2	0

MT2015-T7-9

Encrustation	*Abrasion*	*Fragmentation*	*Black Coating*	*Oxidation Patina*
2	0	2	0	0
2	0	0	0	0
2	0	1	0	0
2	0	2	0	0
2	0	2	0	0
2	0	2	0	0
2	0	2	0	0
2	0	1	0	0
2	0	2	0	0
2	0	2	0	0
2	0	2	0	0
2	0	1	0	0
2	0	2	0	0
2	0	2	0	0
2	0	2	0	0
2	0	2	0	0
2	0	2	0	0
2	0	2	0	0
2	0	1	0	0
2	0	2	0	0
2	0	2	0	0
2	0	1	0	0
2	0	2	0	0
2	0	2	0	0
2	0	2	0	0
2	0	2	0	0
2	0	2	0	0
2	0	2	1	0
2	0	2	0	0
2	0	2	1	0
2	0	2	0	0
2	0	2	0	0
2	0	2	1	0
2	0	2	0	0
2	0	2	1	1
2	0	2	0	0
2	0	1	0	0
2	0	0	0	0

2	0	2	0	0
2	0	2	0	0
2	0	1	0	0
2	0	2	0	0
2	0	2	0	0
2	0	1	0	0
2	0	2	0	0
2	0	2	0	0
2	0	2	0	1
2	0	2	1	0
2	0	2	0	0
2	0	2	0	0
2	0	2	0	0
2	0	2	0	0
2	0	1	0	0
2	0	2	0	0
2	0	2	0	0
2	0	1	0	0
2	0	2	0	1
2	0	1	0	0
2	0	2	0	0
2	0	2	0	1
2	0	2	0	0
2	0	2	0	0
2	0	2	0	0
2	0	2	2	0
2	0	1	0	0
2	0	2	0	0
2	0	2	1	0
2	0	2	1	0
2	0	1	0	1
2	0	2	0	0
2	0	2	0	0
2	0	2	0	0
2	0	2	0	0
2	0	2	0	0
2	0	2	0	0
2	0	1	0	0
2	0	2	0	0
2	0	2	0	0

2	0	2	0	0
2	0	1	0	0
2	0	2	0	0
2	0	2	0	0
2	0	2	1	0
2	0	2	1	1
2	0	2	0	1
2	0	2	0	0
2	0	2	0	0
2	0	2	0	0
2	0	2	0	0
2	0	2	0	0
2	0	2	0	0
2	0	2	0	0
2	0	2	0	2
2	0	2	0	0
2	0	2	0	0
2	0	1	0	0

MT2015-T7-12

Encrustation	*Abrasion*	*Fragmentation*	*Black Coating*	*Oxidation Patina*
2	0	2	0	0
2	0	2	0	0
2	0	2	0	0
2	0	2	0	0
2	0	2	0	0
2	0	1	0	0
2	0	2	0	0
2	0	2	0	2
2	0	2	0	0
2	0	2	0	0
2	0	2	0	0
2	0	1	0	0
2	0	2	0	0
2	0	2	0	0
2	0	0	1	0
2	0	1	1	0
2	0	1	1	0
2	0	2	0	0
2	0	0	0	1
2	0	2	0	0
2	0	2	0	0
2	0	2	2	0
2	0	2	0	0
1	2	1	0	0
2	0	2	2	0
2	0	2	2	0
2	0	2	0	0
2	0	0	2	0
2	0	1	0	0
2	0	1	2	0
2	0	2	0	0
2	0	1	2	0
2	0	2	0	0
2	0	2	0	0
2	0	2	0	1
2	0	2	0	0
2	0	1	0	1
2	0	2	1	1

2	0	2	0	0
2	0	2	2	0
2	0	2	0	1
2	0	1	2	1
2	0	2	2	0
2	0	2	2	0
2	0	2	2	1
2	0	2	0	0
2	0	1	0	2
2	0	2	0	0
2	0	2	0	0
2	0	1	0	0
2	0	2	0	0
2	0	1	0	0
2	0	2	0	0
2	0	2	0	0
2	0	2	0	0
2	0	2	0	0
2	0	1	1	0
2	0	2	0	0
2	0	2	0	0
2	0	2	2	0
2	0	2	1	0
2	0	0	1	0
2	0	0	0	1
2	0	2	0	0
2	0	0	0	0
2	0	2	1	0
2	0	2	0	0
2	0	2	1	1
2	0	1	0	0
2	2	2	0	0
2	0	1	0	0
2	0	2	0	0
2	0	0	0	1
1	1	1	0	1
2	0	1	0	0
2	0	1	0	1
2	0	2	1	0
2	0	2	0	0

2	0	1	0	1
2	0	0	0	2
2	0	1	0	0
2	0	1	2	1
2	0	2	2	1
2	0	2	0	0
2	0	0	0	2
2	0	1	1	2
2	0	1	0	2
2	0	2	0	2
2	0	2	0	0
2	0	1	2	0
1	2	0	2	0
2	0	1	0	0
2	0	2	2	0
2	0	2	0	0
2	0	0	2	0
2	0	2	0	0
2	0	1	0	0
2	0	1	1	0
2	0	2	0	0
2	0	1	0	0
2	0	2	0	0
2	0	2	2	0
2	0	2	0	0
2	0	0	2	1
2	0	1	2	1
2	0	2	0	0
1	0	1	0	0

MT2015-T7-15

Encrustation	*Abrasion*	*Fragmentation*	*Black Coating*	*Oxidation Patina*
2	0	2	0	0
2	0	2	2	1
2	0	2	0	0
2	0	2	2	1
2	0	2	1	0
2	0	2	2	1
2	0	2	1	1
2	0	2	0	0
2	0	2	2	2
2	0	2	2	0

MT2015-T7-20

Encrustation	*Abrasion*	*Fragmentation*	*Black Coating*	*Oxidation Patina*
2	0	0	2	0
2	0	2	2	0
2	0	2	2	0
2	0	2	2	0
2	0	2	2	0
2	0	2	2	0
2	0	2	2	0
0	1	1	1	0
0	1	1	2	1
1	2	0	0	0
2	0	2	2	0
2	0	2	2	0
2	0	2	2	0
2	0	2	1	0
2	0	2	2	0
2	0	1	2	0
2	0	1	2	0
2	0	1	0	0
2	0	2	2	1
2	0	2	2	0
2	0	2	2	0
2	0	2	2	0
2	0	2	1	0
2	2	1	1	1
2	0	2	2	0
2	0	2	1	1
2	0	0	1	0
2	0	2	1	0
2	0	1	0	0
2	0	2	2	0
2	0	2	0	0
2	0	2	2	0
2	0	2	2	0
2	0	2	1	0
2	0	1	1	0
2	0	2	1	0
2	0	2	2	0
2	0	2	2	0

2	0	2	1	1
2	0	2	2	0

MT2016-T9-9

Encrustation	*Abrasion*	*Fragmentation*	*Black Coating*	*Oxidation Patina*
2	2	0	0	0
0	0	1	0	0
0	1	0	0	0
0	1	0	0	0
2	2	1	1	2
0	1	1	0	0
0	1	0	0	0
0	1	0	0	0
0	1	1	0	0
0	1	1	0	0
1	1	0	0	0
2	1	0	0	0
0	1	0	0	0
2	2	0	0	0
2	1	1	0	0
0	1	1	0	0
0	1	1	0	0
0	1	1	0	0
1	2	2	0	0
1	1	0	0	0
0	1	1	0	0
2	2	1	0	2

MT2016-T9-12

Encrustation	*Abrasion*	*Fragmentation*	*Black Coating*	*Oxidation Patina*
0	2	1	0	0
1	2	1	0	2
0	1	0	0	0
0	2	0	0	0
2	0	0	0	2
0	1	1	0	0
2	0	2	0	0
1	1	1	0	0
0	2	0	0	0
1	2	1	1	0
0	1	1	0	0
0	1	0	0	0
1	1	2	0	0
1	1	0	0	0
0	1	1	0	0
1	0	0	0	0
2	0	0	0	2
0	1	1	0	0
2	0	1	0	2
0	2	0	0	0
1	0	2	0	2
1	2	0	0	0
0	1	0	0	0
0	1	1	0	0
1	2	0	0	1
1	2	1	0	2
0	2	1	1	0
0	2	0	1	0
0	0	1	0	0
0	1	0	0	0
0	0	1	0	0
0	1	2	0	0
1	2	0	0	0
0	1	1	0	0
0	1	0	0	0
2	0	0	0	0
1	2	1	0	2
1	2	0	0	1

0	2	2	0	1
2	2	0	0	0
0	1	1	1	0
2	1	0	0	2
0	0	1	0	0
1	1	1	0	1
2	0	0	0	0
2	0	0	0	0
1	1	1	0	0
1	1	1	0	0
2	2	1	1	2
2	2	2	0	2
2	0	1	0	0
2	0	1	0	2
1	2	0	0	0
2	0	1	0	2
2	0	1	0	2
1	1	0	0	0
0	2	1	1	0
1	2	0	0	2
1	1	0	0	0
2	2	1	0	1
0	2	1	0	0
2	0	0	0	1
0	1	0	0	0
2	0	0	0	0
2	2	1	0	2
2	0	2	0	2
2	2	1	0	2
0	1	1	0	0
1	1	0	0	0
0	0	1	0	0
2	0	0	0	0
2	2	1	1	0
2	0	2	0	0
1	1	1	0	0
2	0	1	1	2
0	1	1	0	0
2	2	1	0	2
0	2	1	0	0

2	0	1	0	0
1	1	2	0	0
1	1	0	0	0
1	2	1	0	0
1	1	0	0	0
1	2	1	0	0
2	0	0	0	0
0	1	2	0	0
0	2	1	0	0
1	2	0	0	2
0	1	0	0	0
2	0	1	0	2
2	0	2	0	1
2	0	1	0	1
0	1	1	0	2
0	2	2	0	0
0	1	0	0	0
2	2	2	0	0
2	0	1	0	0
2	0	1	0	2
0	1	0	0	0
0	0	1	0	0
0	1	1	0	0
0	1	1	0	0
0	1	1	0	0
2	0	1	0	0
0	2	1	0	0
2	0	1	0	2
0	1	2	0	2
0	1	1	0	0
1	0	1	0	0
0	1	1	0	0
0	1	1	0	0
2	0	1	0	0
1	2	1	0	0
0	1	1	0	0
0	1	1	0	0
0	1	1	0	0
2	0	1	0	0
0	1	1	0	0

0	0	1	0	0
1	1	0	0	0
1	1	1	0	0
0	1	1	0	0
2	0	2	0	0
0	1	2	0	0
2	0	2	0	0
0	1	1	0	0
0	1	1	0	0
0	1	1	0	0
0	0	1	0	0
0	1	0	0	0
0	0	1	0	0
0	2	1	0	0
0	0	1	0	0
0	2	1	0	0
0	2	1	0	0
1	1	0	0	0
1	0	1	1	0
0	0	1	0	0
2	0	2	0	2
0	0	1	0	0
0	1	1	0	0
1	2	1	0	0
2	0	2	0	0

MT2016-T9-15

Encrustation	*Abrasion*	*Fragmentation*	*Black Coating*	*Oxidation Patina*
1	2	1	0	0
0	1	0	0	0
1	2	1	0	0
0	1	1	0	0
0	0	1	0	0
0	0	1	0	0
0	1	1	0	0
0	1	1	0	0
1	0	1	0	0
1	1	0	0	0
0	1	0	0	0
0	0	1	0	0
0	2	1	0	0
0	1	1	0	0
0	2	1	0	0
0	0	0	0	0
2	1	0	0	1
0	2	1	0	1
0	1	1	0	0
0	1	1	0	0
0	1	1	0	0
0	1	0	0	0
0	2	0	0	1
0	1	1	0	0
0	1	1	0	0
0	1	0	0	0
0	1	0	0	0
1	1	0	0	0
1	1	1	0	0
0	0	0	0	0
0	1	1	0	0
1	1	1	0	0
0	1	0	0	0
0	2	1	0	0
0	1	1	0	0
0	0	1	0	0
0	0	1	0	0
0	2	0	0	0

0	0	1	0	0
0	1	1	0	0
1	1	0	0	0
0	1	1	0	0
0	1	1	0	0
0	1	0	0	0
0	2	1	0	0
0	1	1	0	0
2	0	0	0	0
0	1	1	0	0
0	1	0	0	0
0	1	0	0	0
0	2	1	0	0
2	1	1	0	0
0	1	1	0	0
0	2	0	0	0
0	0	1	0	0
0	2	1	0	1
2	0	0	0	0
0	0	2	0	0
0	0	1	0	0
0	1	0	0	0
0	1	1	0	0
0	1	1	0	0
0	1	1	0	0
2	0	1	0	0
0	0	1	0	0
0	1	1	0	0
0	0	1	0	0
0	0	1	0	0
0	1	0	0	2
0	1	1	0	0
0	1	1	0	0
0	1	1	0	0
0	1	1	0	0
0	1	1	0	0
0	1	1	0	0
0	0	1	0	0
0	1	1	0	0
0	0	1	0	0

0	0	1	0	0
0	1	1	0	0
0	0	0	0	0
1	0	1	0	0
0	0	2	0	0
0	1	1	0	0
0	0	1	0	0
0	1	1	0	0
0	0	1	0	0
0	0	1	0	0
0	1	1	0	0
0	0	1	0	0
0	0	1	0	0
0	0	0	0	0
0	0	1	0	0
0	0	1	0	0
0	0	1	0	0
0	1	1	0	0
0	0	1	0	0
0	0	0	0	0
0	1	1	0	0
2	0	0	0	0
0	1	1	0	0
2	0	2	0	0
0	1	1	0	0
0	0	1	0	0
0	1	1	0	0
0	1	1	0	0
0	0	1	0	0
0	0	1	0	0
0	2	1	0	0
0	0	1	0	0
0	1	1	0	0
0	1	1	0	0
0	0	2	0	0
0	1	0	0	0
0	0	1	0	0
0	0	0	0	0
0	0	0	0	0
0	0	1	0	0

0	1	1	0	0
0	1	1	0	0
0	2	1	0	0
0	0	0	0	0
0	0	1	0	0
0	1	1	0	0
0	0	0	0	0
0	0	2	0	0
0	1	2	0	0
0	1	2	0	0

MT2016-T9-20

Encrustation	*Abrasion*	*Fragmentation*	*Black Coating*	*Oxidation Patina*
2	0	0	1	0
2	0	1	0	0
2	0	0	0	1
2	0	0	0	0
2	0	2	0	2
2	0	0	0	0
2	0	0	0	0
2	2	2	1	1
2	1	2	0	2
2	0	0	0	1
2	0	1	0	1
1	2	1	0	0
2	0	1	0	1
2	0	0	0	0
2	0	2	0	2
2	0	0	0	1
2	0	0	2	0
2	0	0	0	0
2	0	0	0	0
2	0	0	0	0
2	0	0	0	1
2	0	0	0	0
2	0	1	0	2
2	2	2	1	0
2	0	0	0	1
2	0	0	0	0
2	0	1	0	0
1	2	1	0	0
2	0	1	2	0
2	0	0	0	2
1	2	1	0	0
2	0	2	0	1
2	0	2	2	0
2	0	1	0	2
2	0	1	0	0
1	2	0	2	0
2	0	0	0	0
2	0	0	0	0

2	0	1	0	1
2	0	2	0	1
2	0	1	0	2
2	0	1	0	2
2	0	1	0	2
2	0	1	0	2
2	0	1	0	2
2	0	0	0	2
1	2	1	2	0
2	0	1	0	1
2	0	2	2	1
2	0	0	1	0
1	2	0	2	0
2	2	1	0	1
2	0	1	0	2
2	0	0	0	0
2	0	1	0	2
2	2	1	1	1
2	0	2	1	0
2	0	1	0	1
2	0	0	2	0
1	1	2	1	1
2	0	1	0	2
2	0	0	1	2
2	2	1	0	2
1	2	1	2	0
2	0	1	0	0
2	2	0	1	0
2	0	0	0	0
2	0	1	0	2
2	0	2	0	1
2	0	2	0	2
2	0	0	0	1
2	0	2	2	0
2	0	0	0	1
2	0	2	0	1
2	0	1	0	0
0	1	1	2	0
2	0	0	0	1
2	0	1	0	1

2	2	0	0	2
2	0	0	0	2
2	0	2	0	0
2	0	0	0	2
2	0	0	0	0
2	0	1	0	1
2	0	0	0	0
0	2	0	2	0
2	0	1	2	0
2	0	0	0	2
2	0	2	0	1
2	0	1	0	0
2	0	0	0	1
2	0	0	0	2
2	0	2	0	0
2	0	1	0	2
2	0	0	0	2
2	0	0	0	0
2	0	1	0	0
2	0	0	0	0
1	1	0	2	0
2	0	1	0	0
2	0	0	0	0
2	2	2	0	1
2	0	2	0	2
2	0	1	1	1
2	0	1	0	2
2	0	2	0	2
2	2	1	1	1
2	0	1	0	2
2	0	1	0	2
2	0	1	0	1
2	0	1	0	2
2	0	1	0	2
2	0	0	0	0
1	2	2	0	0
2	0	0	0	1
1	2	2	1	1
2	0	2	2	0
2	0	2	0	2

2	0	1	0	0
0	2	1	2	0
2	0	0	0	2
2	0	0	0	0
2	0	1	0	0
2	0	0	0	2
2	0	2	0	2
2	0	1	0	1
2	0	0	0	2
2	0	2	0	2
2	0	0	0	0
2	0	2	0	1
2	0	1	0	1
2	0	2	0	1
2	0	2	0	1
2	0	0	1	1
2	0	0	0	0
2	0	1	0	2
2	0	0	0	1
2	2	0	0	0
2	0	0	0	1
2	0	0	0	2
2	0	1	0	0
2	0	1	0	2
2	0	1	0	0
2	0	1	0	0
2	0	1	0	1
2	0	0	0	2
2	0	1	0	1
2	0	0	0	0
2	0	1	0	1
0	1	1	2	0
2	0	0	0	0
2	0	1	0	1
2	2	0	0	2
0	1	1	1	0
2	0	1	0	2
2	0	0	0	1
2	0	0	0	0
2	0	0	0	2

2	0	1	1	0
2	0	0	0	2
1	2	2	0	1
2	0	1	0	2
2	0	0	0	2
2	0	1	0	0
2	0	2	0	1
2	0	2	0	2
2	0	1	0	2
2	0	1	0	2
2	0	1	0	1
2	0	1	0	2
2	0	2	0	0
2	0	1	0	2
2	0	0	0	1
1	2	0	2	0
2	1	2	2	0
2	0	1	1	2
2	0	1	0	1
2	0	0	0	2
2	0	0	0	0
1	2	1	0	2
2	0	1	1	2
2	0	2	0	1
2	0	0	0	2
2	0	2	0	2
2	0	1	0	2
2	0	1	0	2
2	0	0	2	0
2	0	1	0	2
2	0	2	1	2
2	0	0	0	2
2	0	1	0	0
2	0	0	0	0
2	0	1	0	2
2	0	1	0	2
2	0	2	0	2
2	0	2	0	2
2	0	0	0	2
2	0	1	0	2

2	0	1	0	1
2	0	2	0	2
2	0	1	0	2
2	0	1	0	2
2	0	1	0	2
2	0	0	2	0
2	0	0	1	2
2	0	1	0	1
2	0	2	0	2
1	2	2	0	2
1	1	1	1	0
2	0	1	0	1
0	2	1	0	2
2	0	1	0	2
2	0	1	0	0
2	0	1	1	1
2	0	1	0	2
2	0	1	0	2
2	0	1	0	2
1	0	1	0	0
2	0	2	0	1
2	0	1	1	2
2	0	2	2	0
0	1	1	0	0
2	0	2	0	1
2	0	1	0	2
2	0	1	0	2
0	1	1	2	0
2	0	1	0	0
2	0	2	0	0
2	0	2	0	2
2	0	2	0	0
2	0	2	0	2
2	0	2	0	0