Tanzania Journal of Science 46(2): 460-474, 2020
ISSN 0856-1761, e-ISSN 2507-7961
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Evidence for a Record of Possible Paleo-Tsunami or Storm Deposits in the Fluviatile Neoproterozoic Malagarasi Supergroup of North-Western Tanzania

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Received 20 February 2020, Revised 20 May 2020, Accepted 6 June 2020, Published June 2020
DOI: https://dx.doi.org/10.4314/tjs.v46i2.22

Abstract

Two different localities within the fluviatile Neoproterozoic Malagarasi Supergroup of north-western Tanzania show striking evidence for tsunami related clastic sedimentary deposits. In each locality, the outcrops are characterised by the association of fine grained, thinly laminated shales at the bottom that are overlain by thick deposits of sandstones and conglomerates whose clasts and pebbles vary in size and angularity/roundness. In each case, the two rock units are separated by an erosional surface. The basal shale layers are consistent with deposition in deep shelf environments which are in stark contrast to the immediately overlying conglomerates/sandstones that suggest reworking under high energy conditions. The consistent association of erosional surfaces coupled with the deposition of adjacent low and high energy facies are interpreted as a result of an ancient earthquake triggered tsunami or storm that abruptly changed the depositional energy at the two localities. We propose that a backwash wave transported pebbles and sediments from the shore setting towards the basin interior depositing them on the shale units. Given the limited preservation of such unusual sedimentological deposits in ancient terranes, these two localities in the Neoproterozoic Malagarasi basin provide information on the effects of tsunami or storm impacts in Precambrian basins of Tanzania.

Keywords: Malagarasi Supergroup, Tsunami deposits, Shales, Sandstones, Conglomerates.

Introduction

In a sedimentary setting, tsunami and storm induced deposits (commonly referred to as tsunamites) are defined as discrete event sequences mostly attributable to high energy waves either caused by meteoritic impact, plate tectonics or underwater energetic dynamic processes (Morales et al. 2011). The mechanism of tsunamites deposition defies normal bathymetric interpretations as such deposits are characterised by an erosive base, abundance of marine organisms such as foraminifera and diatoms, sharp grain size contrast in the overlying beds and vice versa (Pratt 1994, Pratt 2002, Varela et al. 2011). Other features are the occurrences of chaotic sedimentary clasts that are different from those where they are deposited (Pratt 2002). Normal sedimentary deposits are mostly characterised by fining upward stratigraphic trends, a feature that is uncommon for tsunamites (Goff et al. 2001).

Such deposits have been documented in a wide range of basins dating back to the Archaean (Hassler et al. 2000), Proterozoic

(Bhattacharya and Bandyopadhyay 1998) and during the Phanerozoic Earth (Schnyder et al. 2005). The models for their occurrences have generally been associated with either earthquakes or storm processes (Reddering 2003, Bryant and Nott 2001, Goff et al. 2001). Additionally, deposition of the tsunamites has been interpreted in terms of powerful tsunami-driven backwash or by mass flow attributed by normal gravity forces (Figure 1, Hartley et al. 2001, Le Roux and Vargas 2005, Spiske et al. 2014, Le Roux 2015). Examples of modern time tsunamigenic deposits include those caused by the 1993 Hokkaido-Nansei-Oki earthquake in Japan (Namayama et al. 2000) and the Okoropunga in New Zealand which formed in the 15th century (Goff et al. 2004).

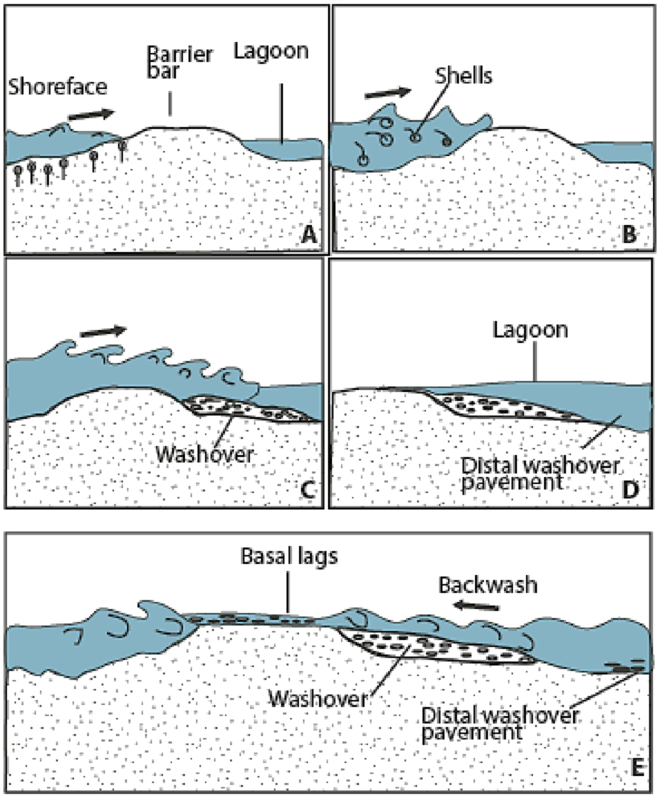

Figure 1: An illustration proposed by Varela et al. (2011) as a plausible model for the formation of the Pantagonia tsunamigenic deposit: In A, B, C & D, shells and bio-clastics are carried by a wave-wash and deposited in the lagoon. In E, a later backwash event, the waters retreat to the sea and the backwash flow reworks the wash-over deposit and thus re-depositing as basal lags on the barrier bar.

It has been suggested that it is difficult to make a distinction between storm and tsunami induced deposits in the absence of extensive outcrop exposures (Namayama et al. 2000, Dawson et al. 1996, Dawson and Smith 2000). Furthermore, Spiske et al. (2014) contended that there is no evidence that tsunami backflows in marine environments cannot produce debris flows that are capable of transporting clasts off-shore. However, a number of studies have been able to precisely discern between storm and tsunami triggered sedimentary deposits (Varela et al. 2011, Schnyder et al. 2005, Spiske et al. 2014). For instance, Varela et al. (2011) studied in detail the tsunamites of the Upper Cretaceous southern Patagonia basin which is rich in marine shells. They were able to characterise wash-over and backwash induced deposits based on sedimentary and taphonomic characteristics (Figure 1).

However, it should be noted that not all tsunami events produce coarse grained deposits, but also soft sediment deformation structures have been reported in other studies and they were interpreted in terms of syn-depositional sediment folding and faulting triggered by earthquakes for unconsolidated strata (Noda et al. 2007, Alsop and Marco 2012). Modes of formation for these deposits include slumping of poorly consolidated sediments caused by high-energy back-wash; deformation of the strata is enhanced by an increase of pore fluids in the sediments that reduces their shear strength and hence folding and/or faulting (Figure 2, Alsop and Marco 2012).

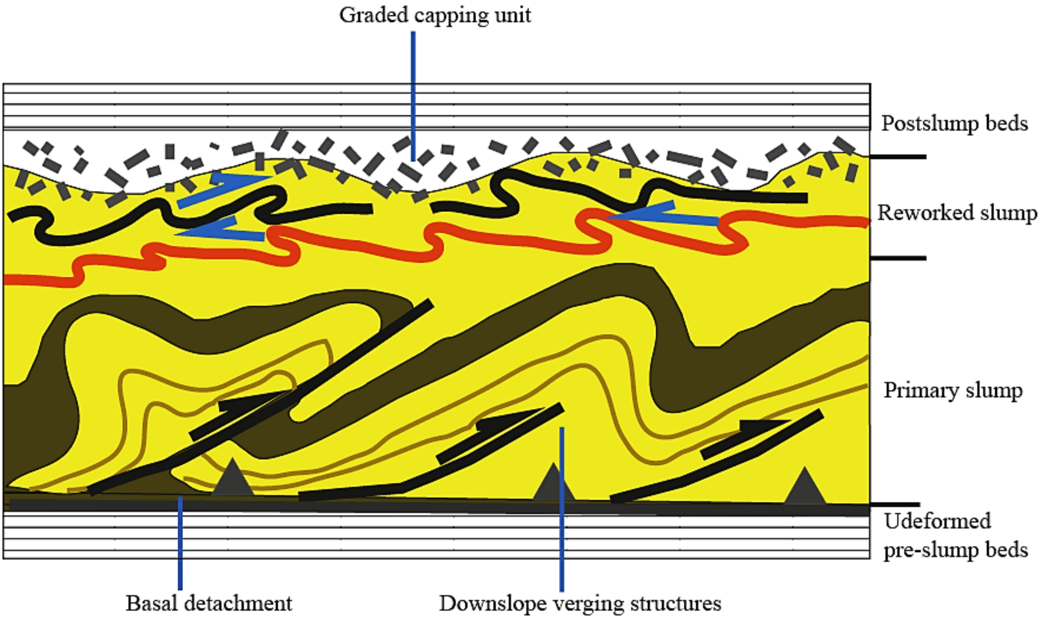

Figure 2: An idealized schematic representation proposed by Alsop and Marco (2012) to illustrate events of soft-sediments deformation caused by seismically triggered tsunami and seiche waves. Folds and thrusts (red arrows) dominate in the primary slump while reworking and upslope vergence (blue arrows) characterise the reworked slump. The reworked unit is overlain by a chaotic breccia unit which indicates vergence culmination (Alsop and Marco 2012).

The fluviatile Neoproterozoic Malagarasi Supergroup (Figures 3 and 4) of north-western Tanzania comprises clastic sedimentary sequences that include sandstones, shales, dolomitic limestones and red beds (Halligan 1962). The sole igneous activity documented in the Malagarasi basin is the effusive eruption of Gagwe amygdaloidal lavas (Halligan 1962). The age of the Malagarasi clastic sedimentary rocks is constrained by the $^{40}Ar/^{39}Ar$ age of 795 ± 7 Ma reported for the Gagwe amygdaloidal lavas by Deblond et al. (2001). This age, therefore, represents the minimum age of deposition of sedimentary sequences. The Malagarasi Supergroup rocks host significant copper mineralisation although its exploitation is exclusively done by artisanal workers (Leger et al. 2015). Despite its economic significance and having the red beds which are geo-indicators of increased atmospheric oxygen levels during the Precambrian, a few studies have been conducted for these rocks in the basin.

Such studies include the geological mapping and descriptions done in the 1960s (Halligan 1962), a palaeomagnetic and geochronological study done on the Gagwe amygdaloidal lavas (Piper 1972) and the geochronological studies which enabled the stratigraphical correlations of the lithological units and Formations in the Malagarasi Supergroup of both Tanzania and Burundi (Tack 1995, Deblond et al. 2001). In this contribution, we describe for the first time, a geological profile from two different localities that record a possible tsunami or storm occurring during the Precambrian in the Malagarasi basin. Because of scarcity of such information in the ancient sedimentary basins of Tanzania, our contribution will add to the few documented ancient tsunamis described in the literature world-wide. Therefore, our objective is to describe the proposed tsunami deposit of north-western Tanzania and propose the mechanism for their sedimentation during the Precambrian.

Geological setting

The Malagarasi Supergroup represents weakly deformed clastic sedimentary sequences and lavas that appear to have been deposited in isolated basins (Deblond et al. 2001). The sediments are typical anorogenic, fluvial and continental in nature. The basin is bordered by the Archaean Tanzanian Craton to the east, the Palaeoproterozoic Ubendian Belt to the south and the Mesoproterozoic Karagwe-Ankolean terrain to the north (Figures 3 and 4). The Malagarasi Supergroup is litho-stratigraphically subdivided into the following units which are punctuated by an unconformity among them (from bottom to top): The Masontwa Group which includes the Mkuyu sandstones and Mokuba shales; Busondo Group which includes the Malagarasi cross-laminated sandstones that are also characterised by ripple marks, Nyanza shale and Uruwira sandstone; Kigonero Flag Group which includes fine grained sandstones, shales and dolomitic limestones; and the Uha Group which includes he Gagwe amygdaloidal lavas, Ilagala dolomitic limestones and the Manyovu red beds (Halligan 1962, Table 1).

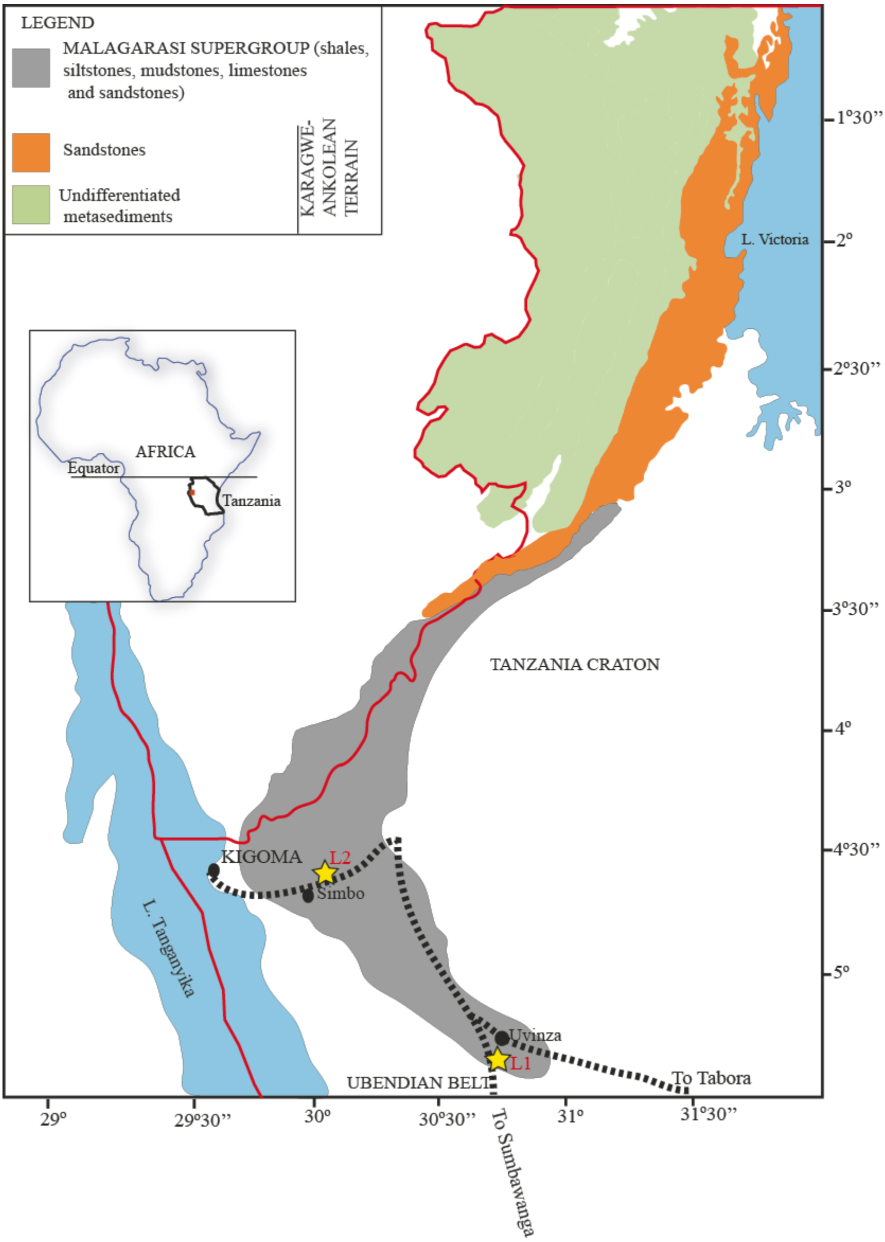

Figure 3: A simplified geological map showing the aerial extent of the Malagarasi Supergroup of north-western Tanzania (modified from Fernandez-Alonso et al. 2012 and Leger et al. 2015). L1 = Locality one; LT2 = Locality two (both shown as yellow stars).

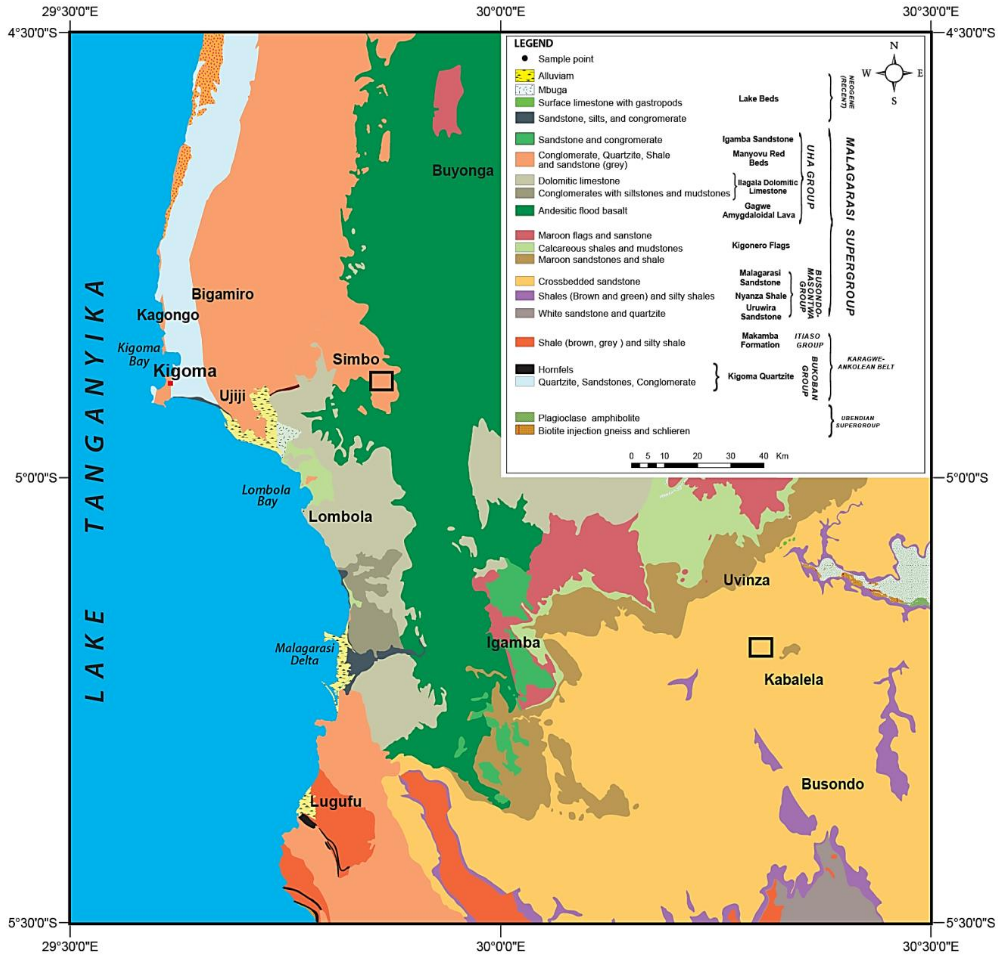

Figure 4: A detailed geological map of the Malagarasi Supergroup. The two studied localities are indicated as squares (map modified from Halligan 1962).

The Malagarasi Supergroup rocks rest unconformably on the gneissic and granitic basement rocks of either the Ubendian Belt or the Tanzania Craton (Deblond et al. 2001). The basin covers a wider aerial extent where it extends up to the neighbouring Burundi in the north-west. According to Tack (1995) and Deblond et al. (2001), the Busondo and Masontwa Groups do not have their correlatives in south-east Burundi. However, the Kigonero flags Group in Tanzania correlates with Musindozi Group in Burundi, whereas the Uha Group in Tanzania is correlated with Mosso and Kibago Groups in Burundi (Table 1). It is in these topmost Groups that the Gagwe lavas in Tanzania whose correlatives in Burundi are the Kabuye lavas do occur. These lavas have yielded ^{40}Ar-^{39}Ar ages of 815 ± 14 Ma (reported for Kabuye in Burundi) and 795 ± 7 Ma (for the Gagwe in Tanzania, Tack 1995, Deblond et al. 2001).

Table 1: Comparative lithostratigraphic column of the Malagarasi Supergroup units of south-east Burundi and north-west Tanzania (after Tack 1995)

SOUTHEAST BURUNDI	NORTHWEST TANZANIA
Malagarazi Supergroup	Malagarasi Supergroup
Kibago Group (865 m) Sandstones, quartzites, shales and basal conglomerates.	
Mosso Group (70-130 m) Silicified dolomitic limestones Kabuye amygdaloidal lava (815 ± 14 Ma) Shaka conglomerate (very local)	**Uha Group** Manyovu red beds Formation (400-600 m) Ilagala dolomitic Formation (150 m) Gangwe amygdaloidal lavas (> 600 m) 813 ± 30 Ma and 795 ± 7 Ma)
Musindozi Group (290-890 m) Dolomites (including stromatolites and cherts) Calcareous shales, sandstones and siltstone Nyangaza basalts Sandstones, quartzites and conglomerates	**Kigonero Flags Group** Fine grained sandstones, shales, limestones and dolomitic limestones
Unconformity upon Burundian Supergroup	**Busondo Group** Malagarasi sandstones, Nyanza shales Uruwira sandstone, Igenda Flags **Masontwa** Mkuyu sandstone, Mokuba shales

Materials and Methods

Field work was conducted between June and July in 2014 along the Sumbawanga-Kigoma highway (Figure 5) where road-cut outcrop exposures aided the documentation and description of geological profiles as well as the lithological facies changes. The two localities (one near Uvinza and the other near Simbo village, Figure 4) were chosen for detailed studies due to their contrasting local lithological assemblages. The vertical and horizontal extents of the exposures were documented in details and photographs were taken for detailed descriptions.

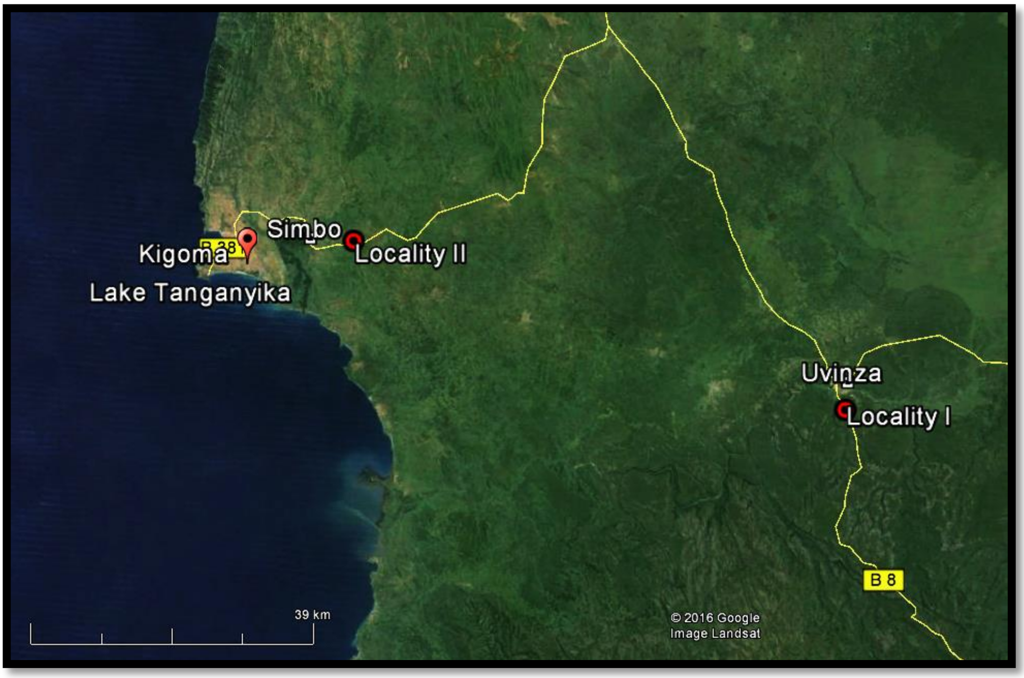

Figure 5: A Google Earth location map showing the geographical setting of the two studied sections.

Results

Locality I - Near Uvinza village

Exposed fluviatile strata in this locality belong to the Busondo-Masontwa Group that characterise the base of the Malagarasi Supergroup. The outcrop at this locality has an overall thickness of between 3 and 10 m that can be traced for nearly 40 m along a road cut and pinches out at the end of the exposure. The outcrop comprises three lithological units (from bottom to top): the frail grey purplish sheared shales (Unit I), the conglomerate layer and the massive cross-laminated sandstones. The basal unit comprises thinly laminated, fragmented micaceous grey-purplish shales. They are highly jointed and sheared characterised with a marked fissility. Localised sand injections are visible within Unit I. The shales are overlain by a clastic supported conglomeratic horizon (Unit II) whose thickness is 80 cm on average. The conglomerate horizon consists of pebbles that range from 3 to 5 cm (Figure 6). The pebbles are rounded and of more or less the same size. The base of Unit II is characterised by a 10-20 mm horizon which is devoid of clasts coarsening upward. Close examinations of the coarser facies revealed sediment injection layers that are chaotically arranged, not in a horizontal manner.

Overlying the conglomerate unit is the jointed massive reddish-brown sandstone (Unit III) whose base consists of a thin clastic–rich conglomeratic horizon (Figure 6). This topmost unit has a maximum thickness of about 4 m. The unit is characterised by cross-laminations at the top section (Figures 6 and 7). None of the units studied in this locality contain fossils.

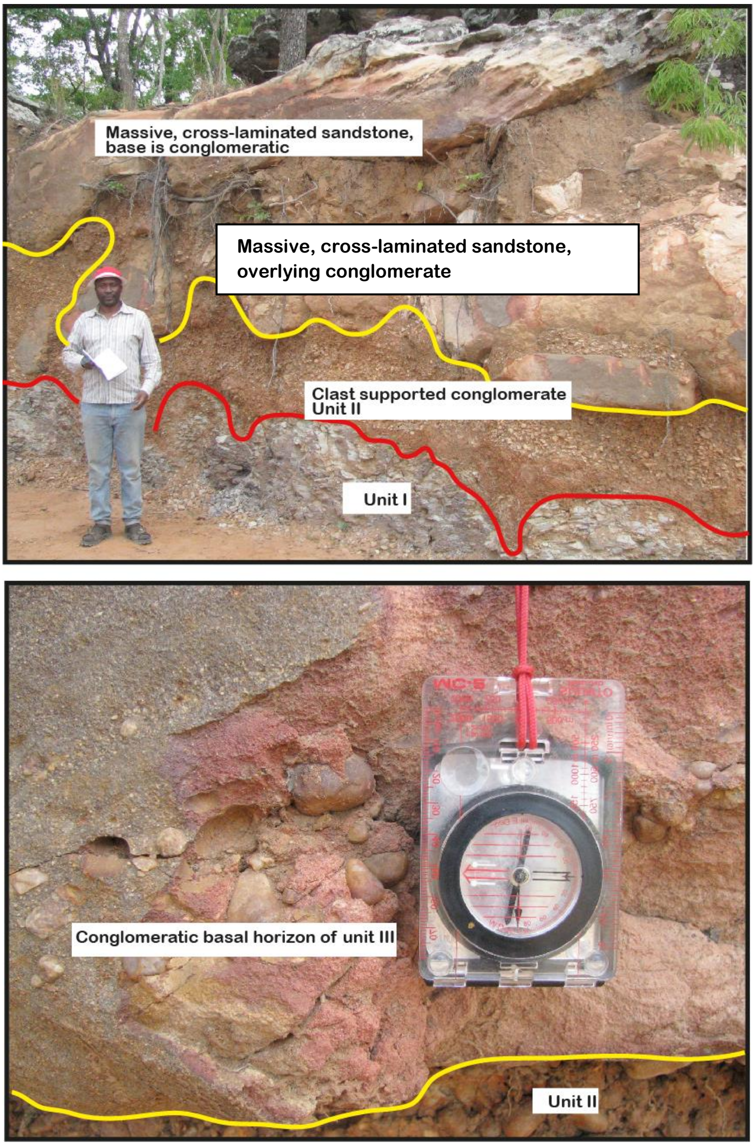

Figure 6: Top: Locality I outcrop showing the lower unit fragmented and fissile grey-purplish shales that are highly sheared overlain by the conglomeratic unit II. The profile is completed by a thick, massive unit of sandstones. The erosional surface is indicated by the red line while the yellow line shows the contact between the clast-supported conglomerates that are overlain by the partly conglomeratic massive sandstone. (Scale: The geologist in the diagram is 175 cm tall). Bottom: A close range photograph of the contact between the unit III sandstones and the conglomerate unit II below it.

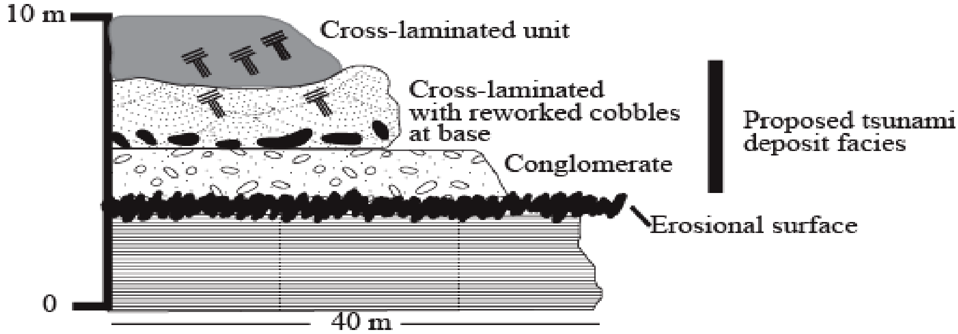

Figure 7: Lithological description of the studied sections at locality I.

Locality II - Near Simbo Village

The deposit is indicated in Figures 3 and 4 and is found near Simbo village, about 20 km from Kigoma town along the Kigoma-Uvinza highway. The outcrop is well exposed along the road cut for about 200 m laterally with a vertical thickness of 10 -15 m (Figures 8 and 9).

The outcrop comprises two important sedimentary units (from bottom to top): the thinly laminated sheared brown shales and thick and extensive conglomerate unit. Like the observations made at locality I, the basal unit at locality II, 70 cm thick on average, is made of brown shales that are thinly laminated and micaceous whose exposure is limited to a few metres and are separated from the overlying thick conglomeratic unit by an erosional surface (Figures 8 b and 9).

The erosional surface can be easily identified by well rounded, clasts of the same size which result in a thin conglomeratic horizon. The topmost unit comprises clasts/pebbles of pre-existing rocks that make up a thick conglomeratic deposit (Figure 8a). The clasts in this unit are of basement rocks (gneissic and granitic), dolomitic limestones and sandstones. These clasts and pebbles are of varying sizes and range from 3 to 15 cm with angular to rounded grain shapes (Figures 8a, c).

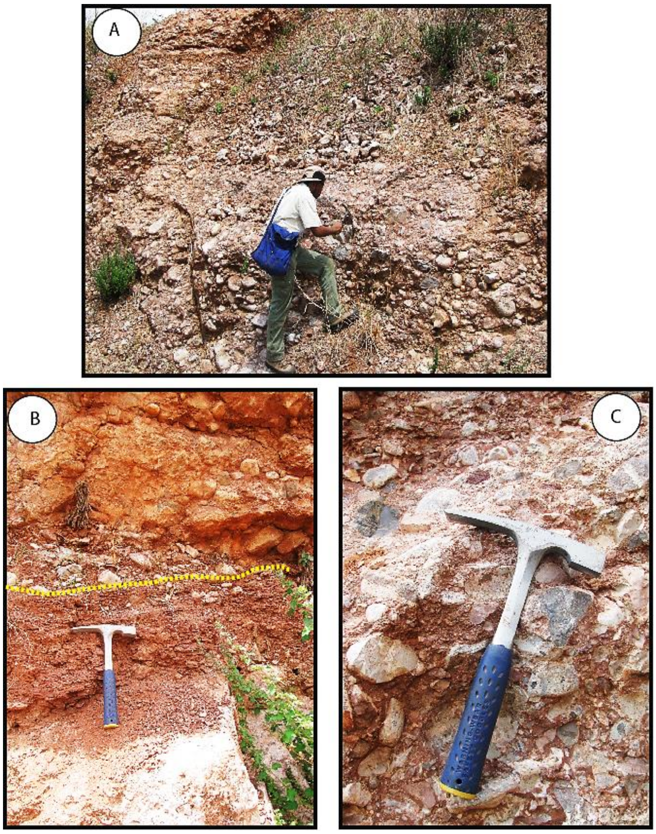

Figure 8: Outcrop documentation. (A) A distance view (4 m) of the deposit at locality II. (B) An erosional surface shown in the yellow dotted line separating the underlying deformed shales and the clast-supported overlying unit above. (C) A close range (0.5 m) photograph of the conglomerate unit with clasts of limestone, sandstones and lavas.

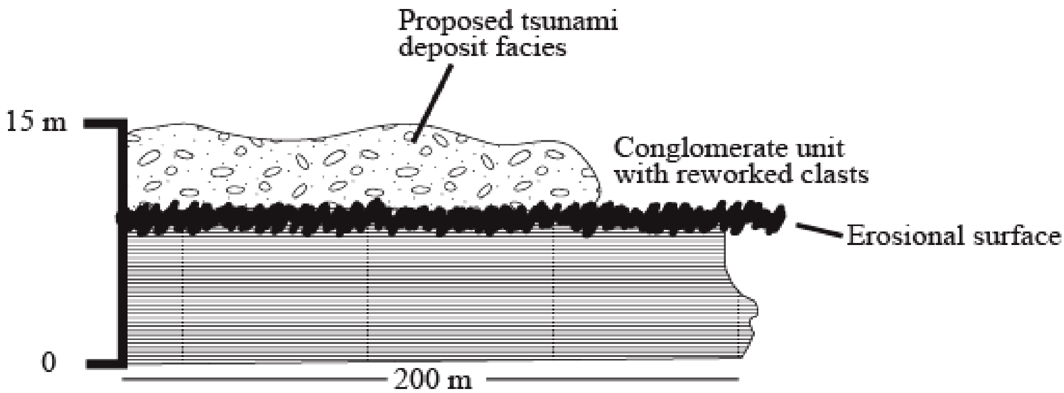

Figure 9: A vertical section with lithological descriptions of the studied units at locality II.

Discussion

Phanerozoic tsunamites are largely characterised by imbricates of organic debris (grass and/or wood debris; Namayama et al. 2000, Shynder et al. 2005), a feature not observed in the two localities. Back-flow or back-wash has been reported to characterise such deposits with other common associated sedimentary features being an erosive base, reworked materials such as clasts and soft sediment deformation structures (Murakoshi and Masuda 1991, Smoot et al. 2000, Takashimizu and Masuda 2000, Du et al. 2001). Such tsunamis-related events that can transport boulders of up to 15 m offshore to a distance of up to 2 km (Paris et al. 2010).

Deposition of the lower shale unit in both localities is suggestive of low-energy clay sedimentation (Murakoshi and Masuda 1991). Unlike the tsunamites characterised by imbricates of organic debris, the deposits at both locations show that, there exists an erosional surface immediately before deposition of the clastic supported conglomerate, and is attributed to deposition lag in both cases. The observations documented in this study do not support a uniform sedimentation regime for the two facies. The abrupt and sporadic changes of contrasting facies in these parts of the basin are unique phenomenon which suggests high energy turbulence to account for the conglomeratic unit being overlain on shales. The two localities are ca. 50 km apart, although they may be contemporaneous but contain contrasting intraclasts which mimic the local geology in the two sites. The sedimentological profiles documented in this study clearly suggest discrete, abrupt changes in depositional energy between the two facies: the low energy for the shales at the bottom and high energy for the overlying conglomerates. The observations made for the two outcrops suggest a high energy event that transported clasts and pebbles together with sediments to deep water environments that are characterised with finer sediments deposition. The horizontal extent of the outcrop deposits at both localities lasts up to a few hundred metres in length (40 m at locality I and 200 m at locality II) and this is suggestive of localised ground tremors that led to a sudden change in the depositional wave energy. Lithostratigraphic descriptions in Figures 7 and 9 may suggest that the two deposits may be laterally related in origin although differing in the type and size of intraclasts (Murakoshi and Masuda 1991, Figures 6 and 8).

Because the deposits extend for only a few metres and given their older age, it is thus difficult to characterise downslope facies changes and such information is likely to have been wiped-out by possible surface geological processes making it difficult to account for tsunami *versus* storm processes. We hypothesize that the high energy waves were triggered by either a tsunami or storm caused by earthquakes during the Precambrian in a scenario analogous to that proposed in Alsop and Marco (2012) on modern (Pleistocene) tsunamites (Figure 10).

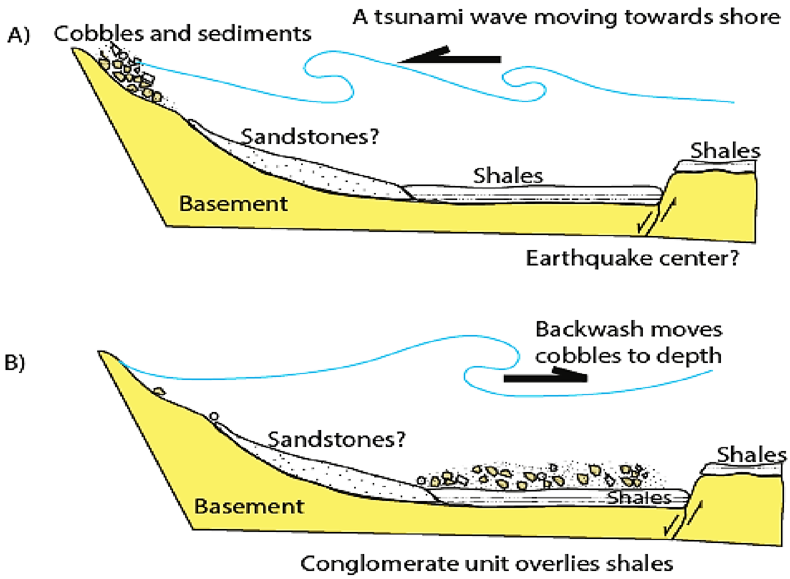

Figure 10: Cartoons illustrating the possible mechanism of the deposits in the current study. (A) An earthquake triggers high amplitude water waves that travel to the shore. (B) Backwash waves transport pebbles and sediments to great depth, overlying the low energy facies shales.

We could not document any faulting evidence in both localities; such features have been reported to cause earthquakes that have the potential of triggering tsunami backwash waves capable of transporting huge clasts towards offshore environments (e.g. Le Roux 2015).

Conclusion

Preliminary evidences for tsunami or storm induced deposits are reported from two separate localities within the Neoproterozoic Malagarasi Supergroup of north-western Tanzania. At both localities, there is striking co-existence of low energy deep water facies and high energy facies which is indicative of abrupt changes in sediment depositional energy in the basin. The basal fine grained facies in both cases imply deposition in deep shelf environments which is contrasting with the overlying poorly sorted units that are consistent with deposition in high energy conditions. The abrupt and sporadic shifts in depositional facies characterised by interbedding of clast-pebble conglomerate with alternating shale are uniquely phenomenon in the basin. We interpret this association, together with the characteristic erosional surface above the underlying shale units, to be a result of backflow by an ancient tsunami or storm that was triggered by an ancient earthquake.

Acknowledgements

We acknowledge the financial assistance we received from the Swedish International Development Agency (Sida) (Contribution Number 75000515) through the “Geology and Mineralization of the Precambrian volcanic and associated plutonic rocks of SW Tanzania” project under the Earth Science Programme of CoNAS, University of Dar es Salaam (2009–2013 extended to June 2015).This assistance enabled us to conduct extensive fieldwork in the Malagarasi basin of NW Tanzania. We acknowledge the anonymous referees and the Chief Editor Prof. John Mahugija for insightful reviews of the manuscript.

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