Malagarasi River Delta Sedimentology: Evidence of Lake Level Changes in Lake Tanganyika

Students: Kate Shick and Kathy Flaccus
Mentor: Dr. Andrew S. Cohen

Introduction

The sediments of the Malagarasi River delta cradle the history of a dynamic river. In relatively recent history, Lake Tanganyika has undergone both transgression and regression, depositing new sediments, altering the delta, and changing the course of the river. Additionally, the river, like all of Lake Tanganyika, is greatly affected by the annual cycle of wet and dry seasons, alternating flood conditions with low flows. We were interested in the dynamics of the Malagarasi delta formation, and chose to study the depositional history of the Malagarasi River delta. With an area of 130,000 square kilometers, the Malagarasi River has the largest watershed of all the rivers flowing into Lake Tanganyika. (LTBP, 1993). The annual flow of the river is gauged at Mberagule to be 6.9 cubic kilometers per year. The river begins near the Burundi border, and flows for 475 kilometers before reaching Lake Tanganyika. (Cohen, 2000) It passes through Precambrian crystalline rocks of Archaean and Proterozoic ages, known as the Dodoma Belt (LTBP, 1998). Locally, agriculture and deforestation increase sediment loads in the river. For example, during the study period we noted fires nearly every day, and on at least one occasion, the fire was directly adjacent to the river. Approximately 80 kilometers from the mouth, the river flows into the Malagarasi-Moyowosi swampland. This acts as a filter, straining out sediments and organic matter. For this reason, the river carries less of a sediment load than might be expected.

The river's tectonic setting also influences its geomorphology. The river enters the lake on a platform side of a half-graben, forming a relatively large delta. According to Cohen (1990), platforms may respond to: 1) slow subsidence, 2) low gradient, 3) absence of structural control, and 4) rapid sediment input by frequently switching lobe position. All of these conditions exist on the Malagarasi River delta. These characteristics make the Malagarasi River delta different from axial deltas like that forming from the Ruzizi River, where the delta is relatively narrow. Tiercelin *et al* (1992) summarized the sedimentation in the lower reach of the Malagarasi River as low gradient, allowing meandering streams to develop. In the delta front, the sedimentation is strongly controlled by coastal processes, forming sand bars and beaches that sometimes lead to the formation of shallow lagoons and swamps. This general description describes the current delta condition and allows us to interpret older deposits in the deltaic system.

Different researchers have investigated lake levels on Lake Tanganyika. Periodically, factors such as climate change have caused up to ~100 – 200 meter changes in lake level in the African rift valley (Johnson, 1992). Hutchinson (1975) reports sublacustrine valleys at the mouth of the Malagarasi. These valleys, which direct the inflow of sediment-laden water, were formed by erosion when lake levels were low, (LTBP, 1993). In more recent times, historical accounts from the late nineteenth century record a lake level that is about ten meters higher than it is today. This was caused by a temporary logjam on the River Lukuga, the only outflow river, causing the lake level to rise approximately 10 meters. When the dam broke up, the lake level quickly fell to its bedrock sill level. Researchers studying annual and short-term changes in lake level find changes about one meter fluctuation. (Gillman, 1933, Edmond et al, 1993). It appears that the magnitude of lake level change depends upon time scale, with a short term change of 1 meter, a periodic change of ten meters, and a long term change of hundreds of meters.

Our goal was to map the sediments exposed along the river in order to understand the depositional history of the river delta. We were particularly interested in determining the relative frequency of high lake stands, and the sequence of lake transgression and regression. If sedimentation rated have increased because of human activity in the watershed, it may be possible to see some signal in the deposits of the delta. We chose a study area beginning six kilometers above the river mouth and extending downstream for three kilometers. This includes the furthest upstream locality of lacustrine mollusk fossils, which indicated the lake had been at least that high. We continued the study downstream until the fossil beds disappeared under the river level.

Methods/Materials

Field methods

We examined a series of 21 measured sections within a three kilometer stretch of the Malagarasi River. Nineteen of our sites were located on the south bank of the river, while two sites were located on the north bank. Each site was assigned a GPS point and located on a map. We measured the entire vertical stratigraphic section at each exposure, measuring thickness and describing lithology for each distinct unit. The lithofacies we identified allowed us to correlate units in separate sites. At representative sections, we collected sediment samples to analyze for total organic carbon (TOC) and total carbonate carbon (TIC), grain size, and fossil content. If mollusk fossils were visibly evident within units, we noted species composition and articulation.

Laboratory Analysis

Total organic content/carbonate

We used loss on ignition measurements for two burn temperatures to calculate TOC and TIC. We placed dry, homogenized samples of known weight in a Thermolyne 1400 muffle furnace and burned for two hours at 550° C to remove organic matter. After cooling in a dissector, the samples were re-weighed, and we used this weight to calculate total organic carbon. To determine total inorganic carbon, we placed the samples back in the furnace and burned them at 925°C for four hours to remove carbonate. After cooling and weighing these samples, we used the difference in weight to calculate total inorganic carbon.

Grain-size analysis

From two sites we collected samples for a grain-size analysis. If the samples appeared to be aggregated, we suspended them in water and froze them to defloculate the clay aggregates. When all aggregates were dissolved, samples of known weights were wet-sieved through 5 sieve sizes to determine their grain-size composition, determining the ratios of different sizes for each unit. At other sites, a more streamlined sieving system was employed, using just sieve sizes 120 and 230, and otherwise following the same protocol.

Paleoecological Analysis

We examined our sieved samples for microfossil content, including ostracods, sponge spicules, and insect parts. If sponge spicules were present, a known weight of sample was examined to determine relative spicule density between samples. Presence or absence of charcoal was also noted. In three samples, we collected charcoal to be used in ^{14}C dating. In conjunction with the macrofossil analysis, we described the micro-characteristics of the sediment particles within the samples, such as angularity and mineral composition.

Results

A description of lithofacies is included in Table 1. This includes physical description, fossil presence, grain size analysis, TOC, TIC, and interpretations. A strip map showing relative position of these units is included with this report (Figure 1). Interpretations are shown in the form of a cross section in Figure 2. Additionally, we have included a graphical representation of grain size for four sites in Figure 3.

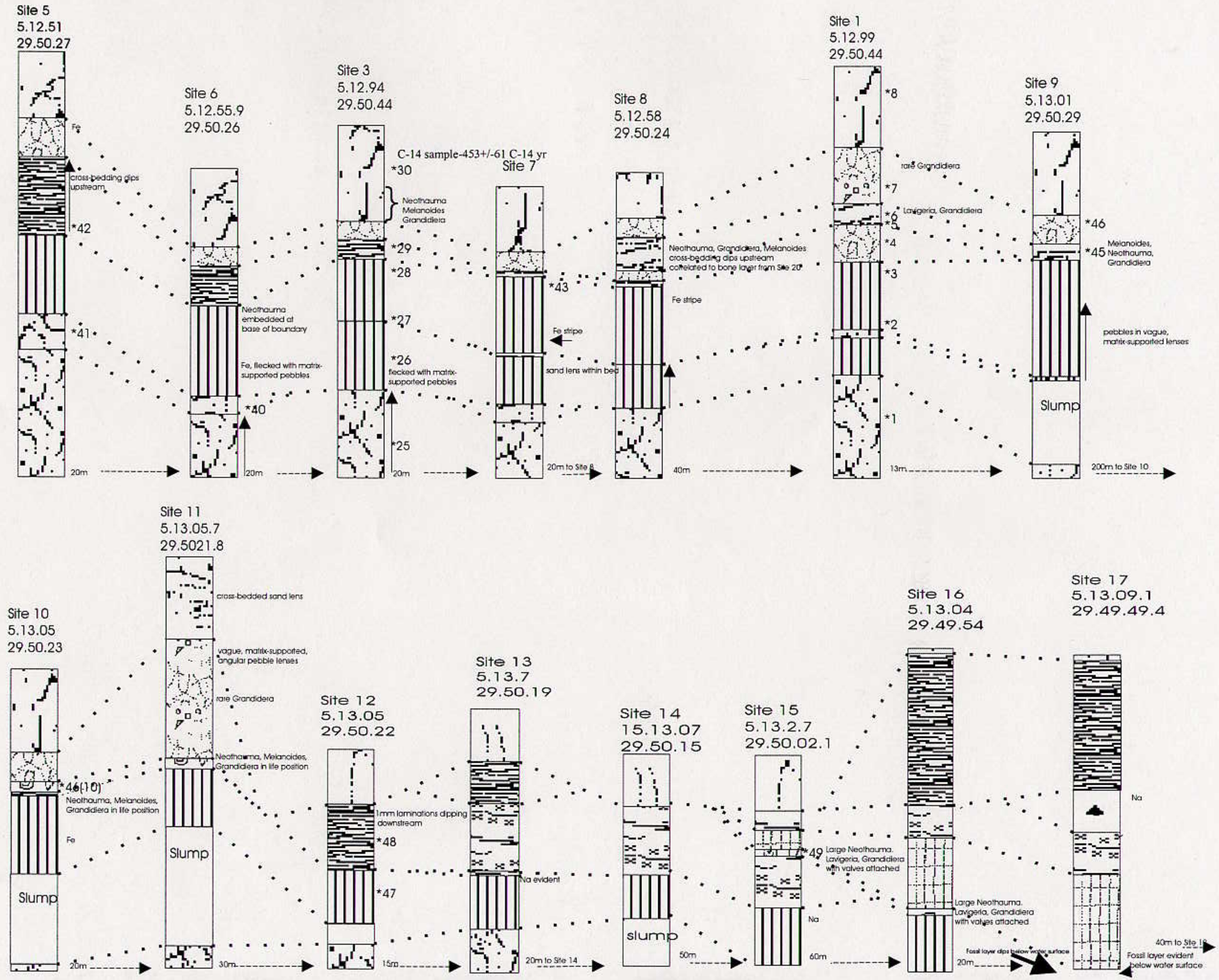
Discussion

There are four distinct depositional facies that can be seen on the upstream cross sections. These can be interpreted to have formed as: 1) lower paleosols, 2) fluvial flood plain deposits, 3) sandy deltaic deposits, and 4) lake deposits. The facies generally show a downstream transition from a fluvial dominated system to one dominated by lacustrine processes. The cross sections are presented in Figure 1.

Table 1. Summary of defined units, their characters, and depositional interpretation

Unit	Samples	Description of unit	Fossils present (*denotes life position)	ostracods	sponge spicules	charcoal	insects	mean % sand	ratio coarse: fine sand	mean % TOC lost	mean % carbonate lost	Interpretation
topsoil	9, 14, 30	blocky, often sandy, high root content, developed soil horizons	*Neothauma* (N), *Melanoides* (M), *Grandidiera* (G)	one unidentified	y	y	y, Trichoptera	66	1.8:1	4.15	1.12	lacustrine pedagically altered soil
compressed soil	3,4,7,8,46	dark, blocky, below topsoil	N,M,G*	*Mecynocypria opaca, Mecynocypria sp., Gomphocythere downingi, Tanganyika cythere*	y	y	y, Diptera	57		6.46	0.32	lacustrine pedagically altered soil
cross-bedded sand	29, 44,48	medium-fine sand, dipping in both direction 1-3cm laminations	N,M,G		y	y	y		.6:1			deltaic sandbar
chocolate brown mud	11,12	mottled, clay-rich, Na leaching		*Mecynocypria opaca*	y	y	y	19		18.95	0.32	shallow water lagoon
massive sand	13,36	no cross-bedding, fine-grained		*Tanganyika cypridocus depressa, Gomphocythere downingi*	y	y	y	100	1.8:1	2.77	1.39	lake-deposited massive sand
cobbles	40,41	matrix-supported, mixture of cobbles and pebbles, often grading upwards			y	n						fluvial cobble deposit
blocky clay	10,35	irregular blocks, Fe and Na mottling			y	y			1.9:1	8.13	0.74	abandoned river channel
shell horizon	5,6,33,34, 45,49,50	sand or mud supported	N,M,G*,*Lavigeria* (L)		y	y	y	49	4.2:1	2.47	2.01	beach/lake deposit
massive brown muddy sand	2,26,27,32 ,28,42,43, 47	blocky, mottled with Fe streaks, flecked with pebbles, often grading upwards, intermittent sand or pebble lenses	N	*Gomphocythere kurta, 2 Mecynocypria sp., Mycynocypria emaciata*	multiple	rare	y	97	3.8:1	3.48	1.15	floodplain deposit
coarse sands	31	sand, gravel, mudball mixture; matrix-supported, uncemented			y	y		79	8.7:1	2.51		fluvial beach deposit
basal muddy fine sand	1	mottled, clay-rich, unstructured, no visible grading, often forming a shelf at water-level			n	n		57	1.8:1	3.32	1.76	fluvial soil deposit

Figure 1. Stratigraphic sections for each site sampled



Paleosols

The lowest (and presumably oldest) section exposed is a paleosol, which appears at the base of the most upstream deposits and is called the basal fine muddy sand on cross sections. Because of secondary features due to soil formation, we were unable to determine if the sediments were originally derived from the lake or the river. No fossils, insect remains, ostracods, charcoal, or sponge spicules were found in this unit. Downstream this facies disappears under the river level by Site 14.

Fluvial flood Plain Deposits

On top of the paleosol is a flood plain deposit, most likely of fluvial origin. This sandy unit, called massive brown muddy sand, appears to be sorted, showing at least two visible episodes of deposition. Lacustrine ostracods were noted in this unit, although it is possible some were transported by birds. At the contact between the paleosol and the flood plain deposit, there are intermittent lenses of gravel that extend laterally for approximately twenty meters and pinch out at both ends The unsorted characteristics of these lenses indicate a high energy system, perhaps as would exist in a debris flow situation. There are several of these lenses, and they are not seen downstream of Site 1. The texture of the massive brown muddy sand facies becomes coarser downstream, and it drops below river level near Site 16. This is on-lapped by the sandy shell layer with mollusk fossils indicating either lake stand or inter-deltaic conditions. The contact between these units is a sharp erosional surface.

Proceeding downstream we observe what appears to be an abandoned distributary channel filled in with fine sediments, identified on the stratigraphic sections as blocky clay sand. Horizontally, the channel pinches out into a small coarse sandy unit that may have been a beach deposit. Downstream we see shells at this same position, indicating lake stand, which would be expected. We see similar morphology today in a channel directly north of the current mouth, the outlet of which is blocked off by beach deposits. A single AMS ^{14}C date on organic matter from this deposit yielded a post-bomb date (i.e. this deposit and all deposits higher and downstream from this are post 1950s modern delta deposits).

This depositional period represents a time when the river was depositing flood plain sediments upstream, whereas downstream the deposits are dominated by lacustrine environments and are more complex. Erosion may have removed the floodplain deposits downstream, and what remains are evidence of a cycle of lake transgression and regression with shell lag, abandoned channels, and beach deposits. The highest lake level during this period was about 5 meters above the current level, and the margin was about 4.5 kilometers upstream from the one we see today. These highest lake beds may represent high stands from the early 1960s El Nino year when maximal 20th Century flooding occurred in the lake.

Sandy Delta Formation

The third depositional period shows the delta transgressing upstream, so that the entire horizontal reach is a mosaic of sand bars, shallow water, shell beaches and lake deposits. In the most upstream reach, cross-bedded sands are exposed, representing a sand bar or delta environment. This deposit looks very much like what we see in the sand bars of the lake margin today, and may represent a period of lake-level stability and progradation of the river. The cross bedded-sand facies changes about eighty meters downstream into beach deposits, containing shells of *Grandidiera ssp, Melanoides admirabilis,* and *Neothauma ssp*. This suite of fossils represents a typical lake margin assemblage (Brown, 1980). Proceeding downstream the facies changes into another sandbar, followed by another layer of shell fossils further downstream. In this layer we found the skeleton of a large vertebrate animal about 1.5 meters from river level near Site 20 on the south bank. This animal appeared to be complete. Although we were unable to completely excavate and identify the animal, it may provide some very interesting insights upon further investigation. The ribs appeared larger than cow ribs, and there is much speculation about what the animal could be. Theories about its identity range from hippopotamus to white bearded gnu. What was especially interesting is that the fossil was imbedded in a thin layer of loose sand and shells, with shells inside the rib cage of the skeleton. Bits of bone and charcoal were collected at this site to be dated using ^{14}C. The progression of

Figure 1 continued

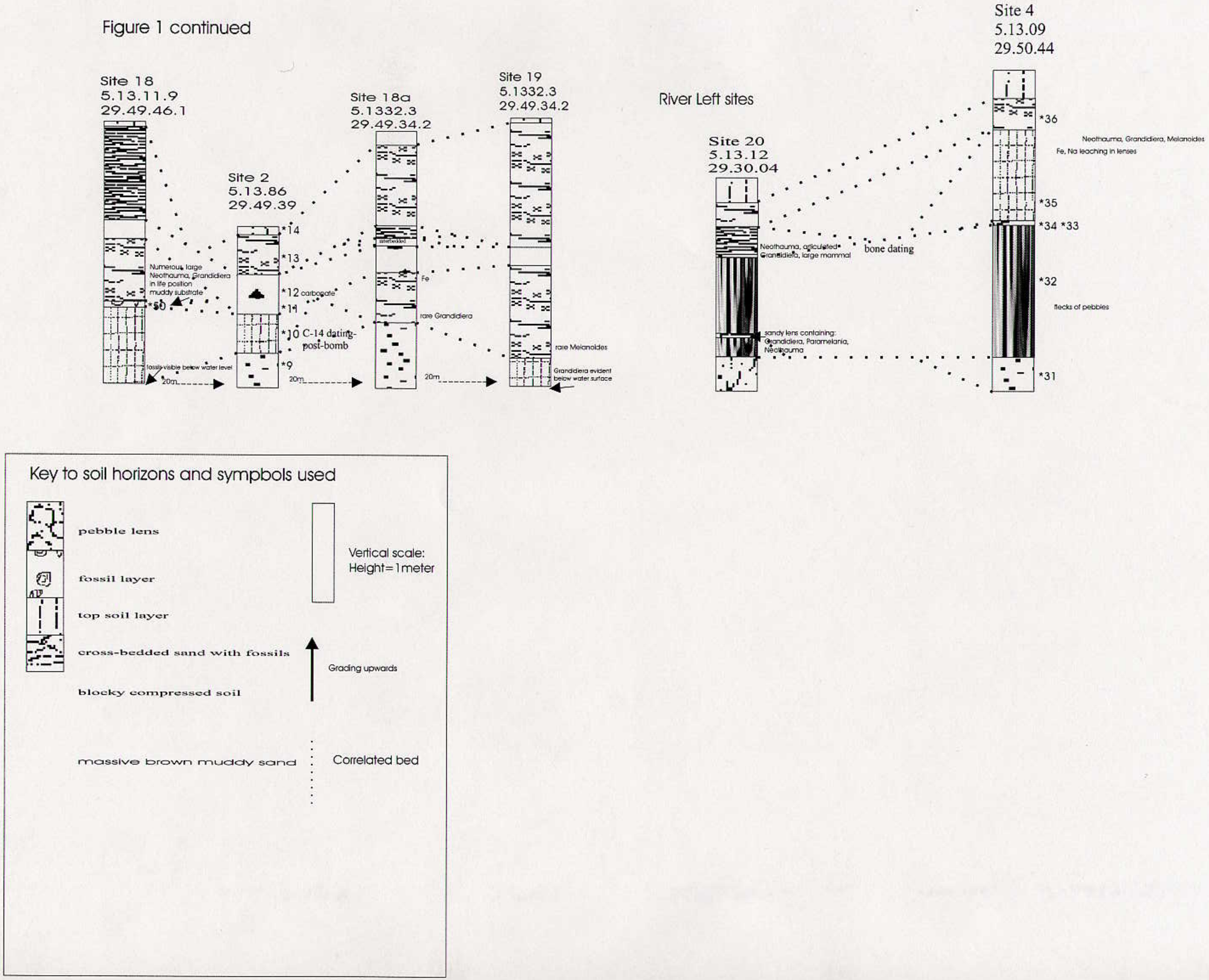


Figure 2. Schematic interpretation of the recent depositional history of the Malagarasi River

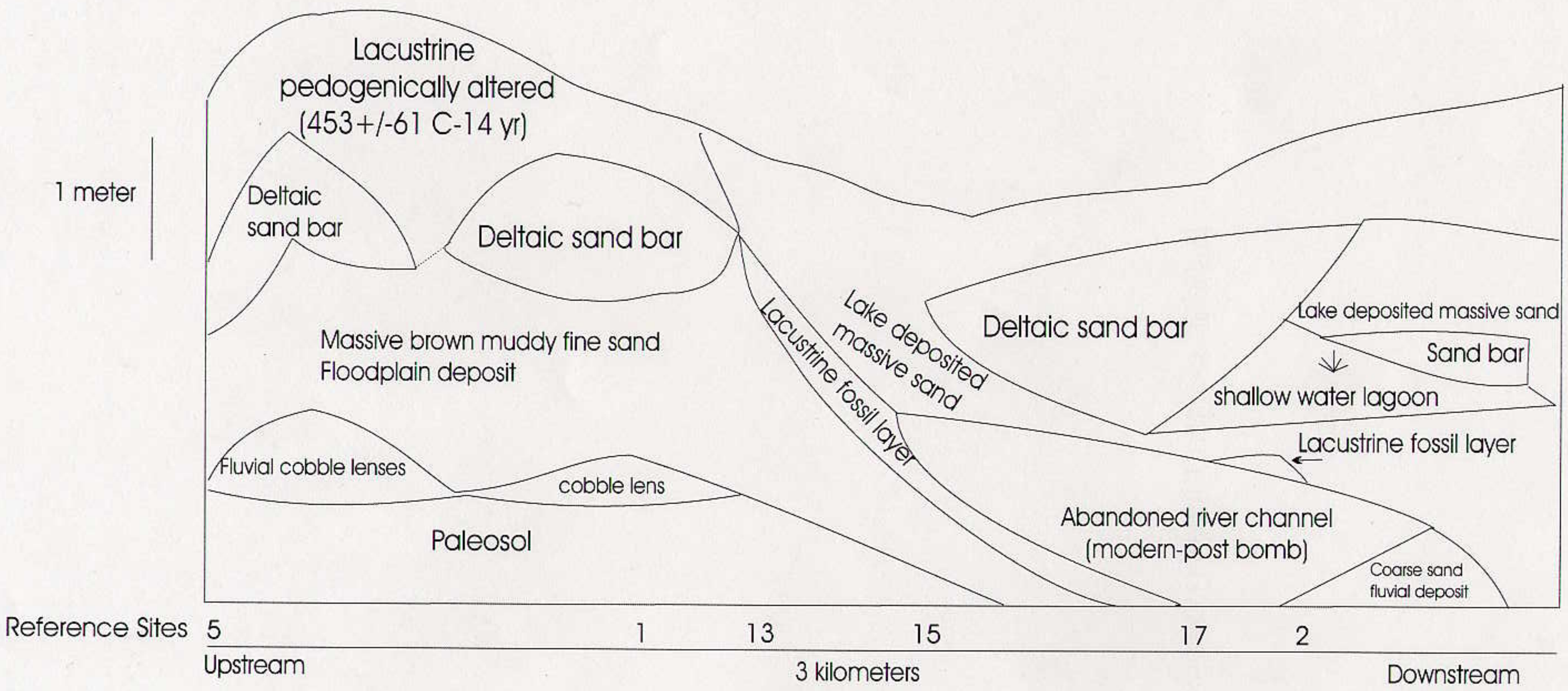
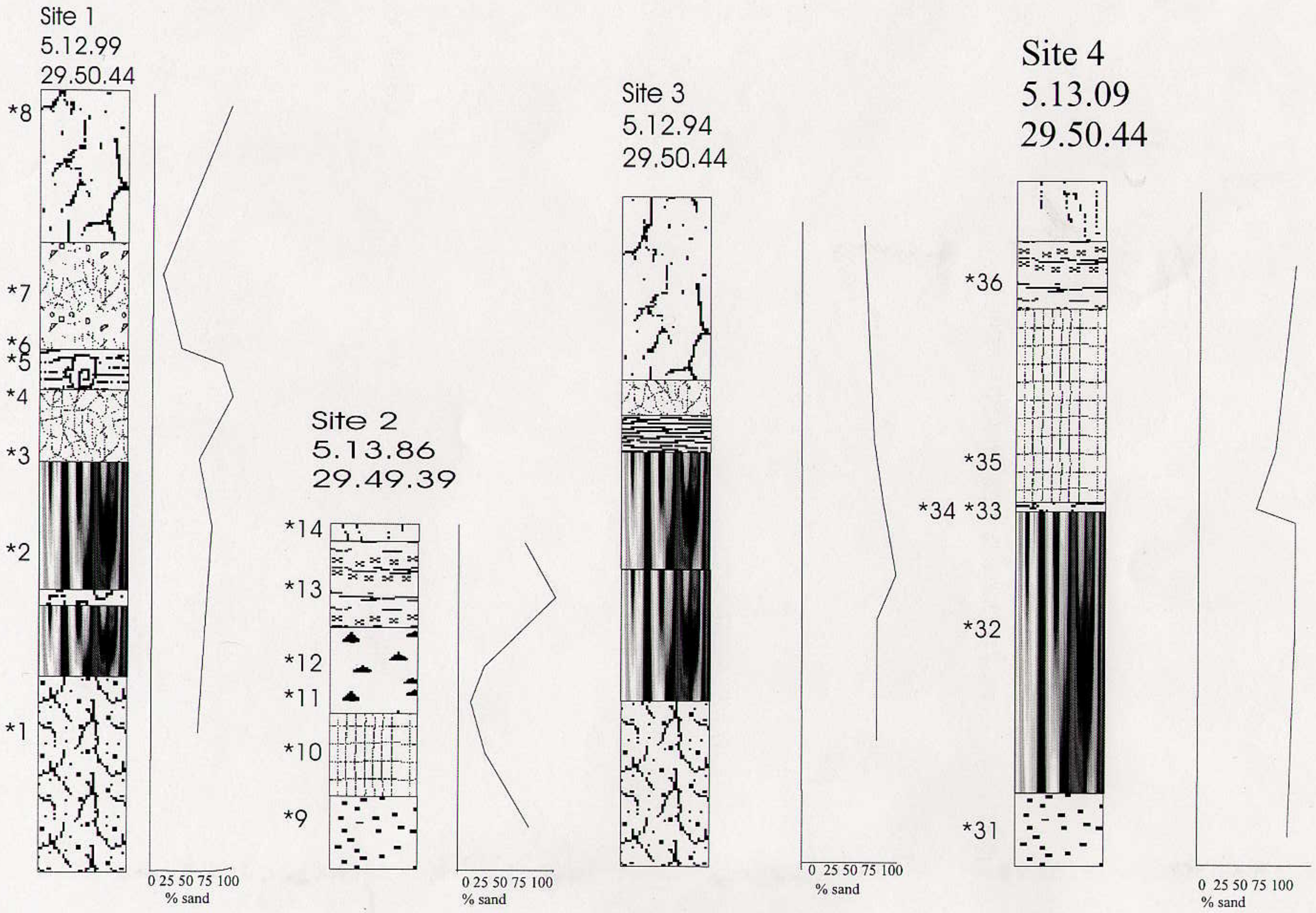


Figure 3. Percentage of sand in soil profile for Sites 1, 2, 3 and 4.



this entire facies, with upstream delta deposits grading into shallow water and sand bar environments, are an indication of a mosaic of delta and lake margin environments, such as now seen at the lake margin. This period indicates a maximum lake level approximately five meters above current levels, and deltaic formations extending as far upstream as the lake transgression. Above the delta deposits in the upstream reach of the cross sections, we see lacustrine deposits that have undergone pedogenesis. This represents the highest transgression of the lake seen in these sections. At this time, the lake was at least six meters above the current level, and the shoreline 6.5 kilometers upstream from the current mouth. A single AMS ^{14}C date on organic matter from this horizon yielded an age date of 453+/-61 yr BP, suggesting that this deposit records the lake high stand that continued at least till the mid 17th Century (S. Alin, pers. Comm.., 2001) and ended prior to the 18th-19th Century low lake level. Downstream, we continue to see evidence of lake level and sand bars, apparently what we see today at the mouth of the river.

Summary & Conclusion

Our stratigraphical interpretation supports a hypothesis of two lake transgressions in the recent past, with lake level reaching a peak of six meters above current height at its most recent transgression. Our interpretations are based on a preliminary investigation, and a more detailed analysis is warranted. Due to time constraints, we chose to focus more time on the interpretation of field conditions than on laboratory analysis. Grain size analysis could be completed on each marker bed for better correlation of beds. The use of a Polaroid camera to take photos would allow an immediate comparison of structures and beds, and would help with report presentation and interpretation. Also, we had difficulty getting consistent readings from the GPS because we used different GPS units on different days. Therefore, we feel that our GPS readings may be slightly inaccurate.

There is much research still to be done in this area, and our study raised more questions than it answered. The delta is much too dynamic to show effects of humans on the watershed. It does not have steady deposits that could record a change in sedimentation rates. How old are these deposits, when did the lake transgression occur? Is it possible to see evidence of older lake transgressions in upstream deposits, and to determine if there is a pattern of transgression and regression? Some of these questions may be answered when the ^{14}C dates are available.

We also recommend that stratigraphic mapping should be continued upstream. Preliminary investigations at sites 12 kilometers upstream show interesting clay-rich deposits which contained lake ostracod species, indicating much higher lake levels than were documented in our study.

In conclusion, we feel that the results of our investigation define some of the parameters of lake transgression and regression, but further detailed study is necessary.

Acknowledgements

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