Using Detrital Zircon Age Distributions to Corroborate Evidence of Early Holocene Megafloods

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BRIEF. Zircon grain age distributions provide information on the origins of early holocene megaflood related sediment.

ABSTRACT. The Tsangpo Gorge megafloods of the early Holocene, caused by the outburst of glacially dammed lakes, had the carrying capacity and velocity to change the flow path of the Brahmaputra River at its confluence with the Ganges River in Bangladesh. The historic flow paths of these rivers have ramifications on the current health of the Bangladeshi citizenry due to the presence of arsenic-laden groundwater associated with the flow pathways. A river's historic flow path identifies groundwater sources which are contaminated with arsenic. In order to better characterize the flow paths and origins of megafloods, sediment layers were sampled from a depth indicative of the Pleistocene/Holocene boundary and at locations along the hypothesized flood spill path. Zircon grains from these samples were analyzed for their ages. Sediments were chosen from three potentially flood-related locations and three control locations. Zircon grains were separated from the samples using magnetic and heavy liquid separation procedures. The uranium to thorium and lead ratios of each grain were analyzed using laser ablation mass spectrometry. Young (10-50 million-year-old) grains were found in flood related sediment samples, which is consistent with Tsangpo Gorge zircon populations, but were not found in control samples. This signifies that the potentially flood related samples did indeed come from the Tsangpo Gorge flood events.

INTRODUCTION.

During the late Pleistocene (~15-11 thousand years ago), the annual patterns of the Bay of Bengal monsoon system began to more closely resemble its modern cycles [1]. The added moisture from the monsoon system promoted the expansion of previously existing glacial systems in the Himalayan Mountains. As glaciers expanded, they periodically impounded river channels, which back flooded to form glacial lakes. These lakes were common features at elevations above 4,500 - 5,500 meters across the globe as evidenced by the sedimentary record of glacial lake outburst floods [2, 3] Similarly, sedimentary evidence of glacial lake outburst floods (GLOFs) has been noted in many river systems [3]. Along the northern stretch of the Brahmaputra River, within the Yarlung Tsangpo Gorge (Fig. 1), one such glacial system expanded, and blocked the Tsangpo River flow. This blockage back flooded the area to create an immense glacial lake which was estimated to hold ~800 km^3 of water [4]. The water often breached the ice dam, causing tremendous freshwater floods, with water moving at around 5 x 10^6 m^3/s (25 times the current flow of the Amazon River). This lake is theorized to have filled and drained dozens of times during the early Holocene, sometimes producing catastrophic floods.

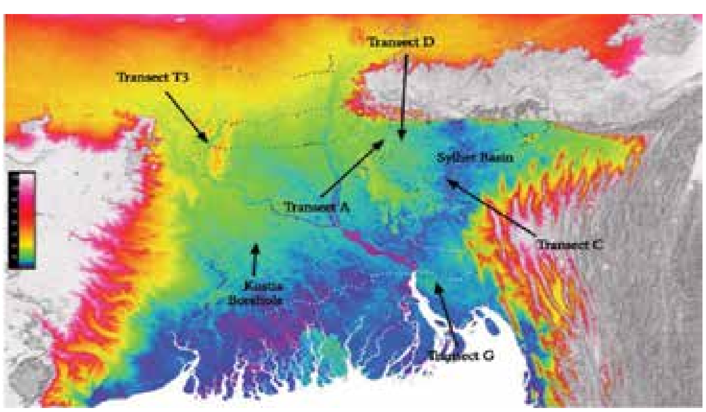

Figure 1. Elevation map of Bangladesh with salient transect and sample locations marked.

These floods leave a trace in the sediment layers of the Bay of Bengal as a layer of sediment is associated with each monsoon cycle. The additive effects of these events creates an illustrated history of the river's flow paths based on the mineral composition of the sediments. These sediment layers contain evidence of sudden events marked by a shift in the grain size of sedimentary particles, or a shift in the mineral composition of the layer. Megafloods like those of the early Holocene were events that would create a drastic visible change in the layers.

The floods agglutinate sediment layers with identifying characteristics. Studies have shown that sediments associated with the floods share the high strontium signature of the Tsangpo/Brahmaputra river, at >140 ppm [4]. Flood-related sediment layers are also typically sandier than surrounding layers, as the higher velocity of the water flow and volume can carry larger and coarser grains. These floods are associated with early Holocene, around 11,000 years ago. The floods leave traces at the Pleistocene/Holocene boundary, which is identified by radiocarbon dates in some locations [2] and a visual analysis of weathering. These identifying characteristics are beneficial for determining broad information about the flood, such as the source basin, or its strength.

Because many previously-used methods are based solely on Stokes' Law, a principle of physics defining how particles settle in liquid, the addition of an unrelated identifying characteristic of the floods could help to produce a more complete understanding of the origin of the floods, and provide evidence of the floods origin and flow. Because of their ability to withstand weathering, their relative abundance, and their ability to record time, the age distribution of zircon crystals has proven to be a useful indicator of source geology [4]. Zircons form under extreme heat and pressure and, during their formation, they include small amounts of uranium [5]. Because uranium has a known half-life, the age of zircon crystals can be calculated. Distinct zircon age distributions within flood-related sediment layers (as opposed to non-flood-related layers) would serve as evidence that these floods tended to preferentially erode along steep rock faces, instead of the already eroded channels of typical river flow.

MATERIALS AND METHODS.

Identifying Flood-Related Samples.

Possible flood-related sediment samples were chosen based on a variety of shared characteristics. Samples were chosen along the flow path in the Sylhet Basin, which due to its topography is a likely overflow zone, should a flood come down the Brahmaputra river channel. Samples with distinct lithology differences from the sediment above and below were chosen, marking an event or change to the system. These changes were marked at transitions from mud layers (with grains of <62 μm) to sand layers (grains between 62 μm -1000 μm). These samples were also chosen from depths that are concordant with the very early Holocene, around 11,000 years ago, when the floods took place. The dates were, in some instances, confirmed using radiocarbon ages from organics found in the sediment. Age is also inferred from lithography changes between Pleistocene layers, which are highly oxidized and orange to red in color, and Holocene layers, which are less oxidized. Finally, the presence of >140 ppm of strontium confirmed that the sample was originated from Brahmaputra overflow and not primarily off of the Shillong Massif to the east. We chose six samples, four of which are flood-related. The flood-related samples are G145-90, A088-43, D072-49, and C065-49 (Fig. 1). The non-flood related samples are T3094-23 and Kustia 33-49 (the Kustia sample originated from a single borehole that was sampled in previous research).

Separating Zircons.

Zircon grains were initially enriched in the sample using a low power magnet to pull off the most magnetic fraction of grains, generally magnetite. After this, a heavy liquid separation procedure using LST (lithium heteropolytungstate) was used to concentrate minerals with a density of greater than 2.82 g/mL together. Both the dense and the light fraction of each sample were saved, rinsed, and dried overnight. After the heavy liquid separation, the samples were run through a Frantz magnetic separation to further concentrate zircon grains together. After this phase, the zircons were handpicked under an optical light microscope and mounted onto epoxy wafers.

Imaging Zircons.

A scanning electron microscope was used to image and map the locations of distinct zircon grains on the epoxy wafers. Secondary electron images were taken of each wafer as a whole, as were cathodoluminescence images of 2 - 3 zircon grains from each sample. Laser ablation mass spectrometry was then used to measure both the trace element amounts and isotope ratios within each zircon grain.

RESULTS.

Variations in zircon grain quantities and morphologies are associated with weathering and river conditions, and are not flood specific characteristics. Mounts T and K are comprised of non-flood-related grains, and Mounts G, C, D, and A are comprised of flood-related grains. Mounts G, T, and K have the most zircon grains, with 17, 29, and 16 grains respectively. In each of these mounts, 50-67% of the grains picked are not zircon (Fig. 2). In these images, the brightest (most white) grains are zircon, and the more grey grains are primarily feldspar and apatite.

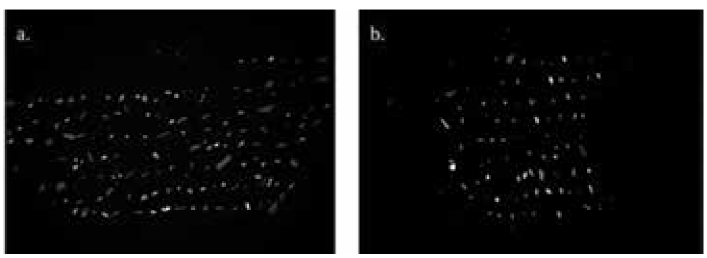

Figure 2. Secondary electron images of all grains on Mount T (a) and Mount G (b), which were used as a reference map during laser ablation mass spectrometry. The brightest grains on the map are zircon grains, the others are not. Each of the zircon grains was laser ablated during mass spectrometry to determine its age. The presence of other types of grains on these mounts is not uncommon.

The grains also have varied age distributions, ranging from 10-50 million years to 750-2000 million years (Fig. 3). As previously stated, Mounts T and K are the designated non-flood-related mounts. These mounts both have an age peak at 500 million years old (myo), and another between 1,000 - 1,200 myo. None of the picked grains from Mount G, the flood-related sample, express this same age distribution. Mount G also has a group of grains whose ages fall between 10-50 myo. This age population of grains is not expressed among the picked non flood-related grains.

Very few zircon grains were found for Mounts D, A, and C. Each mount has between 3-6 zircon grains. The age distributions are still intriguing and varied. These age distributions are shown in Supplemental Figure 1. Mount D has several grains that meet the 500 myo mark, and one grain that is over 2,500 myo. Mount A also has a single grain at 68 myo, which was within the range of younger grains noted in Mount G.

Figure 3. Age distribution of Mounts T, K, and G. These mounts are represented together because enough zircon grains were found to have a degree of statistical viability (50 to 200 grains is the preferred amount). Mounts T and K are both non-flood-related, and share similar age distributions. Many grains on the Mounts T and K were around 50 myo or between 1,000 to 1,200 myo. Mount G was flood-related, and had a distinct grain age distribution from the other mounts, with a group of grains that were ~750 myo, and no documented grains at the 500 myo range.

DISCUSSION.

As can be seen in Figure 3, there are distinct age distributions between the flood-related samples of Mount G and the non-flood related samples of Mount T and K. Mount G does not appear to have the 500 myo zircon population that is present in both T and K, but has a distinct group of zircons at 10-50 myo, and another distinct set at 750 myo. Because of the small quantity of grains that were found, it cannot be assumed that there are no 10-50 or 750 myo grains in the locations represented by Mounts T and K. For this reason, the conclusions discussed here are limited to what grains are present in each, as opposed to the differences between the samples.

As previously stated, Mount G has several young grains (10-50 myo). These young grains are consistent with zircon populations noted in the steep rock faces along the channels in the Tsangpo Gorge, as well as populations that have been noted in flood deposits closer to the source of the flood [3]. The young grains in mid-delta flood deposits have not been noted before. Their presence corroborates the other evidence (the high strontium signature associated with the Brahmaputra River and the coarser grains of high volume floods) that flood overflows followed the Sylhet Basin [4]. A small population of young grains was also noted in Mounts C and A, which are both flood-related mounts, further establishing the young grains as an indicator of flood overflow.

The population of 750 myo grains in Mount G has not been previously noted in flood-related deposits from the Tsangpo Gorge. A single grain of that age is present on Mount A, but was not noted on the other flood-related mounts. However, the 500 myo peak exhibited in Mounts T and K has been previously noted in megaflood deposits [3]. This may indicate that the 500 myo zircon grains are a characteristic of the Brahmaputra River as a whole and not specific to flood deposits.

CONCLUSION

The results from this study suggest that differences can be found between flood-related layers and non-flood-related layers based on the composition of zircon crystals coupled with mineralogical and geomorphic analysis. This knowledge can be used to corroborate the prior evidence of flood waters in the Sylhet basin, and better identify flood-related samples in the future. With a more complete picture of the historic river system we can relate historic changes to current health issues in Bangladesh, such as arsenic poisoning in groundwater which can lead to cancers, diabetes, and neurological damage.

Future studies should focus on developing a model for predicting flood deposits in this region based on a suite of factors, including zircon crystal age distribution. A larger sample size, as well as samples from multiple locations throughout the delta, would lend a more complete picture of the variations in zircon ages from different source rock and different geologic events. Furthermore, additional zircon age mapping would lead to an increased ability to predict where arsenic contamination will be most prevalent.

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