Session 95
Booth 19

Paleoenvironmental implications of the isotope geochemistry and Granulometry of Quaternary alluvial sediments and paleosols from Sai Island, Sudan

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Figure 1: Location of Sai Island.

Abstract

$\delta^{18}0$ and $\delta^{13}C$ analysis of carbonate nodules found in alluvial paleosols on Sai, an alluvial island within the Nile River in northern Sudan, reveals depleted values consistent with pedogenic activity during the last pluvial (humid) phase in the currently hyperarid region. Stratigraphic position of the paleosols and associated archaeological material suggests soil formation was concurrent with the most recent regional humid phase between ~9500 and ~4000BP. Correlation of $\delta^{13}C$ values of surface carbonate samples with SRTM-derived topographic data suggest that these paleosols have undergone erosion since their initial formation. Unusual trends in $\delta^{13}C$ with respect to depth in some locations suggest that different processes of ^{13}C enrichment and depletion dominated in different environments on the island at different times during the Quaternary. Variations (up to ~10‰) in $\delta^{18}0$ of pedogenic carbonates over kilometer scale transects suggest that water was subject to evaporative enrichment either as it flowed downhill from a meteoric source or as it moved to more distal parts of the floodplain of a paleochannel. Variation in sorting and average grain size in clastic material collected from the island suggest the presence of a diversity of depositional environments at different times and locations on the island during the Quaternary. Sai contains a rich archaeological record dating from the Pleistocene to the present, and the results described here provide insight into the history of the regional climate and local landscape over the times of various occupations.

Background

- Sai contains archaeological sites dating from the Pleistocene (Van Peer et al. 2003, 187-93) to the present (Figure 2).
- Sand dunes and gravel bars suggest that the Nile has migrated in the past.
- While the current regional climate is hyperarid, pluvial phases have occurred in the past, most recently between 9500 and 4000BP.
- Environmental changes correlate with developments in human subsistence strategies, including the emergence of pastoralism and agriculture (Garcea and Hildebrand 2009, 304-322; Kuper and Kroepelin 2006, 803-807).
- Sai has been a crossroads of cultural exchange between regions that gave rise to Pharonic Egypt and Nubia (Garcea and Hildebrand 2009, 304-322).


Figure 2: Ottoman ruins on Sai.

Methods

Carbonates were collected from the surface, test pits, and the sides of gullies. $\delta^{13}C$ and $\delta^{18}0$ was measured with a Delta V Plus mass spectrometer. Raw $\delta^{13}C$ and $\delta^{18}0$ values were corrected using NBS-18, NBS-19, and LSVEC standards (Coplen et al. 2006, 3165-3166). Results are reported relative to the Vienna Peedee Belemnite.


Figure 3: Collecting alluvial material from the side of an erosional feature on Sai.

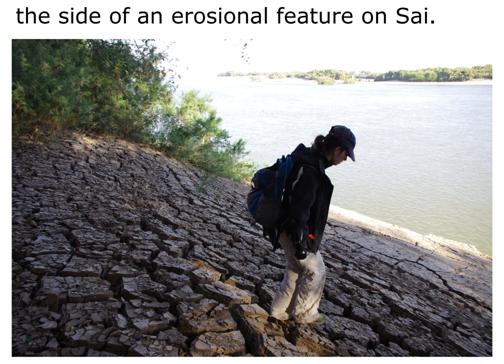
Figure 4: Recent alluvial overbank deposit found on Sai.

Clastic samples were disaggregated by mortar and pestle and dried overnight at 93°C. Granule sized particles were sieved out with a 2mm sieve. Remaining material was analyzed by hydrometer. Grain size calculations, using equations modified from Gee and Bauder (1986), assumed a particle density of 2.65g/cm^3.

Figure 5: Carbonate sample locations.

Isotopic Results

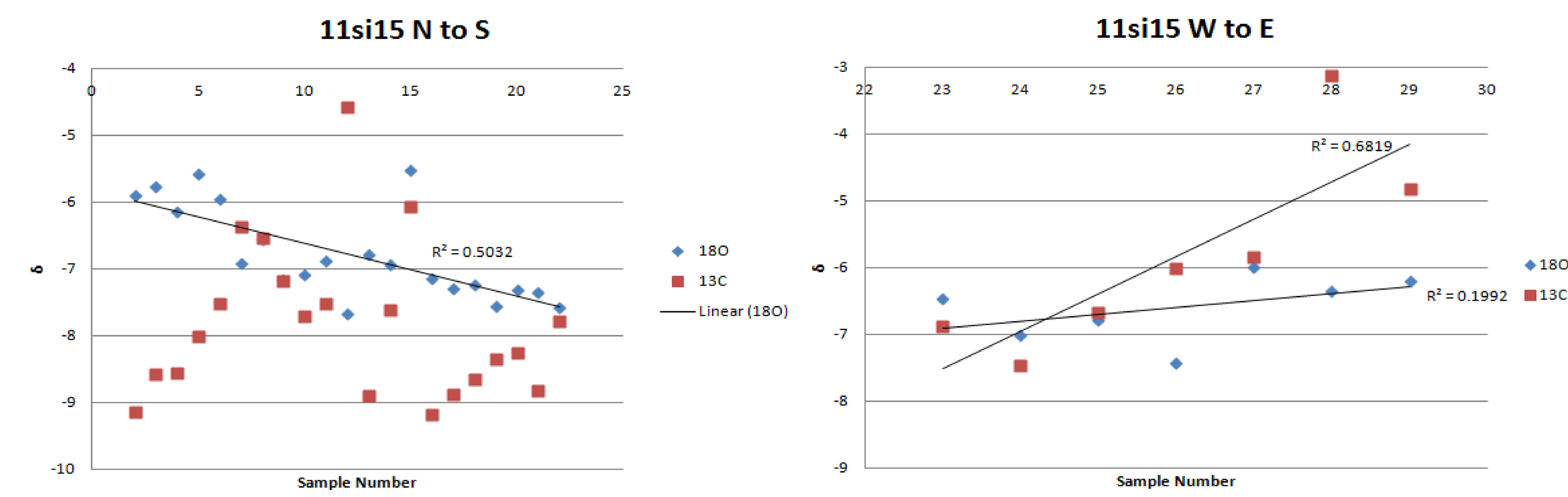

Figure 6: Results from surface carbonate samples, designated 11SI15 in Figure 3, plotted according to number on the map in Figure 4.

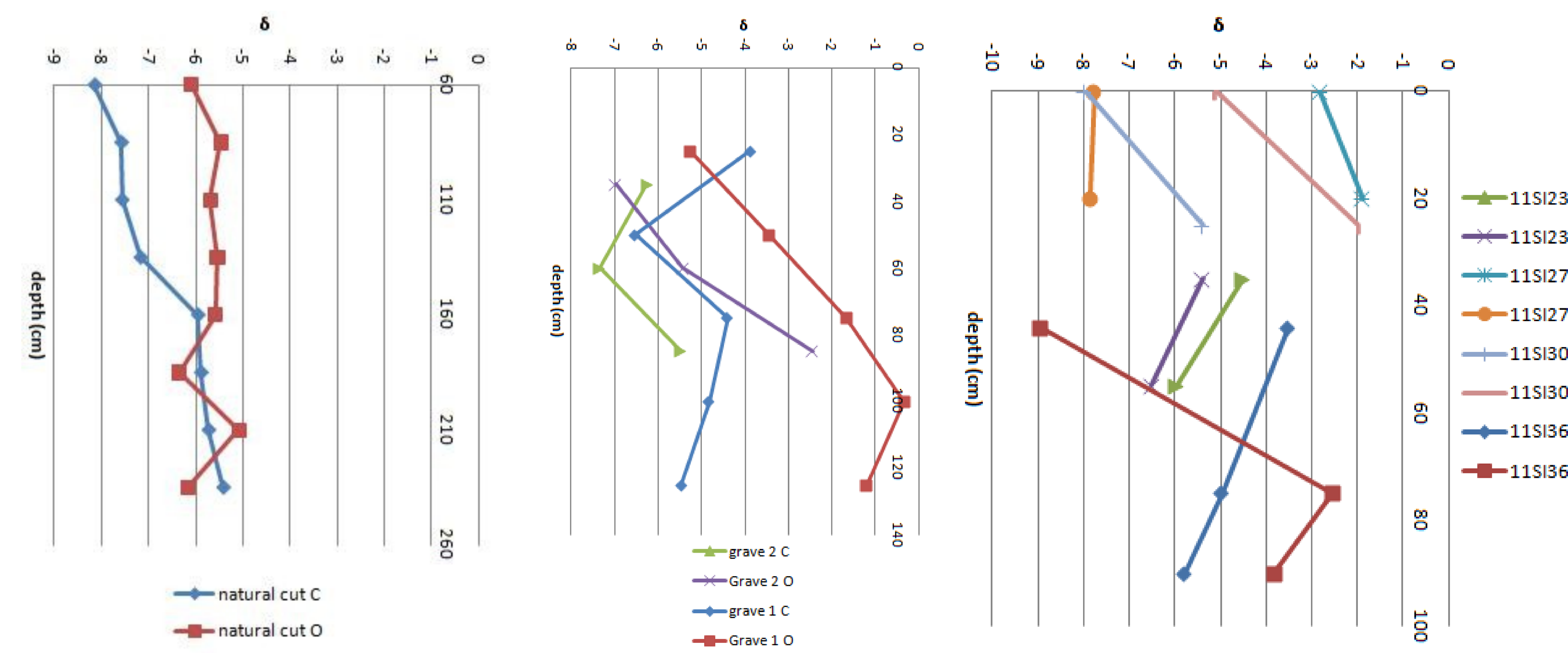

Figure 7: Results from carbonate samples taken at depth. The graphs show isotopic trends with respect to depth down the side of a natural gulley cut at 11SI39 (left), two nearby graves (center), and several erosional cuts elsewhere on the island (right).

Granulometry Results

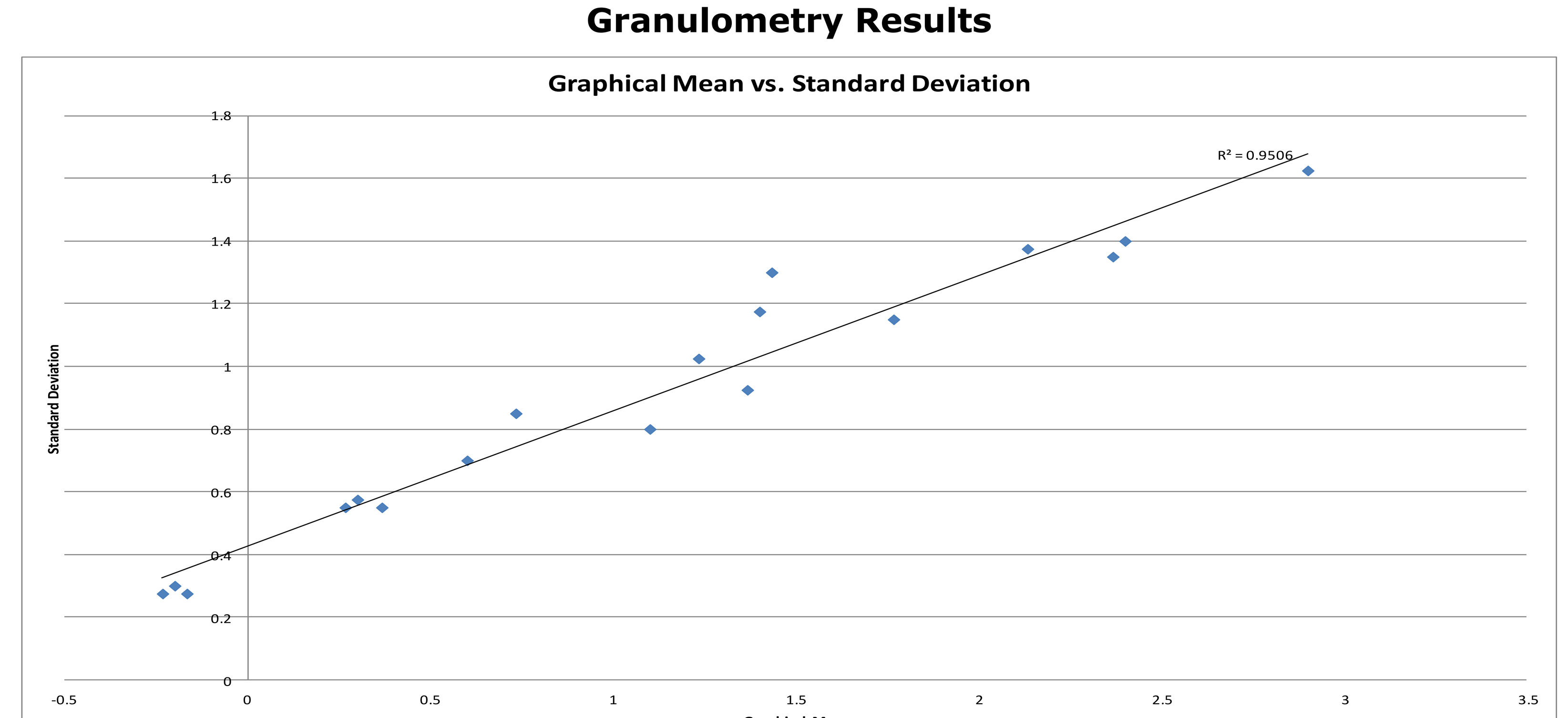

Figure 8: Granulometric results for a number of clastic samples collected at various locations on the island (not shown on map). Axes are in φ units. Note that recent overbank deposits plot near the center of this chart, with mean grain sizes of 1.10φ and 1.36φ, and grain size standard deviations of 0.8φ and 1.0φ.

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Discussion

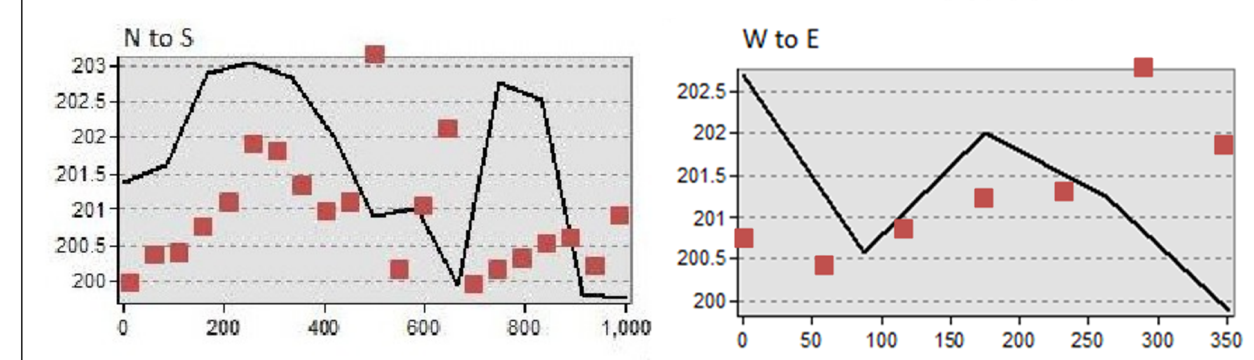

Figure 9: SRTM derived topographic profiles of the two 11si15 transects (black lines), with $\delta^{13}C$ results superimposed (compare to Figure 5). Axes are in meters.

The north-south and east-west 11SI15 transects display trends of $\delta^{18}0$ enrichment in the direction of the modern channel, consistent with evaporative enrichment of water flowing away from the Jebel Adu (Figures 5, 6). There appears to be a correlation between $\delta^{13}C$ and surface elevation (Figure 9). Increasing $\delta^{13}C$ depletion with depth is consistent with lessening atmospheric diffusion and increasing relative contribution of respired and organic CO_2 with depth (Nordt et. al. 1996, 133-154, Figure 10). Heavy samples in the topographic lows may have washed in from elsewhere. 11SI15 $\delta^{13}C$ results may also be explained by variations in vegetation present when soils were active (Figure 11). It is possible that plants better adapted to moist conditions would favor channels where flow was concentrated. Typically wet adapted C3 plants contribute lighter carbon than typically dry adapted C4 plants. SRTM based topographic profiles along the sample transects do not vary by more than the best reported 90% error margin of +/- 4.07m (Gorokhovich and Voustianiouk 2006, 409-415). A thorough topographic survey would be needed to demonstrate this relationship with statistical significance. Isotopic results from the gulley at 11SI39 (Figure 6) display trends contrary to the predictions of Nordt et. al. (Nordt et. al. 1996, 133-154), but consistent with microbial activity such as that reported by Accoe et. al. (Accoe et al. 2002, 2184-2189, Figure 12). Carbonates found here are more indurated and likely older than those found at 11SI15. Isotopes in the two graves sampled at 11SI39 (Figure 7) show different patterns of depletion with depth. Samples taken from other gulley cuts on the island (Figure 7) display various isotopic patterns. The diversity of isotopic compositions suggest the presence of a variety of biomes and rates of evaporation. These samples come from a variety of locations (Figure 5), and likely formed at different times. Diverse average grain size and sorting of clastic deposits (Figure 8) suggest a variety of flow regimes in depositional environments.

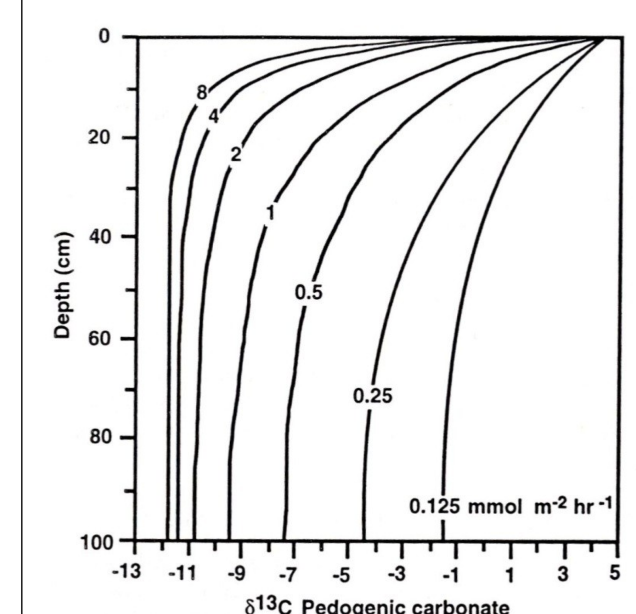

Figure 10: Predicted $\delta^{13}C$ of pedogenic carbonate with respect to depth in a soil profile, based on a theoretical model (Nordt et. al. 1996, 133-154).


Figure 11: A variety of C3 and C4 plants continue to grow on some parts of the island.

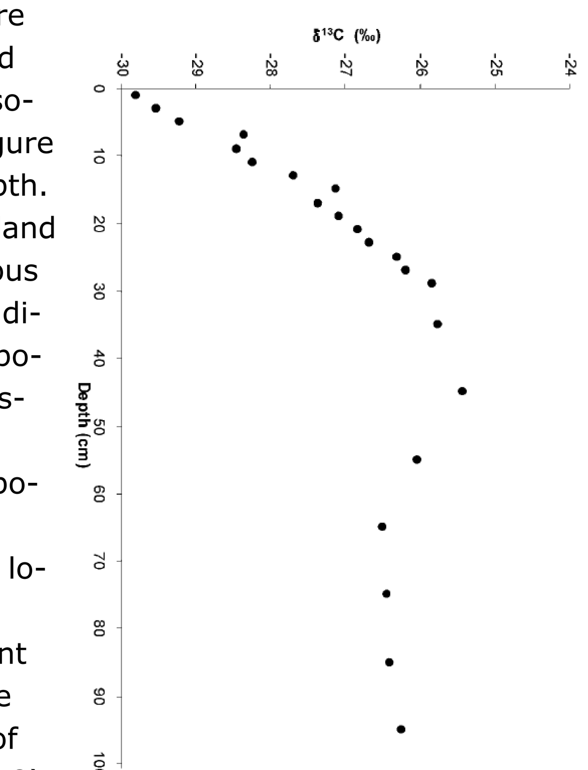

Figure 12: Increasing ^{13}C depletion with depth observed in a grassland soil by Accoe et. al. (Accoe et al. 2002, 2184-2189).

Conclusions

- Isotopic evidence strongly suggests that at least some of the paleosols on Sai were active during the last pluvial phase.
- Previous pluvial phases may have contributed to calcite deposition at some locations.
- If Nile flooding made a significant contribution to paleosols in the 11SI15 area, then it may have occupied a different channel than it does today.
- Varying trends in $\delta^{13}C$ with respect to depth in paleosols indicate that different processes dominated carbon istotope fractionation in soils at different times in the past.
- $\delta^{13}C$ results also indicate either erosion taking place after soils were no longer active, or variations in the type of vegetative cover on the island when soils were active, controlled by differences in available water in varying microenvironments.
- Granulometric evidence suggests that the Nile channel has moved considerably over the course of the Quaternary.


Figure 13: The position of the Nile has changed over time, allowing it to deposit coarse material, such as that found in this sandbar, in places where water no longer flows.