Long-Term Ice Volume History

In class and in the book we noted that the heavy isotope fraction of oxygen $\delta^{18}O$ in ocean water increases during ice ages because the lighter isotope $16O$ evaporates first and collects on land in the form of ice sheets. This ocean water isotope history is incorporated into the shells of tiny sea creatures (e.g. plankton) and piles up as a record in the ocean sediments. If we can dig a core out of the ocean bottom, register it as to time with carbon dating or magnetic reversal dating, then we can create a record of $\delta^{18}O$ that is a proxy for global ice volume.

Note that in ice cores, the $\delta^{18}O$ is more a record of temperature when the ice was formed as snow and fell onto the ice sheet.

Fig. 1 from Raymo and Ruddiman (1992) shows the $\delta^{18}O$ record for the past 70 million years derived from ocean sediment cores in regions of low accumulation rate. Notice:

1. The rapid increase of $\delta^{18}O$ in the past 2-3 million years marking the onset of the Pleistocene glacial age, when substantial ice sheets were present.

2. Prior to that about 40 million years ago a prior increase in $\delta^{18}O$ seems to have happened.

3. 50 million years ago and earlier, the $\delta^{18}O$ was very low in the ocean, indicating that Earth probably had no glaciers at all. This corresponds to the time of the dinosaurs. Eocene period, we have fossil records of crocodiles, ferns and other life forms in very high latitudes, were nowadays these life forms cannot exist because it is too cold. This was a time much more equable climates in which the Tropics were not much warmer than today, but it probably never froze at sea level in polar regions. Thus we think that the atmosphere probably contained much more stable greenhouse gas concentrations than at present, probably CO2. On these time scales the concentration of CO2 in the atmosphere may have been affected by continental drift, volcanism, ocean circulation, or some other interesting process. We are not sure.
Orogeny and Weathering:

One interesting theory is that the weathering process had a lot to do with the CO2 in the atmosphere and with climate. A particular case that has been well developed is the contact of the Indian subcontinent with Eurasia, which happened sometime around 8.5 million years ago. When this happened it is hypothesized that the Asian Summer Monsoon would have started. Evidence for this can be seen in sediments from the Arabian Sea and from soils in Pakistan.

(1) About the time that India crashed into Eurasia, we start to see much more of G. bulloides shells in sediments in the Arabian Sea. Globigerina bulloides really does well in the cool upwelled waters during the summer season as the southwesterlies stream northward along the coast of Saudi Arabia, drawn toward the heating and upward motion associated with the monsoon rains over India. The figure from Molnar et al shows the rapid increase of G. bulloides in the cores from the Arabian Sea at about the time that India collided with Eurasia and we assume that the monsoon circulation started.

(2) Also we can look at the δ^{13}C in pedogenic sediments (old soils) from Pakistan. In this case we know that C3 and C4 plants take up the heavier isotope of Carbon 13C in different abundances compared to 12C. Thus δ^{13}C in soils is a marker for different types of plants, which is turn are favored by different climates. The rapid increase in δ^{13}C in sediments around the time that India crashed into Eurasia again suggests that the Indian Summer Monsoon started about then. This would bring warm water into contact with freshly uplifted continent. This would accelerate the weathering process, which would take CO2 out of the air, which might have led to the Pleistocene decline later on, as Tibet was uplifted after the crash about 8.5 M years ago. Seems a good theory.
Below we show a schematic of the carbon cycle as it relates to the weathering-metamorphosis cycle. During weathering rock is converted into carbonate by the action of CO\textsubscript{2} and water. The carbonate flows into the ocean and becomes locked in sediments. As these sediments are compressed and heated in subduction zones, the reverse of this process occurs and carbonate is converted into rock, releasing CO\textsubscript{2}, mostly in volcanoes. These processes are slow compared to photosynthesis, but the reservoirs of carbon are huge compared to that in the ocean and atmosphere.