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**PALEOENVIRONMENT AND ENVIRONMENTAL DEGRADATION OF A
TROPICAL ISLAND: EVIDENCE FROM CAVE CALCITES**

By Martin Brown, B.Sc.

**A thesis submitted to the Faculty of Graduate Studies in partial fulfilment of the
requirements for the degree of**

Master of Science

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Ottawa, Ontario
May, 2000
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PALEOENVIRONMENT AND ENVIRONMENTAL DEGRADATION OF A
TROPICAL ISLAND: EVIDENCE FROM CAVE CALCITES

Submitted by
Martin Brown, B.Sc.

in partial fulfilment of the requirements
for the degree of Masters of Science

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ABSTRACT

Isotopic (oxygen and carbon) and petrographic (crystal length and roundness) analyses were performed on two speleothem from the tropical island of Mona, Puerto Rico, which grew over the last 1.5 kyrs of the Late Holocene in order to determine if they contain a recognizable paleoenvironmental signal and signs of the historically documented human-induced environmental degradation of the island through extensive guano mining. These records were compared to the nearest well-documented high-resolution proxy, the Quelccaya Ice Core.

Carbon and oxygen isotopes are shown to respond mainly to paleotemperature changes in the pre-1510 timeframe of relative climate stability and for most of the Little Ice Age. For both isotopes, the higher the temperature, the greater the depletion (caused by the cave temperature effect for $\delta^{18}\text{O}$ and the biological effect for $\delta^{13}\text{C}$). Paleoprecipitation becomes a dominant control only in droughts. Crystal morphology is shown to indicate extreme environmental events such as droughts (hot or cold) and hot-wet events. Both of the isotopes and crystallographic records clearly indicate anthropogenically-induced environmental change.

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1.0 INTRODUCTION

Speleothems, the secondary mineral deposits in caves, are produced by mobilization processes which work to redistribute surface-derived components to the subsurface via the downward percolation of fluids (Ford and Williams, 1989). Speleothems include stalactites, stalagmites, flowstones, pool deposits as well as a host of other cave deposits, and can consist of at least 76 different minerals, 15 of which are carbonates (Bar-Matthews et al., 1991). Their carbonate mineralogy can vary from high to low-magnesium calcite, aragonite, dolomite and to rarer carbonates such as huntite, vaterite and nesquehonite. However, low magnesium calcite is by far the most common mineral in the $\text{CaCO}_3\text{-CO}_2\text{-H}_2\text{O}$ system.

The biological component of soils supplies much of the carbon dioxide to the system. Rainwater adsorbs carbon dioxide from the soil to form carbonic acid. Limestone is dissolved at the rock/water contact by the CO_2 -rich waters and the H_2O percolates through the rock. Once these waters emerge into the cave system, the carbon dioxide partial pressure of these waters is out of equilibrium with that of the cave's atmosphere where the $P\text{CO}_2$ approximates that of the ordinary atmosphere and they lose some CO_2 and become supersaturated. Carbonate minerals will precipitate as the excess carbon dioxide is degassed from the waters.

Stalagmites, found on cave floors, are vertically growing mounds formed

by supersaturated water dripping from either a stalactite or the cave ceiling. As the drops hit the floor, the carbonate minerals precipitated by the degassing of carbon dioxide will form a build-up of laminae. Since stalagmites can have a wide variety of shapes, they have been coined colourful names such as broomsticks, totem poles, fried eggs, toadstools and Christmas trees. The most common stalagmite form is a simple candle shape. Their diversity in mineralogy and crystal habit combined with the variability in elements and isotopes allows speleothems to exhibit a wide range of responses to changing environmental conditions, hence making them very useful for paleoenvironmental interpretations. They can be dated by ^{14}C , U-series, electron spin resonance (ESR), and paleomagnetic methods. Organic matter as well as tephra and pollen trapped within the speleothem can be extracted and analysed; trace element analysis can provide useful information; and studies on visible and luminescent banding can also give insight to paleoenvironments (Lauritzen and Lundberg, 1999a).

Although this discipline is still in its infancy, several examples from the literature can be found where speleothem analysis has been used for paleoenvironmental reconstruction. Within temperate regions for example, Norwegian speleothem analysis provided a high resolution paleotemperature proxy record for the last interglacial and confirmed the timescale and unstable climate proposed for substage 5e (Lauritzen, 1995). In another example, annually laminated stalagmites from England, France and Belgium were

analysed to determine their growth rate in relation to water supply. Results indicated that calcite porosity and the seasonal cessation of water supply to the samples affected growth rate (Baker et al., 1998). Within temperate regions of North America, isotopic analysis of speleothem from Cold Water Cave, Iowa, revealed a correlation with well-documented Holocene vegetation changes (Dorale, et al., 1992). Speleothem analysis from the north-central USA also revealed evidence for Holocene fluctuations of the prairie-forest ecotone (Denniston et al., 1999).

The use of speleothem records outside of temperate regions is less common. In an example from the Middle East, the uranium dating and stable isotope analysis of speleothems from Hoti Cave, Oman, yielded evidence of a series of wet periods in Southern Arabia from approximately 9,000 to 6,000 B.P (Burns et al., 1998). Uranium ratio analysis from speleothem located in the Soreq Cave in Israel, reflected the effects of rainfall and soil weathering conditions on drip-water composition and may provide a proxy for climate change (Kaufman et al., 1998). Large isotopic shifts within speleothem from Botswana were associated with changes in the C3 to C4 photosynthetic pathways and could be used as indicators of vegetation change (Holmgren et al., 1995). Speleothem from South Africa indicated that during the Last Glacial Maximum, temperatures were up to 7°C cooler than present during which time significant vegetation changes occurred (Talma and Vogel, 1992). The dating of sea level changes within the Bahamas was provided through the use of

submerged speleothem (Lundberg and Ford, 1994)

These examples illustrate some of the variety of uses of speleothem in paleoenvironmental studies. However, speleothem have not often been utilised for the interpretation of tropical paleoclimates. For this study, two speleothem from Mona Island, Puerto Rico were analysed in an effort to reconstruct its paleoenvironment and address the research questions outlined below.

1.1 General Research Questions

- 1 Do stalagmites from the tropical island of Mona contain a recognisable paleoenvironmental signature ("paleoenvironment" meaning mainly climate and vegetation)?
 - a) Is the paleoenvironmental signature expressed through isotopes of oxygen and carbon, as well as through crystal fabric?
 - b) What was the nature of the environmental conditions over the time period of the chosen sample?

- 2 Is historically documented human-induced degradation of the surface environment (mainly the vegetation and soil) of this island detectable in the stalagmites?
 - a) Is environmental degradation expressed through isotopes of oxygen and carbon, as well as through crystal fabric?

- b) What was the nature of the response in the stalagmite?

1.2 Significance

These two research questions are a small part of two broader academic problems. One of these problems is that proxies for tropical Quaternary climate and vegetation change are very hard to find and there is consequently little information available. Speleothems in temperate regions generally are acknowledged to contain a useful paleoenvironmental proxy record. This research helps to establish whether tropical speleothem could become equally important, thus allowing them to be used as a useful tropical paleoenvironmental proxy. On the local scale, this research will test speleothem as a proxy for Mona Island; if these samples show a paleoenvironmental record, this will lead the way for other samples to be analysed, from other localities and from other time periods.

A function of the scarcity of proxies is the question about the nature of tropical climate change versus that of temperate regions. It is often apparent that glacial periods are expressed in the tropics mainly through humidity changes rather than temperature changes but there is less information on how smaller perturbations are expressed.

Another function of the scarcity of proxies is the question about the geographic extent of changes. For example, the Younger Dryas and the Little Ice

Age (LIA) are generally detectable in all proxies all over the world. However, the Medieval Warm Period is still under debate because it is recorded within historical documents of Europe, pollen, tree lines and glacial movements but is not recorded in tree rings or in ice core isotopes. Is the Medieval Warm Period recorded within the tropics?

This research cannot answer these questions but does contribute some more data for one area and one time period.

The second general academic problem is the significance of anthropogenic versus naturally occurring environmental change. This may be expressed in amplitude and rates of change. For example, there is still some debate regarding the natural global warming that occurred after the LIA versus the anthropogenic global warming from CO₂. There is a need to know and demonstrate the natural amplitudes of change and natural rates of change. Once accomplished, this can be tested to see if human impact causes significantly greater amplitude and rate of change. There is a need for proxies that are sensitive enough to show these changes. If this research shows a clear signal for known human impact, then it may point the way for other speleothem research into anthropogenic impacts.

1.3 The Structure of the Thesis

- 1 Introduction.
- 2 Natural Setting: This section includes a description of the geology of the site. The geology is important in that it was the setting for cave formation, but is not the focus of this research paper.
- 3 Historical Background: This sections includes the documented human activities and impact on Mona Island.
- 4 Academic Background: This includes details of speleothem growth, their crystal morphology and isotopic fractionation.
- 5 Methodology: this includes sampling procedures and laboratory analysis.
- 6 Results and Discussion.
- 7 Conclusions.

2.0 NATURAL SETTING

In 1993, six stalagmites from Isla de Mona (Mona Island), Puerto Rico, were collected for scientific analysis by Dr. Joyce Lundberg of Carleton University's Geoscience Centre. The scope of this project will include the analysis of two of these samples.

Mona Island is a small, uninhabited, carbonate island located in the middle of the Mona Passage, between Puerto Rico and the Dominican Republic (Figure 2.1). The island lies approximately 68 kilometres west of mainland Puerto Rico (80 km west of Mayaguez) and 65 km east of the Dominican Republic, at 18°05' N and 67°55' W.

Physically, this somewhat oval island is approximately 12 kilometres long and 5 kilometres wide with its long axis oriented in a east-west direction. It covers an area of approximately 5,510 hectares and has more than 30 kilometres of coast, 90% of which consists of steep cliffs. It is a flat-topped, raised carbonate platform with 50 to 90 metre high steep cliffs (Figure 2.2) which extend 30 metres below sea level. The highest point of the plateau is about 100 m above sea level. Numerous caves are found on the island.

Due to Mona Island's relatively small size and flat topography, it possesses a drier climate than that of mainland Puerto Rico. The island is classified as having a semi-arid, sub-tropical climate. The mean annual rainfall for the island is 809 mm with the greatest amount of rainfall occurring during

FIGURE 2.1 Locations of Mona Island and the Quelccaya Ice Cap.

Figure 2.2. Oblique aerial photograph of Mona Island, Puerto Rico.

October and November (Gonzalez et al, 1997). Temperatures range from 24°C in January to 28°C in July and August, with a mean annual temperature of approximately 26°C (Gonzalez et al, 1997).

Mona is home to 417 plant species, 8 of which are endemic to Mona and 27 of which are endemic to this region of the Caribbean. Furthermore, 78 of these plant species are rare or endangered in Puerto Rico. Today, palm trees and small shrubs cover much of the area and relatively dense, taller trees are only found on the coastal plain. The island's vegetation was quite different before it was deforested and contained many species of trees including, reputedly, mahogany.

2.1 Tectonic Setting

The northeastern margin of the Caribbean Sea consists of a complex plate boundary dominated by strike-slip motion (Burke et al., 1978; Masson and Scanlon, 1991). This region is bounded by the Puerto Rico Trench on the north and by the Muertos Trough on the south (Mason and Scanlon, 1991). Pindell and Barrett (1990) suggested that the present tectonic regime of the region reflects a change in Caribbean Plate motion from a northerly to a more easterly direction caused by the collision of the Caribbean Plate with the Bahamas Bank beginning in the Eocene. This change in plate motion in the Eocene resulted in

termination of volcanism in the northeastern Caribbean. Reefs have developed in the region since the Oligocene.

The island lies on one of the several small plate fragments containing Puerto Rico and Hispaniola. Isla de Mona and Isla Monito (approximately 5 km to the northwest of Mona Island) are part of an upthrown structural block bounded by several nearly vertical faults (Rodriguez et al., 1977). Monito is separated from Isla de Mona by a shallow graben (Kaye, 1959; Rodriguez et al., 1977). Evidence for tectonic uplift lies in the fact that the plate is rotating clockwise as a result of the oblique strike-slip motion of the surrounding Caribbean and North American plates (Masson and Scanlon, 1991). The tectonic movement has produced broad synclines and anticlines that on Isla de Mona plunge gently to the south or southeast (Kaye, 1959). Rodriguez et al. (1977) suggested that normal faulting in the vicinity of Isla de Mona resulted in a general tilting of both islands to the southwest. A series of south-east trending faults are found to have a vertical displacement of up to 10 m; for example, there is a major fault which has a northwest-southeast trend and passes near Cabo Noroesta (Figure 2.3 shows the location of various Mona Island topographic features). The fault extends across the island; adjacent to this fault line, near the centre of the island, a large karstic depression known as Bajura de los Cerezos has formed. A smaller fault is located in the northeastern corner of the island near Cabo Norte (Briggs and Seiders, 1972). Seismic activity in the region suggests that some of the faults may still be active today (Rodriguez et al., 1977). The bedrock contains

Figure 2.3 Locations of topographic features of Mona Island (Modified from Wadsworth, 1973). The dashed line marks the cliff line separating the coastal plains from the plateau.

vertical joints oriented parallel to the cliffs and Quinlan (1974) noted that caves developed along some of these joints.

2.2 Carbonate Geology

The Isla de Mona plateau is composed of two Neogene lithostratigraphic units, the Lirio Limestone and the Isla de Mona Dolomite, originally described by Kaye (1959) and later redefined by Briggs and Seiders (1972). The upper unit is exposed in the upper plateau surface (Figure 2.4); the lower unit is exposed only in the cliff faces. These units represent mainly a back-reef sand environment. The Lirio Limestone includes a reefal boundstone sequence to the southwest. Kaye (1959) named the lower unit, which makes up the bulk of the carbonates of the island, the Isla de Mona Limestone; he also named what he considered a significantly thinner upper unit, the Lirio Limestone (after Lirio Cave). The lower unit (Isla de Mona Limestone) was described as thickly bedded, dense, white to light yellow, finely crystalline "exceptionally pure" limestone. Kaye (1959) noted that one sample collected from the base of Punta Este was pure dolomite, but he did not define the nature or lateral extent of dolomitization. The Lirio Limestone was described by Kaye (1959) as a thinly bedded, dense, finely crystalline limestone. Briggs and Seiders (1972) recognized the extensive amount of dolomite present in the rocks of Isla de Mona and redefined the lower unit as a

Figure 2.4. Topographic map of Mona Island.
(Adapted from Gonzalez et al., 1990).

thick to very thick, locally cross-bedded, well-indurated, finely crystalline calcitic dolomite. The unit was then re-named the Isla de Mona Dolomite. The Lirio Limestone was redescribed by Briggs and Seiders (1972) as a cavernous, thickly bedded, locally crossbedded, chalky, fine-grained limestone. Kaye (1959) reported an early to middle Miocene age for the Isla de Mona Limestone and suggested a Pliocene to Pleistocene age for the Lirio Limestone, on the basis of corals collected from the southwestern corner of the island. Kaye (1959) interpreted both units as being flat-lying with local undulations of as much as 1 m dip in the lower unit and less than 0.3 m dip in the Lirio Limestone; the Lirio Limestone was interpreted as being deposited on an erosional surface developed on the Isla de Mona Dolomite. Briggs and Seiders (1972) observed that the relationship between the two units was more complex than envisioned by Kaye (1959).

The Isla de Mona Dolomite is exposed in continuous exposures on the northern and eastern seacliffs, in the Centre of the island at Bajura de los Cerezos, and in discontinuous exposures below the Lirio Limestone along the base of the southern seacliffs. The Isla de Mona Dolomite disappears below the Lirio Limestone along the southwestern and western coasts from Playa Uvero to the area south of Punta Capitan on the west, and in the area between Playa de Pajaros and Punta Este on the southeastern coast. The dolomite attains a maximum exposed thickness of approximately 80 m along the northern coast. These exposures of the Isla de Mona Dolomite gradually disappear towards the

southwestern and southern side of Isla de Mona and are replaced by the Lirio Limestone, which has a maximum exposed thickness of 40 m.

Both units exhibit selective dissolution of aragonitic skeletal grains with fabric-retentive replacement of former high-Mg calcite skeletal components, by calcite in the Lirio Limestone and by dolomite in the Isla de Mona Dolomite (Gonzalez et al 1990). Petrographic relationships suggest early diagenetic modification by fluids that were substantially undersaturated with respect to aragonite. This state of undersaturation would preferentially have dissolved aragonitic components, near saturation with respect to calcite/high-Mg calcite during dolomitization, and saturated with respect to calcite during calcitization (Gonzalez et al 1990). The stable isotopic composition of individual dolomitized components and dolomite microspar in the Isla de Mona Dolomite define a hyperbolic trend characteristic of a composition produced by fluid mixing (Gonzalez et al, 1990). The presence of karstification, the nature and chemistry of the fluid responsible for the dissolution and replacement, the isotopic composition of the dolomite and the presence of soil horizons all strongly suggest that diagenetic modification occurred under meteoric-marine fluid mixing. The stratigraphic variations in isotopic composition together with field relationships seem to suggest that dolomitization was achieved by periodic oscillations of the late Miocene sea level (Gonzalez et al, 1990). During lowstands, freshwater lenses could develop within the island's exposed central part which would establish a mixing zone and consequently karstification would

follow.

The Lirio Limestone is karstified with sinkholes in the island's centre and numerous large cave openings exposed along the cliffs which surround the island. Within the Isla de Mona Dolomite, three different soil development episodes can be identified in the central part of the island, and on the periphery of the island several episodes of vadose diagenesis are identified by the presence of vadose silts and paleo-travertines.

The coastal plains of Isla de Mona consist of Holocene carbonate sand deposits from Playa Sardinera on the west side of the island to Punta Arenas. Holocene beachrock (with the most recent ones containing bricks, bottles, and other artifacts from the last two centuries) is common along the sandy shore. The coastal plain on the west side of the island, North of Playa Sardinera, on the southwest part of the island south of Punta Arenas to Playa del Uvero, and along the southeast side of the island from Playa de Pajaros to Punta Este, is composed of Pleistocene coral-reef terraces covered by a thin carbonate sand layer (Kaye, 1959). The Pleistocene reef terraces are better developed on the southwest coastal plain.

2.3 Geomorphic features of Isla de Mona

Isla de Mona consists of a relatively flat carbonate plateau, ranging in

elevation from 20 m in the southeast to 90 m in the northwest, bounded by vertical seacliffs on its north and east sides and a low-lying discontinuous coastal plain on its south and west sides. The plateau surface of Isla de Mona is characterized by the presence of many sinkholes, found mostly in the Lirio Limestone. A vast system of NW-SE-trending fractures (Kaye, 1959; Briggs and Seiders, 1972) can be easily detected from aerial photographs. A large-scale NW-SE-trending fracture system originally described by Kaye (1959) appears to control the development of sinkholes in some areas of the plateau, especially along Bajura de los Cerezos. Originally interpreted as a fault zone by Briggs and Seiders (1972), Bajura de los Cerezos consists of a zone of collapsed blocks of interbedded dolomite and limestone. This linear NW-SE-trending depression extends down into the Isla de Mona Dolomite. A thin layer of Lirio Limestone is present around the periphery of this collapse sink. On the northern and northeastern sides of Isla de Mona, the vertical seacliffs plunge to 30 m below present sea level (Rodriguez et al., 1977). Seismic reflection studies by Rodriguez et al (1977) indicate that the seafloor surrounding Isla de Mona is composed of similar, if not identical, lithologies as those exposed on both Mona Island and Monito Island.

The central interior portions of Isla de Mona are characterized by the presence of residual soils (Rivera, 1973) indicating that local drainage was directed toward those areas. The average thickness of these soils in Bajura de los Cerezos is 60 cm (Rivera, 1973). Lowlands and shallow sinkholes in other

parts of the island are also covered with these red soils. The coastal terrace on the southwestern side of Isla de Mona is overlain by thin, sandy soils. The western portion of the coastal terrace at Playa Sardinera is overlain by calcareous soils and carbonate sand deposits, which are up to 1.5 m thick and are derived from the modern reef developed along this coast (Rivera, 1973).

Dissolution features of various sizes and shapes are widely distributed across the plateau surface. Solution pits are cylindrically shaped, penetrating as much as 20 m deep into the Lirio Limestone and Isla de Mona Dolomite; they frequently become bell-shaped at the bottom. In many areas, the bottom of the solution pits lie within the transition zone between the Isla de Mona Dolomite and the Lirio Limestone and may continue down several metres into the dolomite. Commonly, small passages, always choked with sediment, branch out from the bottom. Shallow bowl-shaped depressions, 1-5 m deep and 10-20 m wide, are also common. These shallow sinks commonly have small caves with very short lateral extension, or have well-developed solution pits. Most solution pits and shallow sinkholes have bottoms filled with reddish sediments (soils). Along the coastline, collapse sinkholes related to the extensive coastal cave system are common.

The coastal cliffs of Isla de Mona, from Punta Este to Cabo Barrionuevo, are distinguished by the presence of multiple levels of caves that penetrate up to 250 m into the plateau (Briggs and Seiders, 1972; Frank, 1993). Caves are more common and better developed within the Lirio Limestone with cave floors

extending down into the dolomite in some cases, although some caves are developed completely within the Isla de Mona Dolomite. The caves are preferentially developed with elongated mazework rooms parallel to the cliff faces, and suggest development in flank margins (Frank, 1993; Ruiz et al., 1993; Mylroie et al., 1994) with no contemporaneous openings. Present-day openings of the caves are the result of scarp retreat after uplift of the Mona Plateau.

2.4 Cave Development

On carbonate platforms, meteoric precipitation infiltrates the porous carbonate rock and enters the subsurface vadose zone. Due to the differences in relative fluid densities, the freshwater will subsequently displace the saline ocean water located beneath it. The result is the formation of a freshwater lens 'floating' above the denser phreatic ocean water. In the case of an unconfined reservoir, the freshwater phreatic lens extends below sea-level by approximately 40 times the height of the water table above sea-level. This is known as the Ghyben-Herzberg relationship (Gillieson, 1996). This is of course only an idealized model and the actual relationship tends to be much more complex. The geometry of the island, the type of recharge, evaporation, evapotranspiration and bedrock permeability and porosity can greatly influence the actual shape of the freshwater lens

Between the meteoric phreatic water and the underlying phreatic oceanic water is the diffusion zone known either a mixing zone or as the halocline. This is an important site for dissolution (Tucker and Wright, 1990). The resulting mixture created by the mixing of the two water masses, even if both waters are saturated with respect to CaCO_3 , can be undersaturated with respect to CaCO_3 . In addition, the presence of organics in the waters allows oxidation to occur, thereby producing further amounts of CO_2 which consequently expedites carbonate dissolution. Mixing-zone waters can aggressively dissolve large volumes of rock thereby allowing the extensive development of caves within this zone.

Flank margin caves are phreatic dissolution caves which develop at the margins of the freshwater lens of carbonate islands. The term is derived from their environment of development in the Bahamas: under the flanks of eolian ridges in the distal margin of a discharging freshwater lens (Myroie et al., 1995). At this location, the freshwater lens thins at the margin and the vadose-phreatic mixing zone at the top of the lens is superimposed on the saline-freshwater mixing zone at the base of the lens, thus maximizing dissolution (Myroie et al., 1995). As the relative sea level changes, as a result of either local tectonism or glacio-eustasy, the position of the lens, and consequently the mixing zone, changes as well (Ford and Williams, 1989). The vertical cliffs of Mona Island contain numerous flank margin caves at various elevation horizons.

The morphology of flank margin cave is dependant on the characteristics

of the freshwater water discharge, water chemistry and availability of time. Flank margin caves have a morphology that is common to caves formed by mixed-water dissolution in other environments. This morphology includes large globular chambers, bedrock spans, thin bedrock partitions between chambers, tubular passages that end abruptly, and curvilinear phreatic dissolutional surfaces (Mylroie, 1995). Flank margin caves are not conduits, but rather mixing chambers; thus they lack ablation scallops, stream channels, and other indications of turbulent conduit flow. They receive water from the lens in the island interior as diffuse flow, and discharge that water, after mixing, as diffuse flow to the ocean. These caves do not require an external opening to either land or the ocean to develop. Entry today is gained as a result of surface erosion breaching the cave. Because flank margin caves develop at the margin of the lens at the edge of the island, they tend to be vulnerable to destruction by scarp and hillslope erosion during subsequent platform emergence. The locus of cave development moves inland as the developing chambers modify the fresh-saltwater interaction. The site of fresh-saltwater mixing moves inland and a new series of chambers begins to form. When this pattern repeats itself several times, the cave system displays pseudo-concentric areas with chambers of decreasing size, with the innermost remaining closed while the outer ones may be eroded to form an opening to the exterior.

Mylroie (1995) noted that the Isla de Mona caves are consistent with the model for flank margin caves. The Mona Island flank caves have one or more

large, central chambers joined to each other by a series of arches and tubes.

The periphery of the caves are marked by wide, low chambers that end in bedrock walls. These bedrock walls often contain very tubular passages that subdivide several times, as well as cusped wall pockets, rock pendants, bedrock partitions and pillars. The caves commonly have floor areas of greater than 50,000 m², and some range up to 128,000 m² (Briggs and Seiders, 1972). The ceiling height of some chambers can be more than 8 m, producing single voids with volumes around 100,000 m³.

The caves on Mona Island tend to be found approximately 70 m above sea level, which is an entire order of magnitude higher than any Quaternary glacio-eustatic sea-level highstand. The setting of the island in an active tectonic province, its deformation, the Miocene-Pliocene age of the cave-bearing carbonates, and the elevation of the caves lead Mylroie et al. (1995) to attest to tectonic uplift of Mona Island. Mylroie et al. (1995) believes that the large size of the caves suggest formation during a period of prolonged stability of sea level after some initial emergence of the platform (necessary to provide subaerial catchment for the development of the freshwater lens). This stability led to a long period of time for flank margin caves development that produced extremely large flank margin caves. These caves would consequently have been formed prior to the large-amplitude, short-duration glacio-eustatic sea-level fluctuations of the Quaternary.

Since emergence and drainage of the caves, they have become inactive

speleogenetically. Surface erosion has exposed many of the outermost chambers so that the cliff is now riddled with holes (Figure 2.5). Continued diagenesis is now expressed through meteoric dissolution of the bedrock and deposition of speleothem, especially in the outermost chambers.

Figure 2.5. Photograph of caves surrounding the plateau. The flank margin cave main chambers are exposed due to backcutting of the cliffs. These caves are completely fossil and some stalactites are exposed to the atmosphere. This photo illustrates something of the nature of the modern vegetation. Palm trees and shrubs are rarer on the plateau.

3.0 HISTORICAL BACKGROUND

Since this study is designed in part to investigate geologic evidence for anthropogenically-induced environmental degradation, this section will briefly discuss the human history that has taken place on Mona Island.

Despite the fact the Mona Island is currently uninhabited and such a small island, it has been occupied on and off by humans for the last 2,500 years. It was originally inhabited by the pre-Columbian Taino Indians. The island's Negra cave is known to have contained pictographs and petroglyphs etched in limestone by the Tainos who called the island Amora (Franks, 1993). It was mainly used as a link in their Caribbean canoeing journeys, possibly up to 2,000 years before Columbus arrived on the island in 1494.

The Spanish noted that the Taino were engaged in resisting Carib attacks from the Virgin Islands. Unfortunately, by the second decade of the 16th century, both Taino and Carib cultures in these areas were almost extinct. Pirate raids forced the evacuation the remaining Taino Indian population from the island in 1578. Subsequently, Mona Island was mainly used by pirates as a base for their raids for nearly 300 years. The Mona Passage maintained considerable naval traffic since all ships traveling through the Caribbean islands would eventually have to use the passage. Table 3.1 testifies to the activity of pirates around Espanola in the 16th Century.

After arriving in the West Indies in April 1699, the notorious Captain Kidd

used the uninhabited island of Mona as a temporary hideout. There, he supposedly hid treasure, possibly 60,000 pounds sterling before sailing to the United States where he was hanged on May 23, 1701. It was not until the execution of the pirate Cofresi in 1828 that the pirates abandoned Mona Island.

Historical accounts indicate that the island supported an indigenous Indian population of 152 (Wadsworth, 1973) and that freshwater was abundant 400 years ago (Gonzales, 1997). During the period of Spanish colonization in the sixteenth century, the island was denoted on nautical charts as an important watering port (Wadsworth, 1973). In the absence of historical data regarding the impact of humans, it is presumed that human use of the island involved mainly selective tree cutting for ship repairs and frequent use of the freshwater supplies.

In the mid 1880's, the guano deposits found in Mona Island caves were deemed as an important economic resource (Franks, 1993). Guano miners moved in and stripped the island of the mineral from as early as 1848 but the first officially legal mining operation did not begin until 1871. The island then supported 300 to 400 workers along with machinery and horses. The guano mining era ended in 1927 and an estimated 160,000 metric tons of guano was removed from Mona's caves. Again, the human impact is not discussed in the historic literature but it must be presumed that such a large population on such a small island in combination with the industrial activity must have had a marked impact. Today the historical forests no longer exist, only the coastal plain has trees whereas the rest of the island has dry shrubs. Furthermore, freshwater on

the island is presently in short supply, the lens being now brackish (Gonzales, 1997). Within the last few centuries, exotics, such as pigs introduced at an unknown time, still inhabit the island without any population control.

Since the mining activity, human occupation has dwindled. In 1922, six families were living on the island and farming 32 acres of land on the coastal plain of the island (Wadsworth, 1973). There was Civilian Conservation Corps camp constructed on Punte Oeste in 1937 which served as a base for 140 men. They worked on several infrastructure improvement projects across the island. Today the island is uninhabited except for temporary research camps.

In summary, the greatest environmental impact on the island was likely to be from the guano mining due to the large population with the big infrastructure and the large extraction. The introduction of pigs, which tend to degrade soil with their digging and tracking, could also have contributed to the environmental degradation of Mona Island.

Table 3.1: Spanish Losses to Corsairs Around Espanola, 1548-1560*

Year	Mona Passage		South Coast		North Coast		Windward Passage	
	Ships Taken	Land Raids	Ships Taken	Land Raids	Ships Taken	Land Raids	Ships Taken	Land Raids
1548	2				2		p	
1549	5		p					
1550			1				2	
1551								
1552	+						1	1
1553	2	1	4	1		1	3	1
1554	2	1		1			1	1
1555						1		
1556	1							
1557	3+							
1558		1			6	2	3	
1559								1
1560								

p signifies possible loss to corsair
 + signifies losses not specified as to number

* Modified after Hoffman, Paul. 1980. *The Spanish Crown and the Defense of the Caribbean, 1535-1585*. Louisiana State University Press.

4.0 ACADEMIC BACKGROUND

4.1 The General Principles of Isotopic Fractionation

The principle behind the use of stable isotopes of oxygen lies in the fact that the ratio of two of its isotopes, ^{16}O and ^{18}O , is controlled by temperature and isotopic composition of the ambient water. The fractionation factor relates to energy levels where differences in the physico-chemical properties of isotopes arise as a result of quantum mechanical effects. Molecules are restricted to certain discrete energy levels where the frequency of their vibrational, rotational and translational motions are dependant on the mass of the isotopes. This implies that different isotopes will have different energy levels and will consequently chemically react differently. During evaporation, condensation and crystallization, a natural fractionation takes place. The heavier isotope will, depending on the situation, either move towards or remain in the more stable form. For example, during evaporation ^{18}O preferentially remains in liquid form; during condensation ^{18}O preferentially moves towards the liquid form, and during crystallization ^{18}O preferentially moves towards the solid form. It is this dependence on temperature which makes stable isotopes very useful in paleoenvironmental reconstruction.

Isotope ratios are measured not in absolute terms but as a relative deviation ($\delta^{18}\text{O}$ per mil) from the ratios of a standard:

$$\delta^{13}\text{O} = 1000 \left[\left(\text{sample } ^{18}\text{O}/^{16}\text{O} / \text{standard } ^{18}\text{O}/^{16}\text{O} \right) - 1 \right] \quad (1)$$

For carbon isotopic analysis, PDB is used as a standard. It is a Cretaceous belemnite from the Pee Dee formation in North Carolina. For oxygen isotopic analysis, SMOW (Standard Mean Ocean Water) is used as a standard. Isotope ratios are expressed as positive or negative values relative to the standard ($\delta=0$ ‰).

Oxygen isotope fractionation is a very well established proxy for environmental change throughout geologic time and in particular the late Quaternary. $^{18}\text{O}:^{16}\text{O}$ ratios in ice cores vary in response to changing ambient temperature as well as distance between the sites of precipitation and evaporation, altitude of site, and changes in the temperature and $^{18}\text{O}:^{16}\text{O}$ ratio of the water which is the ultimate source of the ice. Once the various inputs have been accounted for, including the flow dynamics of the ice sheet, the $\delta^{18}\text{O}$ of the ice provides a record of temperature change.

Oxygen isotopes have also been extensively used from calcite found in foraminifera within ocean cores. Here the changes relate mainly to the changing $^{18}\text{O}:^{16}\text{O}$ ratio of the ocean water as ^{16}O is sequestered within ice sheets. The temperature of crystallization will cause additional isotopic changes as well.

The stable isotopes of paleoenvironmental significance in speleothem are oxygen and carbon. The general principles of fractionation operate in exactly the

same manner as with the ice and ocean cores in that the sample isotopic values vary with conditions of deposition and the isotopic composition of the source. When the isotopic system is well understood, paleoenvironmental information can be acquired.

4.2 Stable Isotopes in Speleothem

The calcite crystal of a stalagmite is the end product of a string of processes, all of which may modify the stable isotopic signature. However, in practice usually only one control is dominant. The oxygen isotope acts as part of the water cycle from ocean to atmospheric water vapour, to the rainfall to the cave drips. The carbon isotope is part of the carbon cycle from atmospheric CO₂ to biological organics, to soil CO₂, to cave drips.

For most of the samples studied, the sites of deposition are within chambers of deep caves which tend to have little air circulation and are consequently atmospherically isolated from the outside environmental oscillations. These chambers are climatically stable with a constant temperature and a relative humidity close to 100%. Ambient temperatures in poorly ventilated areas of deep caves (>11 m) are generally quite stable, reflecting mean surface temperature over several years (Dorale et al., 1992).

Dripwaters are the medium from which meteoric speleothem grow. The

isotopic composition of dripwaters is often stable because seasonal variations in water input are homogenized as they percolate through rock.

Under most conditions, the stable isotopic composition of stalagmites is determined by the isotopic composition of its precipitating drip water and by the temperature of formation. Isotopic equilibrium must be maintained between calcite and the drip water as a result of the slow exsolution of CO_2 from the seepage water, as described according to the criteria of Hendy (1971). During exsolution of CO_2 , there is a preferential loss of ^{12}C and consequently an enrichment of ^{13}C downgradient along the stalagmite. Any ^{18}O enrichment from C^{16}O_2 loss, because of the abundance of H_2O , is insignificant and consequently there is no enrichment of ^{18}O downgradient along the stalagmite. Samples formed in isotopic equilibrium show the absence of a strong positive correlation between the values of $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ of samples taken at intervals along a single growth layer. The isotopic record in the calcite layers remain affected only by the known and predictable equilibrium crystallization processes which are themselves governed by environmental conditions. If, on the other hand, isotopic equilibrium is not maintained due to kinetic loss of CO_2 which occurs during evaporation, fractionation of both isotopes would occur as they flowed along the speleothem growth surface. Excess loss of $^{12}\text{C}^{16}\text{O}_2$ in addition to the loss of H_2^{16}O would cause parallel enrichment in ^{13}C and ^{18}O . The stable isotope record in the calcite would then be controlled by kinetic processes rather than climatic processes and the interpretation of the signal may be complex. A test of the

absence or presence of significant enrichment of both isotopes down a growth layer is called the Hendy test and is usually the preliminary step in any isotopic analysis.

4.3 Oxygen Isotope System

The two principle stable isotopes used in speleothem analysis, oxygen and carbon, represent quite different systems but both are often controlled by climate, although perhaps by indirect means. The following discussion of the controls on the isotopes of cave calcites is taken mainly from an unpublished manuscript by Lundberg (1998).

The oxygen isotope system is simpler and better understood than the carbon isotope system. Consequently, more studies have been made of oxygen isotopes in cave calcites. Each stage in the cave-surface-ocean system may have an effect on the isotopic composition of the cave calcite. This system is predominantly controlled by the following four effects.

1. The cave temperature effect: Since the fractionation of the light isotope from the heavy isotope is temperature dependant, the greatest fractionation will occur in colder caves (Dorale et al., 1992). Consequently, drip waters of the same isotopic composition will produce calcites enriched in ^{18}O for colder caves compared to caves of higher temperatures. With all other factors being equal, the

oxygen isotopic composition of the calcite varies with cave temperature, ultimately the mean annual temperature, where oxygen isotopic enrichment is indicative of colder conditions. The extent of fractionation that can be attributed to the cave temperature effect is controlled by standard equilibrium fractionation laws (O'Neill et al, 1969) and its magnitude is in the order of $0.24\text{‰}/^{\circ}\text{C}$ at 10°C .

2. The ocean temperature effect: During colder times, sea surface waters are colder, especially in polar and temperate regions. The resulting vapour produced from evaporation will tend to be more depleted than during warmer times (Hendy and Wilson, 1968). Consequently, during colder times, the drip waters will also be depleted and the calcites formed will show depletion. This process works in opposition to the cave temperature effect. The ocean temperature effect is stronger at higher latitudes than in tropical regions.

3. The drip-water composition effect: From the site of evaporation to the site of precipitation, the water vapour-laden air mass can be isotopically modified. In colder regions, the air mass becomes more rapidly depleted during transport than in warmer regions. Subsequently, colder temperatures produce depleted drip waters which leads to the formation of depleted cave calcites. On a similar note, latitudinal and altitudinal changes in the water vapour-laden air mass can affect the isotopic composition of the resulting drip waters (Goede, et al., 1986). This drip-water composition effect tends to be more evident when the water vapour travels large distances. This effect enhances the ocean temperature effect but operates in opposition to the cave temperature effect.

4. The ocean composition effect: Glacial-interglacial cycles produce changes in the isotopic composition of the sea water, where lighter isotopes tend to be 'locked-up' in the ice sheets during glacial times. Consequently, the isotopic composition of the ocean water becomes more enriched as the ice volume increases (by approximately 1‰ SMOW; Shrag et al., 1996). With all other effects being equal, the rainfall, the resulting drip waters, and the cave calcites will also be enriched. This ocean composition effect enhances the cave temperature effect but these two effects tend not to occur in synchronicity: there is usually a lag time between the temperature change and the ocean composition change. The ocean composition effect is strongest in tropical regions where cave temperature and ocean temperature may vary little. This effect has also been referred to as the ocean volume effect (Harmon et al., 1978).

The relative importance of these effects will be dependant on the climatic change time-scale on which they operate upon. Over longer term glacial-interglacial cycles, the ocean composition effect may be the dominant control, whereas during smaller scale changes (e.g. during the Holocene), the cave temperature effect may be dominant. Each situation must be evaluated independently.

4.4 Carbon Isotope System

The carbon isotope system can be more complex than the oxygen isotope system and there is little consensus on the interpretation of carbon isotopes in cave calcites due to the fact that any variation in the isotopic system can theoretically be explained by a wide variety of processes. However, the carbon system is usually relatively simple in practice.

Carbon fixation is controlled by photosynthesis whereas carbon release is controlled by respiration. These two processes govern most aspects of the carbon cycle and consequently govern the carbon isotopic composition. Atmospheric CO_2 will diffuse into the leaf stomata, pass through the cell membrane and into the chloroplasts. Within the chloroplasts photosynthesis will occur and carbohydrates will be produced. This is the method by which biomass is created. Carbon is subsequently re-released into the soil and atmosphere. The majority of the carbon is released early on in the process by degradation and respiration but some of it is stored in soil organics and wood. The soil organic degradation process permits a small amount of this biogenic carbon to be stored in the calcite of cave deposits. Since there is usually a link between the carbon system and climate-related processes, the isotopic composition of cave calcites may be indicative of climate change. The main controls on carbon isotopes of cave calcites are as follows:

1. The biological activity effect: The isotopic composition of soil CO_2 is

dependant on the respiratory CO_2 (with $\delta^{13}\text{C}$ values of approximately -30 to -10 ‰) and on the proportion of atmospheric CO_2 (with $\delta^{13}\text{C}$ values of approximately -7 ‰; Bradley, 1999). In cold climates where biomass and respiration rates are low, the soil $\delta^{13}\text{C}$ values are high and tend to be close to atmospheric values. This implies that cold temperatures are associated with enriched carbon isotopes. In warm climates, the soil $\delta^{13}\text{C}$ values are depleted and tend to be directly proportional to the respiration rate. In turn, the respiration rate is dependant on the availability of biomass or the amount of photosynthesis. If a certain region has always had the same type of vegetation (see below), the photosynthetic pathway effect is not applicable and any changes in carbon isotopic values could be attributed to the respiration rate. If water stress does not limit biological activity, then respiration rate typically shows a simple direct relationship to temperature.

2. The photosynthetic pathway effect: Atmospheric CO_2 is taken in by the plant's chloroplasts where carboxylation preferentially fixes the lighter isotope causing the plant's carbohydrates to be depleted. The extent of the depletion is dependant on the atmospheric fixation mode which is controlled by the photosynthetic pathway. There are three pathways and they are as follows:

a. Plants using the Calvin cycle, also known as the C_3 pathway, exhibit extensive isotopic depletion. The average $\delta^{13}\text{C}$ value is approximately -25 ‰ and varies from -32 to -20 ‰ (Boutton, 1991). Most temperate and broadleaf plants make use of the C_3 pathway.

b. Plants using the Hatch-Slack pathway, also known as the C4 pathway, exhibit less isotopic depletion than that found with the C3 pathway. The average $\delta^{13}\text{C}$ value is approximately -12 ‰ and varies from -19 to -9 ‰. Most desert plants and arid-tropical grasses are C4 (Hatch and Slack, 1970). C4 species generally have higher temperature optima for growth and net assimilation rate than C3 species; a higher water use efficiency; and, unlike C3 species, net photosynthesis does not light-saturate even at full sunlight.

c. The crassulasean acid metabolism (CAM) is a rare pathway, typically confined to succulents and, for the purposes of cave calcite analysis, will be ignored.

With all other factors being equal, the carbon signature in a speleothem may show shifts that could be interpreted as changes in the type of surface vegetation. In most situations this would be caused by changes in precipitation, where wet conditions are characterized by C3 plants and an increase in aridity would allow C4 plants to flourish. However, in some circumstances these changes may also represent changes in temperature where colder temperatures would be denoted by C3 plants and warmer conditions would be represented by C4 plants.

3. The drip rate effect: As water drips from the cave ceiling or stalactite onto the tip of the stalagmite, degassing and calcite deposition occurs. The remaining water flowing down the sides of the stalagmite will enrich with respect to the isotopic composition of carbon. This means that the calcite becomes

increasingly enriched in the downflow direction. Slow drip rates allow the drip to remain at the drip point for a longer period of time where an enrichment of the water will occur before it falls off onto the stalagmite. This implies that drier climates cause slower drip rates and the carbon isotopic enrichment of the stalagmite.

4. The bedrock proportion effect: The carbon found in speleothems derives from both the CO_2 (approximately -25 ‰ biogenic to -8‰ atmospheric) and the bedrock CaCO_3 (approximately 0 ‰ PDB). In typical closed systems, where the waters do not have continuous access to a supply of soil CO_2 after dissolution has begun, there tends to be roughly equal carbon input from both sources, but these proportions may vary. The bedrock CaCO_3 input is mostly controlled by the volume and aggressivity of the percolating drip waters, which in turn are controlled by climate and biological activity in a complex manner; e.g. at higher temperatures, the $P\text{CO}_2$ levels are high and the drip waters are more aggressive and dissolve more bedrock. Therefore, with a constant drip rate the isotopic composition of speleothem calcite will show an enrichment as the proportion of bedrock dissolved increases. The first three controls on carbon isotopes are usually much greater than the bedrock proportion effect. However, Shopov et al. (1997) warned that the influence of the bedrock fraction may be able to explain all of the carbon isotope variations. If this is the case, all of the biological and climatic controls must be expressed through bedrock fraction; however, this is probably only true for some samples.

5. The rainfall effect: The isotopic composition of soil CO₂ is dependant on the respiratory CO₂ and on the proportion of atmospheric CO₂. Abnormally heavy rains are theoretically capable of washing out biogenically-derived CO₂ from the soil. Several months may be required for soil atmospheres to recover (Rightmire, 1978). In the tropics, where respiration rates are high, the CO₂ might be replaced rapidly and the isotopic values would remain depleted. At lower respiration rates, such as in colder regions, soil CO₂ levels will remain low and isotopic values will be enriched. Consequently, prolonged heavy rainfalls may result in enrichment, which operates in contradiction to the drip rate effect. There are few studies on this effect and it remains essentially theoretical and will be considered to be a minor effect only.

4.5 Speleothem Crystallographic Structure

There is surprisingly little information regarding the relationship of speleothem crystal morphology with climate change. Crystal morphology has been studied and attempts have been made for a classification system but have not included any specific reference to the depositional environment. Nonetheless, a review of the available literature is pertinent to this study and is presented below.

1. Crystal Morphology

The available literature on the morphology of speleothem crystals does not yet offer clear and unanimous evidence to relate crystal shape with changes in environmental controls. There is even no consensus on the terminology of crystal morphology (Gonzales et al., 1992, Kendall, 1992), the terminology differing according to the writers. Folk and Assereto (1976) were the first to classify calcite morphologies. In many ways the simplest, this classification system still appears to be the most prominent system used today. Using Carlsbad Cavern (New Mexico) speleothems, Folk and Assereto (1976) developed two classes of calcites called a) normal (length-fast) 'palisade' calcite and b) length-slow calcite. Length-fast palisade calcite, the most prevalent form in speleothem, is made up of columnar crystals which are 2-10 mm long. These crystals are nearly parallel, sometimes with a very slight radiating or converging tendency, and have a semi-composite to weakly undulose extinction so that it is almost impossible to define precisely the width of the crystals, but they tend to be roughly 0.2-0.5 mm in width. The optic c-axis is oriented parallel with the fibres and perpendicular to the encrusted surface as is normal for calcite, i.e., the crystals are length-fast, with lower relief when the crystals are oriented N-S in the microscope field. Inclusions are virtually lacking, and the crystals are very transparent in both slide and hand specimen. Length-slow calcite occurs in three distinct forms: a) "coconut-meat" layers, b) tooth-shaped packets, and c) large zoned crystals. 'Coconut-meat' calcite has felted, crudely fibrous crystals which

form stubby undulose fibre-bundles, somewhat flame-like in shape, 0.1-0.2 mm long and 0.001-0.02 mm wide. The optic c-axis tends to lie subhorizontally, sweeping through an angle between 60 and 90° to the fibres. Tooth-shaped packets of length-slow calcite occur as radial to convergent packets of bladed, slightly curved crystals which are 0.1-1 mm long. Some crystals are elongated perpendicular to 60° to the optic-c axis. Zoned crystals form a palisade of calcite in distinct non-undulose crystals averaging 2 mm by 0.2 mm with multiple-zones outlined by abundant fluid inclusions. These crystals have sharp terminations at acute angles.

Kendall and Broughton (1978) developed a different divisive system for crystal morphologies. Unfortunately, the origin of the speleothem samples used in the study is not precisely known. The nomenclature divides crystals into two general groups: columnar and acicular crystals. Columnar crystals are elongated and wider than 0.01 mm. "Fibrous" is often used as a synonym for columnar crystals but they are much narrower. However, Jones and Kahle (1993) recommend defining fibrous crystals as having a length to width ratio of greater than 6:1. Acicular crystals are needle-like (i.e. markedly elongated and pointed) crystals that are less than 0.01 mm wide. The term is used regardless of the mode of packing of these crystals and thus includes material described as: a) Fibrous crystals, which are closely-packed acicular crystals, and; b) Spherulitic crystals, which are radiating, closely-packed acicular crystals.

Radiaxial fibrous calcite refers to calcite with the optic axes converging

away from the substrate (Kendall and Tucker, 1973; Kendall 1985). These crystals have also been referred to as fascicular optic calcite (Folk and Assereto, 1976, Kendall, 1977; Kendall, 1985).

Crystallites is a term used for extremely small crystals which grow syntaxially on the growth surface of the speleothem. If low drip rates prevail, these crystallites will remain small. Under higher drip rates, the coalescence of crystallites will form larger crystals (Broughton, 1983).

Regarding the origin of columnar crystals within speleothems, there is considerable debate. Much of the literature on this topic is based on speculation. Some growth layers can exhibit fabrics which are indicative of competitive crystal growth. This occurs following interruptions of speleothem growth where many small calcite crystals are deposited on its surface. These randomly-oriented crystals would begin to grow competitively with the final product being a palisade fabric oriented perpendicular to the growth surface. The main flaw of this approach is that with competitive growth, one would expect to find regions where competitive growth crystals are oriented in a direction other than perpendicular to the growth surface. Thus Kendall and Broughton (1978) and Onac (1999) believed that crystal fabric in most speleothems did not form by competitive growth. Rather, it was suggested that columnar calcite crystals did not interfere with each other's growth as individuals at the growing surface but coalesced instead.

2. Environmental Controls

The environmental controls for speleothem growth have been studied through the use of crystal morphology, drip water geochemistry and banding. Evidence of depositional environment should be apparent in crystals. Frisia's (1993) study of an Italian flowstone concluded that each single layer should preserve a geochemical imprint capable of representing the environment of deposition; however no examples were given.

As part of the attempt to understand the environmental controls of speleothem growth on the geochemical imprint, it is important to first of all understand the morphology of modern crystals in relation to the modern climate in which they formed. Bar-Matthews et al (1991) describe the morphologies of straw stalactites, stalagmites and helictites found in the Soreq cave in Israel. Low-magnesium calcite (LMC) is the most abundant component of the Soreq speleothem deposits in accordance with its position as the typical stable mineral in the freshwater low-temperature environment. All of these Soreq deposits develop as rhombohedral crystals aligned in an overlapping and radial-layered pattern. This textural form is frequently observed in stalactites and has been ascribed to a relatively enhanced supersaturation and growth rate (White, 1976). A less commonly observed texture in these Soreq speleothem has the c-axis of the calcite grains aligned parallel to growth axis (length-fast). Randomly oriented textures characteristic of rapid growth were rarely observed.

In addition to depositional environment, Frisia (1993) also suggested that

the subsequent history of the speleothem should be evident. Frisia (1996) provided petrographic evidence of diagenesis in speleothems which can be related to the periodic influx of undersaturated drip waters. Ancient speleothem from the Alps demonstrated dissolution and reprecipitation modifications which are probably due to glacial-interglacial cycles.

There has been limited research into the cave seepage fluid's flow and chemistry as a control of crystal morphology. Kostecka (1993) suggest that acicular and columnar calcites form under a high rate of CaCO_3 precipitation from CO_2 -saturated waters beneath the water-air interface whereas finely crystalline calcite would tend to form at the water-air interface. Jones and Kahle (1993) concluded that fibre crystals form from CaCO_3 -supersaturated fluids. They also noted that the crystals form under both biogenic and abiogenic controls and are characterized by diverse morphologies. Gonzales et al. (1992) suggested that under rapid flow conditions, the greater number of nuclei and the faster growth rate tend to produce fibrous calcite. Equant crystals tended to grow in the absence of flow and fibrous fabric may develop through oscillations of the water level, in the absence of flow.

In the 1990's, grey levels profiles, reflectance measurements, laser induced fluorescence and Raman spectroscopy have been used to study speleothem crystalline fabric as a means of palaeoenvironmental reconstruction. These are methods used to study the luminescence banding structures first observed by Shopov (1989; 1990; 1991). The luminescence is the product of the

excitation of humic and fulvic acids derived from the overlying soil. Drip waters are derived from soil waters and consequently incorporate these acids into the speleothems. Genty et al. (1994) as well as Genty and Quinif (1996), found that modern speleothem from France and Belgium are composed, partly or totally, of couplets of white-porous laminae and dark compact laminae of submillimetre dimensions, which are characterized by a different pore density. The measurement of the thickness of these couplets allowed a precise study of the speleothem growth to be made. The results demonstrated that the annual character of laminae couplets is due to water excess variations, and established a correlation between lamina thickness in a stalagmite and water excess. During years with a high water excess, dark compact laminae were more developed and consequently made the speleothem darker. The Belgium speleothem showed an exact correspondence between the number of laminae alternations and the age of the site where it was found. This demonstrated without a doubt that one lamina couplet was deposited in one year (Genty et al, 1994). Studies on a Late Glacial stalagmite reveal successive laminae microsequences which form very regular cycles of 11 years separated by a thick dark lamina. Since the dark laminae of the modern sample corresponds to a period of high water excess, this 11-year cycle may reflect a climate cycle (Genty and Quinif, 1996). Railsback et al. (1994) and Brooks et al. (1999) found that speleothem from Botswana and Madagascar, respectively, were composed of alternations of calcite and aragonite layers indicating that relations between climatic data and growth

laminae do exist. The results showed that the greater the rainfall, the thicker the calcite layers. The presence of aragonite layers is the consequence of an increase in the Mg/Ca ratio of available fluids, which is probably linked to a seasonal increase in the evaporation rate and cave temperature.

The preceding section of this chapter has reviewed the available literature encompassing speleothem crystallography and environmental reconstruction. It is apparent that the study of speleothem crystallography is a relatively young field of study and its use for palaeoenvironmental reconstruction is an even younger field of interest.

5.0 METHODOLOGY

5.1 Speleothem Sampling

A stalagmite (LOS2) and a flowstone (AB1) located in two separate Mona Island caves were collected by Dr. Joyce Lundberg in January, 1993. The samples were removed from the most inland (deepest) chambers of typical flank margin caves where they would not have been exposed to the atmosphere. The cave surveys are not yet available to illustrate the sample location sites.

Sample LOS2 originated from the Cueva de las Loquetas cave located at Punte Este, near the abandoned lighthouse on Mona Island's east coast (Figure 2.1). Cueva de las Loquetas interconnects with Cueva del Lirio and Cueva al Lado del Faro to form the island's largest cave found thus far. The total combined area of these three caves was estimated to be in the order of 202,000 m² (Briggs and Seiders, 1972). The cave system developed along the contact surface between the Lirio Limestone and the Isla de Mona Dolomite. Stalagmite sample LOS2 was collected from a humid bat chamber located at the back of the cave which could only be accessed by crawling. The sample was found on top of a layer of bat guano, was still active and was anticipated to be modern. This study is based principally on this LOS2 sample which has now been shown to have grown over the last 1,500 years or so, covering both the period of stability before significant human impact and the period of guano mining.

Sample AB1 originated from the Cueva del Agua, Playa Brava, a cave located on the southeastern shore of the island, a few hundred metres west of Puerta Los Ingleses (Figure 2.1). Tunnels in this cave has been modified by guano miners who leveled the floor, and piled small pieces of breakdown along the side of the passage to form rough stone walls and debris piles. This flowstone sample was collected from an inner chamber. This sample played a minor role, serving mainly to help in the calibration of the record of LOS2.

5.2 Data Collection

LOS2, the principle sample (Figure 5.1) is a small candle-shaped stalagmite approximately 22 cm long and 5 cm wide for most of its length. It is composed of opaque to translucent, pale yellow-white calcite, with varying content of darker brown bands and a few small dark brown spherules. In view of its location directly on top of bat guano, it is assumed that the dark bands and the spherules represent contamination from guano. Approximately 4.5 cm from the top, the diameter decreases to approximately 3.5 cm. This change is accompanied by a 1 to 1.5 cm wide band of distinctly darker, brownish translucent calcite. The sample shows no evidence of any depositional hiatuses, erosional events or diagenesis of any type.

AB1 is a piece of flowstone 4.2 cm thick that grew directly on top of the

Figure 5.1 LOS2 sample. The shaded areas indicate the 5 subsamples for TAMS dating. The solid rectangle shows the sample for 14-C dating. The dotted lines show the isotopic transect and the Hendy test.

bedrock. It is made up of clear or white, opaque calcite layers showing no evidence of erosional events or diagenetic alterations.

Each sample was cut parallel to its growth axis with a circular rock saw. The cut surfaces were sanded and then polished and marked with a scale. All subsequent sampling was recorded in relation to this scale. Thin sections from one half of the samples were made such that they completely covered the growth axis from the base to the top of the sample. Thin section analysis was performed using a standard petrographic microscope. Photographs were taken under crossed nichols (Appendix A) and then assembled into a composite. Crystal morphologies (width and lengths) were measured along a transect line parallelling the growth axis. Each data point is an average of the 5 crystals touching or closest to the transect line.

Stable isotope samples were microdrilled by hand with a 0.6 mm steel carbide burr bit from the cut and slabbed sections of samples (Figure 5.1). Samples of approximately 0.5 mg were drilled every millimetre along the growth axis for the entire length of the samples and one growth layer from LOS2 was also drilled for a Hendy test. Subsequent to each stable isotope sampling event, the sample slab and drilling burr bit were cleaned to minimize the possibility of cross-contamination. One hundred and sixty-eight (168) samples were obtained from LOS2 and 69 samples were obtained from AB1. The samples were sent to the Stable Isotope Laboratory at McMaster University, Hamilton, Canada for analysis. The equipment used for the analysis was a VG Isogas SIRA mass

spectrometer which has a machine reproducibility (for standards) of ± 0.06 ‰ for $\delta^{13}\text{C}$ and ± 0.07 ‰ for $\delta^{18}\text{O}$. Results are reported as ‰ versus PDB. The analytical error, which is the error of the counting statistics, is typically ± 0.006 ‰ for $\delta^{13}\text{C}$ and ± 0.013 ‰ for $\delta^{18}\text{O}$.

Samples AB1 and LOS2 underwent uranium series dating at Bergen University in Norway. The analysis was performed by Dr. Lundberg using a Finnigan MAT 261 Thermal ionization mass spectrometer (TIMS) in a positive ion counting mode using standard procedures and computer algorithms (e.g. Lauritzen and Lundberg, 1999b). Five LOS2 subsamples (Figure 5.1) and three AB1 subsamples of 2-4 g each for each sample were cut for U-Th analysis. The large sample size was required because of the low uranium content (0.11-0.19 ppm) and the young age of the samples.

Another subsample was cut from LOS2 at approximately 3.5 cm from the base for ^{14}C dating. This 5 mg subsample was sent to Tucson, Arizona for ^{14}C dating at the University of Arizona's NSF Arizona AMS Facility. The advantage of the accelerator mass spectrometry is that it is capable of precisely dating relatively small samples.

Luminescence analysis was performed at the University of Waterloo, Canada. Images were obtained using a confocal laser microscope with a 532 nm wavelength laser which provided the excitation source. This source causes the fulvic and humic acids to luminesce. Preliminary results indicated that there was an absence of banding in any of these calcites. Since it became obvious at

an early stage in the laboratory analysis that paleoenvironmental information could not be derived from these samples through the use of luminescence, the use of this method was terminated. Luminescence photographs of various parts of the samples can be found in Appendix B.

Since the methods of data analysis had to evolve in relation to the findings, the methodology of the data analysis will be discussed within the results section.

6.0 RESULTS AND DISCUSSION OF ISOTOPIC DATA

6.1 Sample Dates

Uranium thorium dating of LOS2 yielded the following ages (dated in years before 1998 and in mm from the base of the sample): 44,740 $\pm$ 122 years at 40.5 mm; 943 $\pm$ 14 years at 123 mm; 3,414 $\pm$ 11 years at 130 mm; 6,015 $\pm$ 28 years at 163.5 mm; and 7,959 $\pm$ 24 years at 174 mm. These dates obviously do not make stratigraphic sense and as a consequence the dating of LOS2 by U-Th will be considered unsuccessful. The technical reasons for this strange result are at present not understood.

A raw carbon-14 date of 1330 years $\pm$ 40 rcybp was measured in the 33.5 to 36.5 mm interval from the base of the LOS2 sample. On this basis the isotopic record for LOS2 covers the Late Holocene timespan of approximately 550 to 1993 AD, the year that the actively growing sample was collected. Since the ^{14}C dating of calcites requires a knowledge of the proportion of atmospheric carbon to rock-derived carbon, the raw dates usually can be taken only as an order of magnitude indicator. Fine tuning of the date is discussed in Section 10.7.

Uranium dating for AB1 was straightforward and made stratigraphic sense. The results indicates that AB1 grew from approximately 35,000 years ago to 19,000 years ago (Table 6.1), which would correspond to the middle to end of the Wisconsinian glaciation at marine oxygen isotope stages 3 and 2 (Figure

6.1).

Table 6.1: Sample Dates

Sample	Distance From the Base of the Sample (mm)	Date (Years)
LOS2	33.5 to 36.5 (Base)	1,330 ± 40 conventional rcybp
AB1	5 to 9 (Base)	34,961 ± 3,470 (by Tims U-Th)
AB1	10 to 14 (Middle)	22,725 ± 97 (by Tims U-Th)
AB1	38 to 41 (Top)	19,895 ± 76 (by Tims U-Th)

6.2 Hendy Test

As previously mentioned in Section 4.2, isotopic equilibrium must be maintained between calcite and the drip water in order for isotopic data to be meaningful for a simple temperature reconstruction (Hendy, 1971). If no evaporation occurred, the results would not indicate a strong positive correlation between the sequential values of $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ of samples taken at intervals along a single growth layer (Figure 6.2 (a)). Furthermore, the isotopes would not indicate a sequential increase in fractionation with distance from the central axis (Figure 6.2 (b)). Figures 6.2 clearly indicates that evaporation did not occur during the growth of LOS and consequently the isotopic results can be used to provide a relative temperature curve for the time covered by the speleothem growth (Gascoyne, 1992).

Figure 6.1. The relative ages of LOS2 and AB1 in relation to the Marine Ocean Isotope Stages (MOIS). AB1 grew during the isotope stages 2 and 3. LOS2 grew during the historic period of the Holocene.

Figure 6.2 Hendy test results.

6.3 Dominant Isotope Controls on Mona Island

The controls on the $\delta^{18}\text{O}$ and the $\delta^{13}\text{C}$ of cave calcites have been discussed in Section 4; the dominant controls on Mona Island are discussed below. The physical setting for Mona Island and the relatively quick growth of LOS2 limits the complexities of oxygen and carbon isotope control systems.

The oxygen isotopic controls are probably relatively simple:

- i) The Sea Surface Temperature (SST) of tropical waters around Mona Island did not appear to vary substantially between the present and the Last Glacial Maximum (LGM) of 18,000 years B.P. Within the Caribbean Sea, near Mona Passage, the difference between the modern SST and that of 18,000 years B.P. was between 0-2° cooler during August and between 2-4° cooler in February (Bradley, 1999; Figures 6.23 and 6.24, pp. 227-228). These temperature differences would have been even less between the present and 1,500 years ago. This would indicate that the source water temperature control would not have a significant effect on Mona Island.
- ii) The drip water composition control would not likely have an effect on Mona Island since the travel route from the source, the ocean surrounding the island, is minimal because Mona is a tiny island surrounded by the

Atlantic. Rozanski et al. 1993 noted that tropical island stations showed an inverse relationship between $\delta^{18}\text{O}$ and the amount of rainfall (termed the "amount effect"). The cave calcites of Mona Island may show an amount effect, which would be in the order of approximately 1.3‰ depletion for the doubling of the Mona Island rainfall. The nearest precipitation proxy (Thompson and Thompson, 1989) shows only a 28% increase during the extreme wet period of the LIA. A 28% increase in precipitation on Mona Island would produce a depletion of only 0.5‰. Normal isotopic variability would be less than this value.

- iii) Since LOS2 is only 1500 years old, the source (ocean) composition effect would have been essentially constant and therefore would not affect the $\delta^{18}\text{O}$ of LOS2 since the ocean mixing time is in the order of 500 to 1,500 years (Bradley, 1999).

However, AB1 would most likely have been affected by the source (ocean) composition effect since it grew during the last glaciation. The equatorial Pacific V28-238 marine core (NOAA, 1999) indicates an average $\delta^{18}\text{O}$ value enrichment of approximately +2‰ from 35,000 to 19,000 years ago compared to the present.

- iv) Having removed all other controls, this leaves the cave (mean annual) temperature as the most likely control on the $\delta^{18}\text{O}$ of cave calcites in Mona Island during the timespan covered by LOS2. For AB1, even though the source (ocean) composition would control the placement of the mean

$\delta^{18}\text{O}$ values, the variations around the mean would be controlled by the cave (mean annual) temperature.

The carbon isotopic controls may be a little more complex:

- i) The photosynthetic pathway of broad-leaved tropical forest species is C3. The lifespan of tropical trees can be in the order of 100-300 years (Kritcher, 1997). This means that the photosynthetic pathway is not likely to change while the forest remains intact and throughout minor climatic changes or short-lived climate changes. Over the millennium of LOS2's growth, before the significant climatic perturbations of the Little Ice Age, it is likely that C3 plants remained dominant. However, during the LIA, especially the dry part of it (see below), there may have been a change to C4 plants. It is probable that C4 plants had taken over during the Wisconsin glacial which implies that AB1 may represent only C4 vegetation.
- ii) The drip rate control is likely to be very similar to the photosynthetic pathway control and again operate mainly in the extreme climatic change of the LIA.
- iii) The bedrock proportion effect is likely to have been minor; details of the ^{14}C dating of LOS2 (discussed in Section 6.7) indicate a very low contribution of carbon from the bedrock.
- iv) For the majority of the record of LOS2 and AB1, the oscillations in the

$\delta^{13}\text{C}$ record are most likely to indicate simply a change in the biological activity. The hotter and wetter that Mona Island becomes, the greater the biological fractionation and the more negative the carbon isotopic value.

6.4 The Need for an Independent Paleotemperature Record

Isotopic studies on cave calcites usually require a way to calibrate the signal (Lauritzen and Lundberg, 1999a,b; Brooks et al., 1999) using some known date and known environmental conditions (eg, the Young Dryas or glacial time periods of known temperature drop can be used in glaciated regions). For example, Lauritzen and Lundberg (1999b) used pollen, pine trees, diatoms and the LIA for calibration of samples.

For the present study, an independent tropical paleotemperature record was required in order to compare with, and interpret, the environmental changes which occurred on Mona Island. Furthermore, a secondary record would provide reliable dates. The availability of climatic records for tropical and subtropical regions is generally scarce. The latitudes which encompass Mona Island generally lack historical records or meteorological observations. Their distal relationship to polar regions preclude the use of polar ice caps as a proxy for climate change. Furthermore, low latitude conditions inhibit the formation of seasonal rings, preventing the formation of dendroclimatological records. A reliable independent

temperature paleorecord for Mona Island had to be found further afield. Fortunately ice fields located in the Andes provide a proxy for climate change. Thompson and Thompson (1987, 1989) have interpreted two ice cores recovered from the Quelccaya Ice Cap of the Peruvian Andes located only 13° south of the equator (Mona Island is located 18° north of the equator). The ice cores developed in a region where human-induced environmental degradation has not likely occurred and their isotopic data were considered to reflect only climatic changes (the annual oxygen isotopes and accumulation for these ice cores can be found in Appendix C). The Quelccaya ice cores were therefore used as an independent paleotemperature record for this part of the tropics.

6.5 Quelccaya Ice Cores

Thompson and Thompson (1987, 1989) have interpreted two ice cores recovered from the Quelccaya ice cap in 1983 (13°56' S., 70°50' W), situated in the easternmost glaciated mountain chain of the Peruvian Andes. This ice cap is located approximately 3,800 kilometres from Mona Island but at almost the same latitude on the other side of the equator (Figure 2.1). The Quelccaya ice cap covers an area approximately of 55 km² and has a summit elevation of 5,670 m. Precipitation on the ice cap falls as snow throughout the year with the main source originating from the east, ultimately the Atlantic Ocean.

The Quelccaya ice cores have been dated to AD. 1500 with an estimated uncertainty of ± 2 years. The very accurate dating is the direct result of the use of multiple stratigraphic features that exhibit seasonal variability. The dominant control of $\delta^{18}\text{O}$ for the Quelccaya ice cores is temperature. The distance and elevational difference of the ice cap from its source imply that colder conditions are characterized by more negative δ values. This mechanism operates in opposition to the δ values in the cave calcites.

Data are available for two cores and they have a slightly different signal. A correlation coefficient (r^2) of only 0.24 for the raw data of the two cores indicates poor correlation, although smoothing of the data by 22 years raises the r^2 to 0.55. Nonetheless, one of the cores had to be chosen to use for the cave calcite calibration. Thompson and Thompson (1996) noted that the ice cap has recently experienced an accelerated rate of retreat as the snowline has risen in response to warming conditions. The $\delta^{18}\text{O}$ record from the core drilled at the summit compared with Core 1 revealed that the isotopic seasonal signal was no longer preserved within Core 1 and that the isotopic average was enriched by 2‰. The Quelccaya Summit ice core was therefore chosen as the best independent paleoenvironmental proxy with which to calibrate the cave isotopic record.

Since the ice core data are of such high resolution, they cannot be directly compared with the LOS2 data. Therefore, the data had to be smoothed in order to become useful. Smoothing of the data clarifies trends and reduces the effect of individual or local variables. Attempts were made to find an optimum running

mean time period which allows peaks and troughs to remain visible without excessive simplification or excessive detail. The 49-year running mean proved to be an optimum running mean time period and as a consequence the data for 49-year running mean were used for correlation purposes.

6.6 Interpretation of Tropical Paleoclimate As Recorded by the Quelccaya Ice Cap

The most valuable paleoclimate signals in the ice core record are the paleotemperature indicated by the $\delta^{18}\text{O}$, and the paleoprecipitation indicated by the accumulation. The climate record is divided into two obvious phases, especially apparent in the temperature record.

- i) The pre-LIA time period is characterized by low interannual variability in temperature which is visible in both the raw data as well as the 49 year mean for both cores (Figures 6.3 and 6.4). Low amplitude cyclicity is also apparent. The precipitation as shown by the accumulation record during the pre-LIA is also characterized by low interannual variability (Figure 7.1(a)) but with no apparent cyclicity.
- ii) In the Northern Hemisphere, the Little Ice Age (LIA), lasting from approximately the early 1500's to the late 1800's, is represented by a period characterized by colder temperatures and advancing glaciers

(Thompson and Thompson, 1989). The time frame for the onset and termination of this event varied historically depending on the locality and proxy utilized. The onset of the LIA in the tropical Andes through the analysis of $\delta^{18}\text{O}$ from the Quelccaya ice cap is characterized as a sharp drop to more negative δ values beginning in the 1520's and ending approximately in 1880. Two centuries ago southern Peru would have been in the middle of the LIA and temperatures would have been lowered by an estimated to 1-5°C depending on the location. A plot of the raw data (Figure 6.3) shows a greater interannual variability in the δ values during the LIA which may be partly due to greater seasonal variability (Thompson, 1989). Superimposed on the LIA signal is a shorter event from AD 1590 to 1630, there is a sharp decrease in the annual range of oxygen isotope variations which may be due to a larger scale atmospheric circulation change of the LIA onset and possibly partly due to Huaynaputina eruption of AD 1600.

- iii) The Quelccaya accumulation records illustrate that there have been significant changes in precipitation over the last 1500 years. The ice cap data reflect El Niño-Southern Oscillation (ENSO) events. El Niño events are associated with depressed accumulations on the ice cap. Droughts are recorded from AD 1720 to 1860 as well as from 1933 to 1945, the latter being a historically recorded drought. The periods AD 1500 to 1720 and 1880 to the present are associated with extremely wet conditions.

Figure 6.3. Raw data from Quelccaya Ice Core

Figure 6.4. The Quelccaya Ice Core 49 point smoothing of the isotopic data

The accumulation on the ice cap during the AD 1500 to 1720 period was 20 percent higher than the 1500-year average.

6.7 Tuning of LOS2 with Quelccaya Summit Ice Core

The radiocarbon dating of LOS2 from Section 6.1 was based on the assumption that none of the carbon found in the sample was “dead” carbon derived from bedrock input. Using this date, along with the fact that the sample was found to be still active when it was collected, a date for each LOS2 isotopic value was calculated using the assumption that the speleothem grew linearly. On this basis, the LOS2 sample would have started growing in AD 554. When a graph of the isotopes from LOS2, based on the ^{14}C date and the simple linear growth model (Figure 6.5(a)), is compared with the graph of the Summit core isotopes (Figure 6.5(b)), the peaks and troughs appear to coincide in pattern but are offset temporally and correlate poorly as evidenced by a low r^2 value. This is not surprising since the date was not corrected for dead carbon input and has not been calibrated for the ^{14}C flux.

Holmgren et al. (1994) noted that the dead carbon input in speleothems was dependant on the type of system that was dominant during the growth of the sample. An open system allows the replenishment of atmospheric or biogenic CO_2 to the dripwater as it permeates through the bedrock. Such a system will

show a small proportion of rock-derived carbon to atmospheric-derived CO_2 and may not require a correction for the input of dead bedrock. Once the drip water permeates through the bedrock, it is typically denoted by low $\delta^{13}\text{C}$ values. A closed system occurs when the supply of atmospheric CO_2 is severed once the drip water reaches and starts to permeate through the bedrock. A fully closed system has a 50% rock-derived carbon and 50% atmospheric-derived carbon proportion and will require a correction for the input of dead bedrock; it is typically denoted by relatively higher $\delta^{13}\text{C}$ values. For LOS2, a dead carbon input correction had to be estimated. Values typically used for the dead carbon input range from 0% to 50%. Dead carbon gives a fixed offset; for example a 1% dead rock input will offset a carbon date by 80 years. The higher the dead rock input, the higher the offset. The dead carbon correction must be assessed empirically. Typically the same growth layer is dated by ^{14}C and then by U-Th (eg. Holmgren et al, 1994). The U-Th is considered to be the reliable but much more expensive date, (hence the need to use carbon dates) and from this the the proportion of dead, rock-derived carbon is calculated. In this case the U-Th dating proved to be completely unreliable. Since the Summit core provides a dating precision of ± 2 years (Thompson, et al., 1989), it was used to date the LOS2 isotopic data by tuning LOS2 to it.

By matching up key characteristic peaks from the LOS2 5-point running mean isotopic data, which represents roughly 40 to 50 years integrated, to the Summit core (49-point running mean), a re-dated version of the LOS2 sample

A) - Untuned 5 Point Running Mean

B) - 49 Year Running Mean

C) - Tuned

Figure 6.5 The tuning of LOS2. The untuned LOS2 data (A) was tuned to Quelccaya (B) to produced the tuned LOS2 at C.

and all sample points was achieved. The tuning of LOS2 assumed that linear growth occurred between the key tuning peaks. The tuning of the key peaks was as follows:

- i) The LOS2 peak 136.5 mm from the base of the sample was fitted to the AD 1510 Quelccaya peak;
- ii) The LOS2 peak 97.0 mm from the base of the sample was fitted to the AD 1338 Quelccaya peak;
- iii) The LOS2 peak 45.0 mm from the base of the sample was fitted to the AD 1085 Quelccaya peak;
- iv) The LOS2 peak 29.0 mm from the base of the sample was fitted to the AD 977 Quelccaya peak;
- v) And, the LOS2 peak 9.0 mm from the base of the sample was fitted to the AD 806 Quelccaya peak.

The tuned LOS2 data are shown in Figure 6.5(c) and in Appendix D.

Using these new dates, the LOS2 sample would have started growing in approximately AD 729, just before the beginning of the ice record. The similar timing in the start date for the growth of the ice core and LOS2 may not necessarily be significant and is more probably a function of the timing that the cave drip rate became established. Using the re-tuned dates, the carbon dated sample grew at approximately AD 1014. It is interesting to note that in order to achieve this re-tuned date, a value of 4.13% for the dead carbon input would be

required in order to give an age of 990 conventional radiocarbon years prior to 1950. This confirms that the cave system on Mona Islands would have approximated that of an open system. Using the Oxcal v2.18 program (Stuivier and Kra, 1986) to calibrate for ^{14}C flux based on dendrochronological records, the 990 conventional radiocarbon years prior to 1950 would give the desired calendar year of AD 1014 (Appendix E).

6.8 Characteristics of Speleothem Isotopic Record

The LOS2 isotopic records ($\delta^{18}\text{O}$ and $\delta^{13}\text{C}$) on the tuned timescale are shown in Figure 6.6(a) and in Appendix D. From the plot, the most apparent features are:

- i) the relationship between the isotopes of carbon and oxygen,
- ii) the cycles,
- iii) the difference between the pre-1510 and post-1510 timeframes.

The oxygen and carbon isotopes appear to correlate well with each other; the raw data show a correlation factor of 0.862 ($r^2 = 0.74$). The 5-point running means reveal an even higher correlation factor of 0.917 ($r^2 = 0.84$), indicating that there is a strong positive relationship between the isotopes of carbon and oxygen found in LOS2. This strong correlation is not surprising considering that both isotopes are controlled mainly by temperature or temperature-controlled biomass.

The second major characteristic of the data is the cyclical nature. The isotopic record reveals a fairly repetitive cycle between the peaks found at AD 806 and AD 1510 (i.e. the pre-1510 period). Within this timeframe, the cycle is approximately 140 years. The wavelength of the cyclicity cannot be measured confidently with only four wavelengths of data available. However, it is of interest that the periodicity of 140 years is in the same order of magnitude as the Gleissburg cycles of sunspot activity (Frick et al., 1997), variously quoted as between 90 and 140 years.

The third major characteristic is the division into two periods, each showing markedly different behaviour. The division occurs at approximately AD 1510. The cyclicity breaks down after AD 1510, where there is a dramatic drop in both the oxygen and carbon values. The isotopic values approximate their former range after AD 1753 (i.e. towards the end of the LIA) but then fall again after AD 1871 and rise again after AD 1927. Table 6.2 shows that the $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ values prior to AD 1510 tend to have a narrow total range in values. On the basis of the obvious change in behaviour occurring after approximately AD 1510, the data were then divided for the rest of the analysis into the pre-1510 and post-1510 era.

While not the focus of this study, it is interesting to see that similar features can be seen in the AB1 glacial sample (Figure 6.6(b)), although the cyclicity is a different order of magnitude temporally. The AB1 oxygen and carbon isotopes appear to correlate well with each other and have a small total

Figure 6.6 a) LOS2 stable isotopes and, b) AB1 stable isotopes

range. The raw data also have a high correlation coefficient of 0.749 ($r^2 = 0.56$) and 0.739 ($r^2 = 0.55$) for the 5-point running mean.

Table 6.2: Speleothem Isotopic Averages, Ranges and Correlation with Quelccaya Results

Sample	Time frame	$\delta^{18}\text{O}(\text{‰})$			$\delta^{13}\text{C}(\text{‰})$		
		Average	Total Range	Correlation with Quelccaya (r^2)	Average	Total Range	Correlation with Quelccaya (r^2)
LOS2	AD 729- 1993 (Complete)	-3.11 $\pm$ 0.52	2.41	0.4	-7.34 $\pm$ 1.07	5.24	0.36
LOS2	AD 729-1510 (Pre-1510)	-3.36 $\pm$ 0.31	1.58	0.49	-7.78 $\pm$ 0.68	3.03	0.39
LOS2	AD 1510-1993 (Post-1510)	-2.68 $\pm$ 0.52	1.96	0.03	-6.58 $\pm$ 1.19	4.25	0.07
AB1	33,000 to 17,000 BC	-2.51 $\pm$ 0.39	1.53	N/A	-3.72 $\pm$ 0.67	2.91	N/A

6.9 Interpretation of the ^{18}O record of LOS2

Can LOS2 be calibrated?

If the $\delta^{18}\text{O}$ record of LOS2 is to be used as a paleotemperature record then it must be calibrated, ideally to give absolute temperature changes but more realistically to give relative temperature changes. It was the intent that the calibration of LOS2 would be performed through the use of AB1 but unfortunately this was not completely successful. AB1 had been included in this

study because it grew during the Wisconsinian glacial, a time marked by increased aridity and slightly subdued temperatures in the tropics (Bradley, 1999). It was hoped that the isotopic averages of AB1 could be used in the interpretation of LOS2 to represent cooler conditions and indeed the average isotopic values from the glacial sample AB1 are shifted to a more enriched value than the average for LOS2. However, as discussed above in Section 6.3, during the time of AB1 growth, the source ocean water composition would have been significantly enriched. The equatorial Pacific V28-238 marine core (Shackleton, 1977) demonstrated an average $\delta^{18}\text{O}$ enrichment of approximately $+2\text{‰}$ from the glacial time range of 35,000 to 19,000 years ago to the present. Since the average $\delta^{18}\text{O}$ value difference from AB1 with respect to the entire LOS2 oxygen isotopic record is only approximately $+0.60\text{‰}$ (or 0.75‰ from the pre-1510 value), the difference can be entirely explained by Source (Ocean) Composition Control. Therefore, the $\delta^{18}\text{O}$ values of AB1 cannot be used to calibrate LOS2. Consequently, the calibration was done through the use of the Quelccaya ice core.

Are the oxygen isotopes of LOS2 representative of temperature?:

Figure 6.7(a) shows LOS2 $\delta^{18}\text{O}$ and ice core $\delta^{18}\text{O}$ records. In order to see if the oxygen isotopes of LOS2 can indicate temperature changes, the correlation coefficients of LOS2 $\delta^{18}\text{O}$ and the ice core $\delta^{18}\text{O}$ were calculated. This regression of LOS2 onto the Quelccaya Summit ice core is, in some

respects, a circular argument since LOS2 was tuned to the ice core. However, the correlation series serves to demonstrate that the cave calcite has a similar pattern to the ice core. Since the ice core is acknowledged to be a proxy for climate, the cave calcite must also be indicative of climate. Furthermore, since the ice core represents undisturbed (by humans) conditions, the regression will also serve as a test of the impact of human activity on Mona Island.

The results for the regression of LOS2 5-point mean against the Quelccaya 49-point mean are included in Table 6.2. It can be seen that they do correlate to some extent ($r^2=0.40$ for the whole time frame). When the record was divided into the pre-1510 and post-1510 period, the r^2 value increased to 0.49 for the pre-1510 time frame and decreased to 0.03 for the post-1510 period. These results suggest that:

- i) the pre-1510 LOS2 $\delta^{18}\text{O}$ record is indicative of a temperature control.
- ii) the post-1510 LOS2 $\delta^{18}\text{O}$ is not controlled only by temperature but by another factor as well, possibly human involvement.

Do oxygen isotopes of LOS2 indicate human impacts?

If LOS2 was modelled such that a temperature-only control was used in the post-1510 period, then the possible human involvement could be characterized. Since the pre-1510 LOS2 and Quelccaya time frame display a

(a) - Quelccaya Isotope Correlation with LOS2 Isotopes

(b) - LOS2 Modeling Result

Figure 6.7 a) LOS2 18-O plotted with the ice core 18-O, and
b) plot of the unmodeled and modeled LOS2

similar cyclicity, a linear regression analysis was performed between these two sets of data for the pre-1510 period. The results indicate that the mathematical representation of their relationship is as follows:

$$y = (-0.94207)x + (-20.1008) \quad (2)$$

where x is the ice record and y is the LOS2 record. Using the $\delta^{18}\text{O}$ of the ice core to represent temperature changes without any human impacts, this equation was then used to model the post-1510 LOS2 isotopic curve. Figure 6.7(b) illustrates a graphical representation of this modeled LOS2 isotopic curve along with the actual data. The curves differ substantially in the post-1510 period in 4 respects:

- i) The beginning of the LIA appears in the modeled data as a sharp drop beginning at 1520. This seems to occur some 80 years later in the real data.
- ii) The real data drop to approximately 1‰ below the modeled data for the years AD 1700 to 1800, so the temperatures of LOS2 during the LIA would appear to be somewhat lower than expected.
- iii) The modeled data show the expected simple temperature rise after approximately AD 1750 - 1800 denoting the end of the LIA. The real data begin this recovery at approximately AD 1750; however AD 1870 - 1920 marks a sudden drop back down almost to the LIA values. It is only after 1920 that the post-LIA warming resumes.

- iv) The real data do not recover to their pre-LIA values

Discussion of the LOS2 $\delta^{18}\text{O}$ record:

- i) The pre-1510 environment is indicated by a higher $\delta^{18}\text{O}$ average than the post-1510 environment. These $\delta^{18}\text{O}$ values tend to have a narrower range and show relatively slight temperature fluctuations. In relation to the pre-1510 isotope average, relatively warmer periods occur from the earliest record to AD. 850, AD. 925 to 1000, AD. 1040 to 1125 and AD. 1275 to 1410. Relatively cooler than average periods occur from AD. 850 to 925, AD. 1125 to 1275 and AD. 1410 to 1500. These patterns can also be seen in the Quelccaya Summit ice core.
- ii) The post-1510 LOS2 environment is indicated by a much lower $\delta^{18}\text{O}$ average than that found during the pre-1510 environment. With an average $\delta^{18}\text{O}$ value of -2.68 ‰, the post-1510 environment exhibits an average value more typical of the last glacial period as indicated by the average $\delta^{18}\text{O}$ of AB1 of -2.5 ‰. Even though this time frame encompasses the LIA, the average value would still be considered quite low. The LIA is characterized by cooler than average temperatures but never approximated that of glacial times. Thompson and Thompson (1989) noted that the onset of the LIA through the analysis of $\delta^{18}\text{O}$ from the Quelccaya ice cap began in the 1520's and ended approximately in 1880. The onset of the LIA through the analysis of $\delta^{18}\text{O}$ from LOS2 also

indicates that the LIA began soon after this time on Mona Island.

- iii) The extraordinary drop in $\delta^{18}\text{O}$ at AD 1871 - 1920 is exactly co-incident with the timing of the guano mining operations, suggesting that the oxygen isotopes do show a response to the anthropogenic environmental degradation although the mechanism for the response is not clear. This is further discussed in the next section.
- iv) The $\delta^{18}\text{O}$ values have never returned to their pre-LIA values, suggesting that the impact of humans is still apparent in the cave calcites.

6.10 Interpretation of the ^{13}C record of LOS2

Is the $\delta^{13}\text{C}$ of LOS2 controlled by humidity (drip rate effect)?

If $\delta^{13}\text{C}$ is controlled by drip rate it should correlate with the precipitation records. When compared to the Quelccaya precipitation record (Figure 6.8(a)), LOS2 does not correlate ($r^2=0.0117$). Even if the record is divided into pre-1510 ($r^2=0.049$) and post-1510 ($r^2=0.00024$), neither section shows a correlation. It appears that during the pre-1510 era of LOS2, when the forest cover would have remained intact, the carbon signal correlates with temperature and does not correlate with precipitation ($r^2=0.39$). This indicates that the carbon only responded to temperature controlled biomass levels (see Figure 6.8(b)).

Consequently, the drip rate was probably not an important factor in the pre-1510 period.

During the dramatic climate changes of the early LIA with the sharp temperature drop and huge increase of precipitation (as indicated by the ice core $\delta^{18}\text{O}$ and accumulation) it is likely that the controls on $\delta^{13}\text{C}$ of LOS2 changed; however, the absence of any correlation with precipitation suggests that drip rate was not important for this period either.

Is the $\delta^{13}\text{C}$ of LOS2 controlled by changes in the photosynthetic pathway?

There are two pieces of evidence which can be used here to answer this question. First of all, the AB1 $\delta^{13}\text{C}$ probably represents C4 vegetation. It has an average value of 3.7 ± 0.77 ‰ (3 to 4.4 ‰ range). The LOS2 $\delta^{13}\text{C}$ pre-1510 values never approach the AB1 values and therefore presumably never represent C4 vegetation. However, the post-1510 LOS2 values do reach the AB1 range at approximately AD 1750. The carbon signal for AD 1750 in LOS2 has a value of -4.24‰.

Another piece of evidence which is relevant to this argument is the evidence in bat guano (McFarlane, 2000, personal communication, unpublished data). Modern bat guano found in the coastal plain caves of Mona indicate a C3 pathway. This correlates with the fact that there are presently trees on these coastal plains. However, bat guano from AD 1750 indicate that the C4 pathway was dominant. The Quelccaya accumulation record indicates that in AD 1750

Figure 6.8. a) LOS2 13-C plotted with the Quelccaya accumulation, and b) LOS2 13-C plotted with the Quelccaya 18-O.

there was a drought (Thompson and Thompson, 1989). The coincidence of the drop in $\delta^{13}\text{C}$ values to C4 values and the drought in the ice core suggests that dry periods on Mona would be indicated by a C4 pathway. This is an indication that some parts of the post-1510 era were in fact influenced by precipitation expressed through vegetation type (in spite of the low correlation coefficient).

Do carbon isotopes of LOS2 indicate human impacts?

The carbon isotopes follow roughly the same pattern as the oxygen isotopes. The end of the LIA ice age coincides with a return to average $\delta^{13}\text{C}$ values, but this recovery is again interrupted in the period AD 1870 - 1920 and again followed by an incomplete recovery. It appears that carbon isotopes in LOS2 also respond to human impacts.

Discussion of the LOS2 $\delta^{13}\text{C}$ record:

- i) the $\delta^{13}\text{C}$ does not respond to the photosynthetic pathway during the pre-1510 period but only to biomass levels, which implies that the drip rate was probably not an important factor in the pre-1510 period.
- ii) During the LIA $\delta^{13}\text{C}$ values continue to be controlled by temperature (the carbon values begin to drop along with the ice core $\delta^{18}\text{O}$ values at approximately 1520). However, the LIA drought caused a shift to C4 vegetation which shifted the dominant controls in the carbon isotopes to drip rate and the photosynthetic pathway.

- iii) The carbon isotopes show a response to anthropogenic environmental degradation during the time of the guano mining when $\delta^{13}\text{C}$ values approached the C4 values. Since the $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ of LOS2 correlate well together, they both indicate parallel enrichment, possibly due to evaporation. One possible mechanism for evaporation to take place is by increasing the cave temperature such that the relative humidity decreases enough to allow evaporation to occur. It is possible that the source for the increased heat derived from the lighting system used by the guano miners, however this is purely speculative.
- iv) The carbon isotopic signature has never returned to the pre-1510 C3 forest values, which is not surprising since the plateau vegetation is now still severely depleted.

6.10 Paleoenvironment of Mona as indicated by the isotopic record of LOS2: summary

The record is divided into the pre-1510 and the post-1510 periods.

The pre-1510 period:

- i) demonstrates a strong relationship of $\delta^{18}\text{O}$ with temperature.
- ii) demonstrates a strong relationship of $\delta^{13}\text{C}$ with biological activity.
- iii) demonstrates no change of vegetation type from C3 trees.

- iv) demonstrates oscillations of temperature and biological activity within a small range.

The post-1510 period:

- i) demonstrates high amplitude and very rapid changes.
- ii) demonstrates a relationship with precipitation during certain times.
- iii) demonstrates shifts of vegetation from C3 trees to C4 grasses.
- iv) demonstrates a strong indication of anthropogenic environmental degradation in the form of a sharp shift towards C4 of $\delta^{13}\text{C}$ values at a time of increasing wetness and enrichment of $\delta^{18}\text{O}$ values at a time of increase in temperature.

7.0 RESULTS AND DISCUSSION OF THE CALCITE MORPHOLOGY

Thin section analysis indicated that LOS2 and AB1 did not appear to have been diagenetically altered. The primary fabric was intact and there was no evidence that dissolution, transformation or recrystallization of the calcites occurred. Furthermore, there was no evidence of any erosional surfaces present which would be indicative of hiatuses. This implies that the crystal size and shape at the time of formation has been preserved.

Chapter 4 revealed that there is a lack of consensus on the terminology to be used to classify crystal fabric. In order to simplify the discussion below, no specific terminology is used; the crystal descriptions are based solely on their length and roundness. The raw data for the crystal measurement are found in Appendix F. The measurements reveal that the crystal width tends not to vary considerably (mean values of 0.20 ± 0.16 mm for LOS2 and 0.34 ± 0.21 mm for AB1) and that the dominant control on crystal morphology is crystal length (mean values of 0.80 ± 0.65 mm for LOS2 and 0.79 ± 0.52 mm for AB1).

Since we are examining the LOS2 crystal morphology in relationship to environmental controls, and the Quelccaya ice cap is being used as a proxy for climate, the LOS2 crystal measurements were plotted with the accumulation and $\delta^{18}\text{O}$ of the ice core record (Figures 7.1(a) and 7.1(b)). The ice accumulation was used as a proxy for precipitation and the $\delta^{18}\text{O}$ was used as a proxy for temperature. In order to pick out the most important controls, the extremes of

Figure 7.1. A) The accumulation and 18-O record of Quelccaya, and b) The crystal morphology of LOS2.

environmental conditions were examined first.

7.1 The Dry Extreme

The ultimate limiting factor for crystal growth is the drip rate. Without a drip, there is no crystal growth at all. Since the drip rate is an expression of the rainfall to evaporation ratio, the crystal morphology during droughts was examined. The $\delta^{18}\text{O}$ of the ice core record (Thompson, 1989) indicated that droughts, which are characterized by colder and drier conditions (Thompson, 1989), occurred at the times found in Table 7.1. The crystal forms associated with these times are also included in Table 7.1: they are without exception short (less than 0.4 mm) and round (less than 2.5:1).

Table 7.1: Cold and Dry Events and Associated Crystal Morphology

Cold and Dry Events	Crystal Morphology
AD 900 to 950	Short and Round
AD 1450 to 1510	Short and Round
AD 1750 to 1800	Short and Round

There is also an interesting correlation between the temperature during the droughts and crystal morphology. Not only do these severe droughts

correspond to the development of the majority of LOS2's shortest and roundest crystals but, the colder the drought, the shorter the crystals developed.

Further evidence of drip rate control can be found from AB1 crystal measurements. Since this sample grew during the relatively cooler and drier glacial period, it is not surprising to see that these crystals tend to be generally rounder than those found in LOS2.

Crystal morphology was also examined for conditions where warm temperatures prevail but the drip rate is a limiting factor. These periods and their associated crystals are presented in Table 7.2. Generally, during warm and dry periods, the crystals tend to be short and round, but not quite so short as in the cold dry times.

Table 7.2: Warm and Dry Events and Associated Crystal Morphology

Peaks in Warm and Dry Events	Crystal Morphology
AD 975 to 1000	Short and Round
AD 1310 to 1390	Short and Round

The evidence of crystal morphology during cold, dry and warm, dry conditions showed that:

- i) Extreme dryness is the overriding limiting control for crystal growth.
- ii) Temperature is the secondary control. While temperature does have a small direct influence on the crystallization process by increasing reaction

rates, its principal effect is indirectly, through biological action and the production of soil CO₂.

- iii) There is competition between controls when it is warm (high CO₂) but dry (low drip rate), which implies that there is no clear simple relationship of crystal length and temperature.
- iv) Crystal roundness and shortness seems to always be indicative of dryness. This implies that short and round crystals could be considered to be diagnostic crystal shapes.

7.2 The Wet Extreme

The other extreme of wetness occurs when there is no limitation at all on drip rate, then crystal length rather than roundness seems to be the most significant indicator. However, this is strongly controlled by temperature. On Mona Island, it is most common to find high temperatures associated with wet periods. The high temperatures cause high ocean evaporation rates and high rainfall levels. Therefore hot and wet events were picked out and compared with crystal morphology (Table 7.3).

Table 7.3: Hot and Wet Events and Associated Crystal Morphology

Peaks in Precipitation and Heat	Crystal Morphology
AD 780 to 840	Tall and Round
AD 1060 to 1160	Tall with Average Roundness
AD 1910 to 1933	Tall and Elongate

The crystal form demonstrated by all three events is the length of the crystals, with all crystals being longer than 1.8 mm. Crystal roundness is clearly more variable.

The temperature control is obvious when the cold and wet events are compared with crystal morphology. There is only one period of cold wet conditions which occurs at the beginning of the LIA at approximately AD 1510 to 1700. During this period there is an abundance of water but there is also a very sharp temperature drop which limits soil CO₂ levels. During this period the crystals are only of average length, ranging from approximately 0.5 to 1.5 mm in length.

The conclusion for the warm and wet periods and the cold and wet period is as follows:

- i) Wet conditions produce long crystals.
- ii) Temperature is again the second control, lower temperatures reducing crystal length, even when the water supply is plentiful.

This study of crystal form in relation to climatic conditions shows that :

- i) Crystal form only appears to be diagnostic at extreme environmental conditions.
- ii) The general rule which states that long crystals can be considered diagnostic of wet conditions, is not as clear as the general rule stating that small and round crystals are diagnostic of dry conditions.

7.3 Human-induced Environmental Degradation Control

The crystal morphology during the recent human history of Mona Island was compared to the climate data from the ice core (Table 7.4). From AD 1850 to 1870, the calcite crystals are tall and elongated, likely due to their response to high precipitation levels and post-LIA increasing temperatures. Between AD 1870 and 1900 the crystals become noticeably shorter and rounder even though precipitation levels remain high and temperature continues to increase. From AD 1900 to the present the crystals are the shortest and roundest in the recent human history of Mona Island, while the temperature for this period is the highest in the recent human history of Mona Island. With the precipitation levels also being above average, the climatic conditions for this time period are unique and should produce tall elongated crystals. However this is not the case and it is quite plausible that other controls are suppressing the growth of the crystals. The

shift from the tall to the shorter crystals coincides exactly with the onset of guano mining activity. This may be evidence that human-induced environmental degradation affected the growth of cave calcites. This effect is probably a result of deforestation and soil erosion which would reduce the production of soil CO₂.

Table 7.4: Recent Human History of Mona Island, Climate and Crystal Morphology

Year (AD)	1850-1871	1871-1900	1910-1927	1927-1933	1933-1945	1945-Present
Historical Events		Guano Mining			Drought	
Temperature			Warm			
Precipitation	Wet					
Crystal Morphology	Tall	Short	Shortest			

8.0 THE USE OF ISOTOPES AND CRYSTAL MORPHOLOGY FOR PALEOENVIRONMENTAL RECONSTRUCTION: SUMMARY AND CONCLUSION

The first general research question asked whether or not stalagmites from the tropical island of Mona contain a recognisable paleoenvironmental signature. In order to test this hypothesis oxygen and carbon isotopes of the sample LOS2 were compared with the temperature and precipitation records of the nearest tropical proxy, the icecap, Quelccaya Summit. A summary graph of all the LOS2 data and ice core data is shown in Figure 8.1. The isotopic results indicate that the paleoenvironmental record can be divided into two main categories: pre-1510 and post-1510. This division is not obvious from the crystallographic data.

1. The pre-1510.

This period begins at the beginning of the LOS2 isotopic record and ends at the onset of the LIA. LOS2 isotopes correlate well with the temperature records of the ice core. $\delta^{18}\text{O}$ of the cave calcite is controlled largely by the cave temperature effect, higher temperatures in the calcite indicated by more depleted isotopes. This period is characterized by a stable climatic regime. The oxygen isotopes show low amplitude cyclicity with an approximately 140 year wavelength. Since the sea surface temperature surrounding Mona Island during

Figure 8.1 Summary graph of all environmental parameters.

the LGM was only approximately 1-2°C cooler than present and the LIA temperature change in the tropics was roughly only in the order of 1°C, then the pre-1510 temperature oscillations, as shown on Figure 8.1, are likely only in the order of 0.3°C.

The carbon isotopes indicate that C3 vegetation prevailed within the pre-1510. $\delta^{13}\text{C}$ of the cave calcite is controlled indirectly during this period by temperatures. Increased biological activity is evident in the $\delta^{13}\text{C}$ record as more depleted values. Since the conditions were mainly warm and wet during this stable climatic period, any drought events would not have been long-lived enough to affect the photosynthetic pathway. Carbon levels correlate with temperature and biomass levels.

The crystal record appears to be sensitive only to certain environmental conditions. During drier periods, regardless of temperature, the calcite crystals remained short and round. Periods of higher than average precipitation permitted the calcite crystals to increase in height and become noticeably elongated. This pre-1510 period encompasses the times of the Medieval Warm Period of Europe (approximately AD 1100 to 1300) and of the Dark Ages Cold (approximately AD 500 to 1000). None of the records from LOS2 shows any change that could be related to these events (although the precipitation peak centred over AD 1150 in the ice core might relate to the Medieval Warm Period).

2. Post-1510

The LIA period, which began at approximately AD 1510 and ended in AD 1880 is a more complex period.

The first half is characterized by cooler than normal temperatures and with a large increase in precipitation from the LIA's onset to approximately AD 1750. Both the oxygen and carbon isotopes in LOS2 respond to the temperature drop during this period, although the oxygen response is lagged by approximately 80 years.

The second half of the LIA shows a marked change. The ice core record indicates that there was a severe drought from AD 1750 to 1800 while the temperatures remained low. During this time, carbon levels no longer correlate with temperature and biomass levels. The temperature control, which dominated until the middle of the LIA, has been replaced by a precipitation control. This shift also caused a change in the photosynthetic pathway to occur at approximately AD 1750, where a drought allowed the C4 pathway to dominate. Further evidence of this drought comes in the form of bat guano analysis which indicated that in AD 1750 the dominant photosynthetic pathway was C4.

The crystal morphology during the LIA is more complex and less conclusive. Crystal morphology is apparent when the temperature control operates at certain extremes. With water being the limiting control factor, cold and dry as well as warm and dry conditions impede crystal growth. Hot and wet conditions promote crystal growth. During the first half of LIA, the environmental

conditions do not generally match the aforementioned conditions. For example, from approximately AD 1510 to 1700 the conditions were cold and wet. During this period there is an abundance of water but there is also a very sharp temperature drop which limits soil CO₂ levels and crystals grew to only an average length. The drought in the second half of the LIA is shown very clearly in the very short round crystals.

The end of the LIA is marked by the ice core $\delta^{18}\text{O}$ starting to rise at approximately AD 1800 and reaching their peak at the 1940s. At the same time, precipitation increased. The response in the calcite seems to have begun after the AD 1750-1800 drought with a rise in all three measures - $\delta^{18}\text{O}$, $\delta^{13}\text{C}$, and crystal length. However, all three suddenly shift immediately after AD 1871. This brings us to the next part of the research.

The second general question asked if historically documented human-induced degradation of the surface environment is detectable in stalagmites. The best known time of human occupation occurred during the mining activity of AD 1871 to 1927.

The period immediately preceding the mining activity is characterized by a strong increase (peak of depletion) in the oxygen and carbon isotopes which corresponds to the end of the LIA. The ice core record indicates that temperatures continued to increase from this period to the present. However, the Monna isotopes indicate a very sharp decrease in the isotopes of both oxygen

and carbon occurring at approximately AD 1870. It is probable that this drop in isotopes, which by all indications should not be occurring, is due in part to the mining activity which operated using 300 to 400 workers with horses and equipment. Both the carbon and oxygen isotopes begin to increase only after AD 1927, the year that the mining operation ceased. Even though the isotopes have risen since that time, present values are still lower than the pre-1510 averages. This appears to be isotopic evidence of human-induced environmental degradation. It is quite probable that a deforestation event occurred during this period due to the industrial need for wood.

The crystal morphology appears to also operate in an unconventional manner during the mining activity. The period immediately preceding the mining activity is characterized by wet conditions with temperatures continually increasing. This time period is characterized by tall, elongated crystal. At the onset of the mining activity, the crystals begin immediately to shorten and become considerably rounder. This appears to be crystal morphological evidence of human-induced environmental degradation. It is quite probable that the deforestation event due to the industrial need for wood, affected the growth rate of the calcites on Mona Island.

The first overall conclusion of this research is that oxygen and carbon isotopes on Mona do respond to paleoenvironmental changes, the interpretation of which is about as simple or as complex as anywhere else in the world. It is

shown that tropical stalagmites are indicative of paleoenvironmental conditions and themselves could be used as proxies for other paleoenvironmental research. On a local scale, the results of this research on Mona Island can be used as a paleoenvironmental proxy for other samples to be analysed from different localities and time periods.

Crystal morphology is more difficult to interpret than isotopes in that average conditions produce crystals of average length and roundness. It is only extreme events that can be seen in the crystal morphology. Short and round crystals are always indicative of dry events while very elongate crystals usually indicate wet conditions but it need also to be warm for the longest crystals. In certain circumstances crystals could be more sensitive than isotopes - for example, crystals can record singular, short-lived events such as flood events or sharp droughts that may not be apparent in the 0.6 mm diameter isotope samples.

The second overall conclusion is that the isotopic and crystallographic records do indicate anthropogenically-induced environmental change on a small, local scale. Due to the many natural environmental factors which control isotopes and crystal shape and size, it is more difficult to quantify the extent of the natural versus human input and to explain the mechanism by which human activity can affect $\delta^{18}\text{O}$ of calcites. This research will hopefully point the way for other speleothem research into anthropogenic impacts.

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APPENDICES

APPENDIX A

Thin Section Photographs

Composite photograph of thin section LOS2 Number 1. This photograph represents the bottom of the LOS2 sample. The calcite sample found within this thin section is 30.4 mm long from top to bottom.

Composite photograph of thin section LOS2 Number 2. The calcite sample found within this thin section is 27.1 mm long from top to bottom.

Composite photograph of thin section LOS2 Number 3. The calcite sample found within this thin section is 15.2 mm long from top to bottom.

Composite photograph of thin section LOS2 Number 4. The calcite sample found within this thin section is 20.9 mm long from top to bottom.

Composite photograph of thin section LOS2 Number 5. The calcite sample found within this thin section is 26.6 mm long from top to bottom.

Composite photograph of thin section LOS2 Number 6. The calcite sample found within this thin section is 21.2 mm long from top to bottom.

Composite photograph of thin section LOS2 Number 7. The calcite sample found within this thin section is 20.6 mm long from top to bottom.

Composite photograph of thin section LOS2 Number 8. The calcite sample found within this thin section is 17.25 mm long from top to bottom.

Composite photograph of thin section LOS2 Number 9. This photograph represents the top of the LOS2 sample. The calcite sample found within this thin section is 23.1 mm long from top to bottom.

Composite photograph of thin section AB1 Number 1. This photograph represents the bottom of the sample. The calcite sample found within this thin section is 18.0 mm long from top to bottom.

Composite photograph of thin section AB1 Number 2. This photograph represents the top of AB1. The calcite sample found within this thin section is 24.8 mm long from top to bottom.

APPENDIX B

Luminescence Images

Composite photograph of luminescence of thin section AB1 Number 1. This photograph represents the bottom half of the AB1 sample. The calcite sample found within this thin section is 18.0 mm long from top to bottom.

Composite photograph of luminescence of top part of thin section AB1 Number 2. This photograph represents the top half of the AB1 sample. The calcite sample found within this thin section is 19.4 mm long from top to bottom.

APPENDIX C

Quelccaya Isotopic and Accumulation Data

QUELCCAYA ICE CORES DATA, PERU

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Year (AD)	Del 18-O (per mil)				Accumulation (m)	
	Raw Data*		49 Year Running mean		Raw Data*	49 Year Running mean
	Core 1	Summit	Core 1	Summit	Summit	Summit
1984	-19.93	-19.93	-19.93	-19.93	1.521	1.521
1983	-13.73	-14.11	-17.37	-18.01	1.171	1.171
1982	-18.45	-19.99	-17.15	-17.45	1.704	1.48
1981	-17.29	-17.58	-16.63	-16.95	1.521	1.48
1980	-16.36	-15.65	-17.32	-17.60	1.461	1.44
1979	-17.33	-17.42	-17.23	-17.18	1.522	1.28
1978	-17.18	-17.36	-17.35	-17.23	0.971	1.24
1977	-17.99	-17.89	-17.83	-17.85	0.947	1.18
1976	-17.91	-17.82	-18.46	-18.16	1.312	1.23
1975	-18.73	-18.76	-17.37	-17.48	1.164	1.32
1974	-20.51	-18.99	-17.26	-17.38	1.752	1.36
1973	-19.76	-19.49	-17.27	-17.37	1.406	1.44
1972	-19.22	-18.80	-17.29	-17.38	1.162	1.46
1971	-18.48	-19.15	-17.33	-17.41	1.692	1.46
1970	-18.80	-19.13	-17.34	-17.41	1.312	1.40
1969	-16.20	-16.43	-17.34	-17.42	1.721	1.40
1968	-15.04	-15.74	-17.33	-17.43	1.128	1.36
1967	-15.70	-16.44	-17.30	-17.40	1.167	1.55
1966	-16.05	-16.17	-17.23	-17.36	1.456	1.61
1965	-16.29	-16.28	-17.20	-17.33	2.279	1.69
1964	-16.63	-16.46	-17.16	-17.30	2.034	1.84
1963	-17.07	-16.95	-17.13	-17.27	1.526	1.78
1962	-18.06	-18.05	-17.10	-17.25	1.886	1.60
1961	-18.05	-17.87	-17.17	-17.33	1.159	1.46
1960	-18.08	-17.15	-17.21	-17.35	1.379	1.46
1959	-17.33	-18.25	-17.13	-17.28	1.357	1.46
1958	-16.07	-15.74	-17.20	-17.37	1.492	1.47
1957	-15.60	-16.23	-17.19	-17.35	1.195	1.47
1956	-16.92	-16.12	-17.22	-17.38	1.314	1.47
1955	-19.19	-17.73	-17.28	-17.44	1.454	1.49
1954	-18.11	-18.65	-17.28	-17.45	1.852	1.48
1953	-18.69	-19.77	-17.29	-17.46	1.469	1.49
1952	-16.25	-18.76	-17.28	-17.44	1.512	1.50
1951	-17.85	-18.99	-17.27	-17.43	1.099	1.50
1950	-18.60	-19.08	-17.21	-17.38	1.645	1.51
1949	-17.61	-18.52	-17.13	-17.32	1.83	1.50
1948	-17.82	-17.96	-17.07	-17.26	1.503	1.51
1947	-16.93	-16.77	-17.03	-17.23	1.69	1.52
1946	-18.29	-18.38	-17.04	-17.22	1.883	1.52
1945	-18.08	-18.55	-17.06	-17.24	1.598	1.53
1944	-15.52	-15.48	-17.12	-17.31	1.544	1.53
1943	-17.52	-17.26	-17.17	-17.35	1.446	1.53
1942	-15.23	-15.90	-17.28	-17.39	1.449	1.55

Year (AD)	Del 18-O (per mil)				Accumulation (m)	
	Raw Data*		49 Year Running mean		Raw Data*	49 Year Running mean
	Core 1	Summit	Core 1	Summit	Summit	Summit
1941	-17.18	-15.46	-17.35	-17.45	0.946	1.55
1940	-14.66	-14.27	-17.36	-17.50	1.154	1.53
1939	-14.19	-15.53	-17.37	-17.51	1.693	1.52
1938	-15.58	-16.00	-17.34	-17.49	1.29	1.53
1937	-15.75	-15.56	-17.33	-17.47	1.444	1.52
1936	-15.59	-15.48	-17.31	-17.45	1.296	1.52
1935	-16.01	-16.48	-17.30	-17.47	1.524	1.53
1934	-17.13	-18.46	-17.34	-17.51	1.578	1.54
1933	-17.91	-19.03	-17.40	-17.58	1.802	1.53
1932	-18.67	-19.07	-17.49	-17.65	1.583	1.55
1931	-19.36	-18.92	-17.52	-17.69	2.183	1.55
1930	-17.30	-17.54	-17.44	-17.64	1.07	1.54
1929	-17.86	-18.02	-17.37	-17.56	1.718	1.53
1928	-17.27	-16.90	-17.36	-17.54	1.243	1.54
1927	-17.60	-17.47	-17.41	-17.55	1.548	1.54
1926	-15.48	-16.11	-17.41	-17.51	1.399	1.55
1925	-16.95	-15.96	-17.35	-17.43	1.62	1.54
1924	-16.49	-16.94	-17.31	-17.39	1.426	1.53
1923	-17.51	-17.14	-17.31	-17.41	1.984	1.53
1922	-18.80	-18.78	-17.33	-17.44	1.593	1.52
1921	-20.08	-20.19	-17.30	-17.43	1.644	1.51
1920	-19.14	-19.58	-17.26	-17.40	1.941	1.51
1919	-17.44	-17.85	-17.32	-17.47	0.976	1.52
1918	-21.01	-18.28	-17.35	-17.54	2.113	1.52
1917	-19.23	-19.09	-17.45	-17.63	1.633	1.52
1916	-16.97	-18.60	-17.46	-17.68	1.382	1.53
1915	-17.26	-17.29	-17.54	-17.77	1.648	1.54
1914	-15.38	-15.78	-17.63	-17.84	1.576	1.54
1913	-17.46	-17.33	-17.69	-17.89	1.436	1.53
1912	-17.03	-16.74	-17.71	-17.92	1.523	1.54
1911	-17.96	-18.04	-17.74	-17.95	1.8	1.54
1910	-19.11	-20.00	-17.80	-18.00	1.564	1.54
1909	-19.24	-19.33	-17.82	-18.01	1.167	1.55
1908	-19.82	-19.70	-17.84	-18.02	1.993	1.54
1907	-18.40	-18.24	-17.81	-18.00	1.3	1.54
1906	-15.48	-15.20	-17.79	-17.98	1.144	1.52
1905	-14.68	-14.82	-17.77	-17.96	1.492	1.53
1904	-18.04	-18.70	-17.76	-17.96	1.6	1.52
1903	-18.56	-19.03	-17.79	-17.98	1.674	1.54
1902	-17.89	-17.22	-17.74	-17.95	1.732	1.55
1901	-15.45	-15.33	-17.79	-18.00	0.842	1.55
1900	-15.72	-16.59	-17.82	-18.06	1.577	1.55
1899	-17.82	-18.50	-17.89	-18.12	1.532	1.55
1898	-18.25	-18.68	-17.95	-18.18	1.264	1.54
1897	-16.72	-17.64	-17.96	-18.19	1.55	1.53

Year (AD)	Del 18-O (per mil)				Accumulation (m)	
	Raw Data*		49 Year Running mean		Raw Data*	49 Year Running mean
	Core 1	Summit	Core 1	Summit	Summit	Summit
1896	-15.90	-16.99	-17.94	-18.17	1.275	1.53
1895	-18.36	-19.17	-17.95	-18.18	2.144	1.52
1894	-19.45	-20.33	-17.98	-18.21	1.366	1.53
1893	-19.75	-20.28	-17.92	-18.20	1.545	1.52
1892	-17.94	-18.19	-17.92	-18.23	1.604	1.52
1891	-18.38	-18.69	-17.96	-18.24	1.456	1.52
1890	-18.45	-18.91	-17.94	-18.19	1.473	1.52
1889	-18.65	-18.60	-17.98	-18.22	1.171	1.52
1888	-16.63	-16.99	-18.02	-18.28	1.701	1.52
1887	-17.21	-16.92	-18.04	-18.31	1.45	1.51
1886	-18.82	-18.81	-18.03	-18.29	1.308	1.51
1885	-18.49	-18.97	-18.06	-18.30	2.004	1.51
1884	-18.52	-19.43	-18.04	-18.30	1.531	1.51
1883	-17.62	-18.11	-18.02	-18.27	1.548	1.50
1882	-18.06	-18.24	-18.04	-18.29	1.196	1.50
1881	-16.38	-16.55	-18.09	-18.34	1.721	1.51
1880	-17.49	-17.88	-18.13	-18.38	1.246	1.51
1879	-18.84	-17.96	-18.13	-18.35	2.029	1.50
1878	-14.94	-15.62	-18.11	-18.34	1.95	1.49
1877	-17.95	-19.01	-18.10	-18.38	1.49	1.48
1876	-18.36	-18.50	-18.17	-18.42	1.521	1.50
1875	-20.05	-20.15	-18.24	-18.49	1.536	1.49
1874	-20.34	-20.05	-18.25	-18.49	1.417	1.48
1873	-19.32	-19.09	-18.26	-18.50	1.401	1.49
1872	-19.31	-19.34	-18.31	-18.54	1.431	1.48
1871	-19.36	-20.15	-18.33	-18.51	1.239	1.47
1870	-19.01	-19.07	-18.31	-18.49	1.658	1.46
1869	-18.10	-18.07	-18.27	-18.43	1.738	1.46
1868	-19.03	-20.28	-18.22	-18.37	1.446	1.45
1867	-19.00	-19.45	-18.22	-18.37	1.611	1.44
1866	-16.42	-14.51	-18.23	-18.37	1.426	1.44
1865	-17.46	-17.33	-18.18	-18.33	1.462	1.43
1864	-19.24	-20.47	-18.18	-18.31	1.448	1.43
1863	-17.93	-18.23	-18.17	-18.32	1.378	1.42
1862	-17.57	-16.98	-18.20	-18.37	1.696	1.43
1861	-20.38	-20.28	-18.20	-18.38	1.478	1.43
1860	-18.64	-19.41	-18.19	-18.35	1.435	1.41
1859	-18.80	-18.51	-18.20	-18.34	1.332	1.41
1858	-19.31	-18.98	-18.18	-18.31	1.432	1.39
1857	-17.94	-17.58	-18.17	-18.32	1.357	1.40
1856	-16.51	-16.66	-18.20	-18.35	1.369	1.39
1855	-17.83	-17.38	-18.23	-18.38	1.381	1.39
1854	-18.03	-18.36	-18.20	-18.37	1.333	1.37
1853	-17.35	-19.29	-18.22	-18.39	1.039	1.36
1852	-18.51	-17.57	-18.21	-18.36	1.603	1.36

Year (AD)	Del 18-O (per mil)				Accumulation (m)	
	Raw Data*		49 Year Running mean		Raw Data*	49 Year Running mean
	Core 1	Summit	Core 1	Summit	Summit	Summit
1851	-19.18	-19.69	-18.20	-18.31	1.337	1.35
1850	-18.50	-18.55	-18.08	-18.20	1.223	1.34
1849	-18.93	-19.49	-18.05	-18.19	1.455	1.34
1848	-18.75	-19.29	-18.07	-18.18	1.212	1.33
1847	-17.01	-15.57	-18.02	-18.19	0.791	1.33
1846	-17.59	-18.38	-18.02	-18.16	1.538	1.33
1845	-17.41	-17.30	-17.99	-18.12	1.171	1.32
1844	-17.10	-17.12	-18.13	-18.21	1.253	1.32
1843	-17.96	-18.41	-18.14	-18.20	1.197	1.32
1842	-18.86	-18.78	-18.16	-18.22	1.274	1.31
1841	-15.93	-16.80	-18.25	-18.35	1.284	1.31
1840	-18.70	-17.54	-18.30	-18.44	1.09	1.30
1839	-16.51	-17.78	-18.32	-18.42	1.304	1.30
1838	-18.66	-19.13	-18.33	-18.45	1.591	1.30
1837	-18.85	-19.21	-18.36	-18.50	1.429	1.29
1836	-17.66	-17.73	-18.31	-18.46	1.019	1.28
1835	-19.24	-18.72	-18.32	-18.46	1.472	1.28
1834	-16.37	-16.83	-18.35	-18.50	0.849	1.27
1833	-17.94	-18.41	-18.34	-18.50	1.531	1.27
1832	-17.72	-18.13	-18.34	-18.54	1.014	1.26
1831	-18.81	-19.32	-18.46	-18.62	1.262	1.27
1830	-17.48	-17.71	-18.46	-18.60	1.469	1.27
1829	-15.66	-16.46	-18.39	-18.57	1.199	1.26
1828	-17.43	-17.40	-18.37	-18.56	1.453	1.27
1827	-18.21	-16.40	-18.37	-18.61	1.089	1.26
1826	-14.08	-14.85	-18.39	-18.59	1.21	1.26
1825	-18.80	-19.35	-18.37	-18.56	1.37	1.26
1824	-20.26	-18.73	-18.30	-18.55	0.843	1.26
1823	-16.94	-19.54	-18.36	-18.55	1.544	1.26
1822	-19.51	-18.61	-18.39	-18.66	1.127	1.28
1821	-17.31	-17.46	-18.47	-18.65	1.135	1.27
1820	-25.20	-22.22	-18.46	-18.66	1.576	1.27
1819	-19.29	-19.93	-18.46	-18.66	1.388	1.27
1818	-19.89	-20.55	-18.43	-18.61	1.397	1.27
1817	-20.97	-20.69	-18.37	-18.58	1.205	1.27
1816	-19.94	-21.57	-18.37	-18.61	1.294	1.27
1815	-20.09	-19.52	-18.35	-18.65	1.465	1.28
1814	-18.39	-19.64	-18.41	-18.69	1.065	1.28
1813	-19.44	-19.68	-18.41	-18.67	1.361	1.27
1812	-17.72	-18.43	-18.40	-18.68	1.12	1.26
1811	-19.22	-19.18	-18.42	-18.72	1.252	1.27
1810	-20.08	-20.76	-18.43	-18.74	1.008	1.27
1809	-18.74	-18.95	-18.49	-18.71	1.099	1.27
1808	-18.30	-19.43	-18.43	-18.71	1.106	1.27
1807	-22.06	-20.35	-18.41	-18.73	1.908	1.27

Year (AD)	Del 18-O (per mil)				Accumulation (m)	
	Raw Data*		49 Year Running mean		Raw Data*	49 Year Running mean
	Core 1	Summit	Core 1	Summit	Summit	Summit
1806	-18.05	-16.66	-18.40	-18.70	1.265	1.27
1805	-14.39	-16.95	-18.39	-18.73	0.822	1.27
1804	-16.64	-18.49	-18.48	-18.85	1.611	1.26
1803	-18.49	-20.38	-18.56	-18.89	1.007	1.25
1802	-20.08	-18.52	-18.56	-18.93	1.542	1.26
1801	-17.53	-17.24	-18.65	-19.05	1.108	1.26
1800	-15.58	-18.74	-18.68	-19.07	1.337	1.26
1799	-21.44	-19.55	-18.66	-19.05	1.479	1.27
1798	-18.70	-20.74	-18.67	-19.02	1.442	1.26
1797	-21.52	-18.14	-18.65	-19.03	1.042	1.27
1796	-16.60	-17.69	-18.69	-19.00	1.503	1.27
1795	-17.12	-17.19	-18.51	-18.93	1.282	1.25
1794	-16.64	-16.02	-18.50	-18.90	1.105	1.26
1793	-16.00	-16.97	-18.48	-18.92	1.296	1.25
1792	-15.75	-18.24	-18.49	-18.86	1.21	1.24
1791	-17.69	-19.71	-18.45	-18.74	1.403	1.24
1790	-19.47	-19.81	-18.41	-18.73	1.317	1.24
1789	-18.90	-18.19	-18.42	-18.73	1.04	1.24
1788	-18.09	-19.40	-18.39	-18.70	1.33	1.24
1787	-18.98	-19.90	-18.39	-18.70	1.05	1.25
1786	-19.57	-19.57	-18.39	-18.71	1.536	1.25
1785	-19.37	-15.40	-18.37	-18.65	1.235	1.25
1784	-14.81	-18.30	-18.35	-18.65	1.425	1.25
1783	-16.92	-19.29	-18.38	-18.66	1.12	1.26
1782	-18.29	-17.74	-18.41	-18.69	1.174	1.25
1781	-17.16	-19.38	-18.46	-18.77	1.121	1.25
1780	-19.65	-22.18	-18.54	-18.81	1.126	1.26
1779	-21.33	-19.14	-18.58	-18.82	0.993	1.26
1778	-18.30	-18.50	-18.62	-18.79	1.197	1.26
1777	-18.50	-20.74	-18.59	-18.81	1.403	1.26
1776	-20.47	-20.49	-18.61	-18.84	1.309	1.27
1775	-19.17	-17.82	-18.65	-18.82	1.416	1.27
1774	-17.70	-18.03	-18.59	-18.80	1.117	1.27
1773	-18.45	-19.12	-18.56	-18.73	1.275	1.25
1772	-19.22	-15.94	-18.42	-18.67	1.332	1.26
1771	-16.37	-18.85	-18.46	-18.70	0.515	1.27
1770	-18.74	-18.52	-18.52	-18.78	1.757	1.27
1769	-18.71	-21.15	-18.55	-18.84	0.934	1.28
1768	-21.42	-18.01	-18.66	-18.90	1.147	1.28
1767	-18.08	-15.47	-18.74	-18.96	1.047	1.29
1766	-18.10	-19.23	-18.78	-18.95	1.577	1.28
1765	-18.93	-19.36	-18.72	-18.89	1.161	1.29
1764	-18.20	-18.37	-18.69	-18.87	1.166	1.30
1763	-17.55	-18.39	-18.68	-18.84	1.384	1.30
1762	-19.18	-19.62	-18.62	-18.78	1.389	1.31

Year (AD)	Del 18-O (per mil)				Accumulation (m)	
	Raw Data*		49 Year Running mean		Raw Data*	49 Year Running mean
	Core 1	Summit	Core 1	Summit	Summit	Summit
1761	-19.38	-18.11	-18.60	-18.77	1.288	1.30
1760	-17.46	-18.95	-18.59	-18.85	1.077	1.30
1759	-19.93	-19.87	-18.66	-18.86	1.514	1.31
1758	-23.69	-21.81	-18.76	-18.89	1.303	1.33
1757	-20.14	-20.28	-18.79	-18.92	1.144	1.33
1756	-18.61	-18.99	-18.91	-18.99	1.368	1.34
1755	-18.57	-18.96	-18.92	-18.93	1.647	1.35
1754	-20.26	-19.32	-18.89	-18.94	1.102	1.35
1753	-18.63	-19.11	-18.86	-18.88	1.549	1.35
1752	-18.57	-18.79	-18.83	-18.82	1.333	1.35
1751	-17.40	-17.85	-18.78	-18.81	1.672	1.35
1750	-18.64	-18.49	-18.81	-18.85	1.231	1.36
1749	-17.04	-17.56	-18.88	-18.93	0.786	1.36
1748	-14.81	-14.91	-18.82	-18.84	1.577	1.36
1747	-18.76	-19.46	-18.74	-18.82	1.583	1.36
1746	-19.73	-21.07	-18.71	-18.79	1.362	1.38
1745	-18.37	-18.94	-18.71	-18.80	1.594	1.37
1744	-21.23	-19.62	-18.68	-18.72	1.485	1.38
1743	-19.83	-21.44	-18.61	-18.73	1.49	1.38
1742	-19.77	-19.30	-18.64	-18.81	1.265	1.39
1741	-16.52	-16.57	-18.68	-18.83	1.385	1.39
1740	-17.11	-17.22	-18.70	-18.86	1.621	1.39
1739	-17.92	-17.94	-18.75	-18.87	1.627	1.40
1738	-15.97	-17.28	-18.77	-18.89	1.166	1.41
1737	-18.23	-19.05	-18.71	-18.82	1.169	1.40
1736	-19.00	-19.33	-18.67	-18.79	1.408	1.41
1735	-18.42	-18.72	-18.65	-18.77	1.765	1.42
1734	-21.80	-20.52	-18.59	-18.72	2.243	1.41
1733	-19.78	-19.08	-18.44	-18.60	0.829	1.42
1732	-22.90	-22.90	-18.45	-18.60	1.901	1.42
1731	-20.34	-19.53	-18.44	-18.58	1.668	1.42
1730	-19.54	-19.49	-18.52	-18.55	0.717	1.43
1729	-17.03	-15.61	-18.49	-18.57	1.439	1.43
1728	-16.77	-17.93	-18.51	-18.58	1.323	1.43
1727	-18.43	-19.86	-18.54	-18.60	1.327	1.44
1726	-20.33	-19.81	-18.58	-18.61	1.935	1.44
1725	-21.48	-21.65	-18.58	-18.65	1.213	1.44
1724	-15.22	-14.70	-18.62	-18.66	0.973	1.48
1723	-15.37	-15.35	-18.72	-18.76	1.342	1.48
1722	-14.95	-17.22	-18.78	-18.80	1.468	1.47
1721	-18.62	-19.11	-18.77	-18.77	1.595	1.47
1720	-17.39	-17.24	-18.77	-18.76	1.231	1.47
1719	-18.08	-18.48	-18.72	-18.72	1.234	1.48
1718	-19.33	-19.42	-18.64	-18.63	1.609	1.47
1717	-19.99	-19.88	-18.61	-18.60	1.241	1.47

Year (AD)	Del 18-O (per mil)				Accumulation (m)	
	Raw Data*		49 Year Running mean		Raw Data*	49 Year Running mean
	Core 1	Summit	Core 1	Summit	Summit	Summit
1716	-20.00	-21.23	-18.66	-18.67	1.493	1.48
1715	-20.92	-18.82	-18.65	-18.65	1.747	1.48
1714	-18.22	-19.29	-18.71	-18.71	1.614	1.48
1713	-16.51	-15.89	-18.80	-18.80	1.129	1.48
1712	-17.38	-17.04	-18.79	-18.75	1.635	1.50
1711	-16.45	-17.62	-18.74	-18.69	1.513	1.51
1710	-16.70	-17.72	-18.76	-18.72	1.138	1.51
1709	-16.30	-15.69	-18.71	-18.70	1.521	1.49
1708	-20.93	-20.35	-18.69	-18.67	1.525	1.50
1707	-18.17	-18.04	-18.61	-18.60	1.401	1.50
1706	-22.18	-17.46	-18.54	-18.55	1.66	1.49
1705	-18.86	-20.30	-18.52	-18.54	1.536	1.50
1704	-19.53	-19.81	-18.61	-18.62	1.54	1.51
1703	-20.16	-19.47	-18.69	-18.65	1.672	1.54
1702	-19.17	-18.63	-18.71	-18.67	1.806	1.54
1701	-19.03	-20.46	-18.63	-18.64	1.163	1.54
1700	-19.02	-17.95	-18.62	-18.58	2.851	1.55
1699	-19.45	-19.53	-18.68	-18.67	1.559	1.57
1698	-21.97	-21.57	-18.76	-18.76	1.042	1.58
1697	-19.12	-19.43	-18.88	-18.81	1.305	1.58
1696	-18.37	-18.82	-18.89	-18.81	1.701	1.59
1695	-18.53	-17.66	-18.89	-18.81	1.574	1.60
1694	-16.05	-16.72	-18.90	-18.84	0.986	1.60
1693	-18.15	-17.80	-18.89	-18.83	1.252	1.61
1692	-19.19	-20.26	-18.85	-18.81	1.981	1.61
1691	-16.61	-16.42	-18.84	-18.78	1.787	1.62
1690	-21.07	-20.44	-18.78	-18.77	1.791	1.62
1689	-19.98	-21.67	-18.86	-18.84	1.196	1.62
1688	-18.03	-16.84	-18.94	-18.93	1.732	1.65
1687	-16.51	-16.51	-19.01	-18.99	2.27	1.65
1686	-19.40	-20.09	-18.99	-18.96	1.472	1.64
1685	-19.42	-19.54	-19.04	-18.97	1.341	1.67
1684	-18.81	-17.81	-19.12	-19.06	1.479	1.68
1683	-18.82	-19.24	-19.05	-19.01	1.616	1.68
1682	-17.14	-16.88	-19.02	-18.99	1.35	1.69
1681	-18.38	-19.20	-18.87	-18.93	1.082	1.69
1680	-21.19	-19.55	-18.85	-18.85	2.033	1.69
1679	-21.06	-19.33	-18.82	-18.83	2.581	1.70
1678	-19.01	-20.66	-18.82	-18.83	1.498	1.69
1677	-16.85	-18.58	-18.79	-18.83	1.774	1.69
1676	-20.86	-18.84	-18.75	-18.74	1.914	1.70
1675	-18.30	-18.80	-18.76	-18.79	1.918	1.69
1674	-18.88	-20.05	-18.72	-18.76	1.647	1.69
1673	-21.01	-19.56	-18.65	-18.69	1.788	1.71
1672	-19.31	-19.16	-18.59	-18.63	1.93	1.71

Year (AD)	Del 18-O (per mil)				Accumulation (m)	
	Raw Data*		49 Year Running mean		Raw Data*	49 Year Running mean
	Core 1	Summit	Core 1	Summit	Summit	Summit
1671	-17.06	-17.33	-18.56	-18.58	1.796	1.72
1670	-18.68	-19.59	-18.57	-18.58	1.246	1.72
1669	-18.66	-19.09	-18.58	-18.60	1.941	1.73
1668	-18.23	-19.12	-18.64	-18.65	1.251	1.75
1667	-19.34	-19.62	-18.62	-18.62	2.228	1.75
1666	-18.31	-18.41	-18.74	-18.74	1.814	1.75
1665	-22.23	-22.73	-18.69	-18.73	1.468	1.75
1664	-20.22	-19.95	-18.63	-18.64	2.311	1.77
1663	-20.75	-20.36	-18.67	-18.69	1.684	1.78
1662	-15.68	-15.94	-18.73	-18.76	1.266	1.77
1661	-18.74	-18.41	-18.70	-18.71	2.466	1.77
1660	-20.62	-19.94	-18.57	-18.59	2.047	1.78
1659	-17.35	-17.75	-18.50	-18.56	1.697	1.79
1658	-16.86	-17.37	-18.49	-18.54	1.842	1.79
1657	-14.78	-14.17	-18.49	-18.56	1.704	1.79
1656	-17.95	-16.79	-18.51	-18.56	1.494	1.81
1655	-18.06	-18.64	-18.48	-18.58	1.71	1.81
1654	-19.90	-19.46	-18.43	-18.58	1.571	1.81
1653	-17.67	-18.59	-18.50	-18.57	1.86	1.82
1652	-17.17	-16.24	-18.52	-18.61	1.434	1.81
1651	-19.55	-20.13	-18.51	-18.63	2.14	1.82
1650	-17.66	-18.32	-18.53	-18.66	1.871	1.82
1649	-18.49	-18.16	-18.48	-18.62	1.932	1.82
1648	-15.90	-16.09	-18.42	-18.57	1.444	1.82
1647	-17.08	-16.63	-18.43	-18.58	2.17	1.82
1646	-18.91	-17.55	-18.46	-18.61	1.595	1.81
1645	-16.68	-17.61	-18.42	-18.58	1.452	1.83
1644	-20.94	-20.23	-18.40	-18.54	2.183	1.83
1643	-18.37	-19.05	-18.36	-18.50	1.895	1.83
1642	-22.41	-22.39	-18.34	-18.48	1.753	1.82
1641	-18.52	-19.77	-18.34	-18.49	1.902	1.80
1640	-17.29	-17.29	-18.27	-18.41	1.906	1.79
1639	-20.03	-19.52	-18.23	-18.38	2.497	1.78
1638	-19.45	-19.72	-18.19	-18.35	1.618	1.78
1637	-17.70	-17.61	-18.24	-18.40	1.769	1.78
1636	-13.01	-13.81	-18.25	-18.39	1.625	1.75
1635	-15.50	-16.35	-18.24	-18.39	1.923	1.74
1634	-18.17	-17.89	-18.24	-18.40	1.779	1.73
1633	-17.35	-17.94	-18.24	-18.40	1.485	1.73
1632	-19.02	-19.15	-18.28	-18.46	1.785	1.72
1631	-19.97	-20.65	-18.26	-18.46	2.236	1.73
1630	-18.35	-19.42	-18.26	-18.46	2.389	1.73
1629	-22.66	-20.01	-18.22	-18.46	1.795	1.74
1628	-18.05	-20.89	-18.24	-18.47	1.499	1.74
1627	-20.24	-19.65	-18.30	-18.56	2.252	1.75

Year (AD)	Del 18-O (per mil)				Accumulation (m)	
	Raw Data*		49 Year Running mean		Raw Data*	49 Year Running mean
	Core 1	Summit	Core 1	Summit	Summit	Summit
1626	-19.00	-20.24	-18.32	-18.57	1.955	1.73
1625	-16.83	-18.22	-18.38	-18.63	1.808	1.72
1624	-17.65	-17.04	-18.39	-18.64	1.661	1.72
1623	-20.09	-19.61	-18.44	-18.70	1.815	1.73
1622	-18.67	-18.91	-18.45	-18.73	1.742	1.72
1621	-16.70	-17.79	-18.41	-18.74	1.821	1.72
1620	-17.31	-17.36	-18.41	-18.73	2.129	1.72
1619	-16.56	-17.26	-18.32	-18.66	1.371	1.70
1618	-18.05	-18.58	-18.29	-18.62	1.374	1.70
1617	-18.44	-18.95	-18.19	-18.51	1.223	1.69
1616	-18.92	-18.49	-18.16	-18.48	1.072	1.68
1615	-18.25	-18.49	-18.18	-18.49	1.381	1.67
1614	-18.69	-19.05	-18.15	-18.47	1.768	1.65
1613	-18.23	-18.35	-18.13	-18.45	1.14	1.66
1612	-19.30	-18.15	-18.18	-18.49	1.404	1.66
1611	-19.83	-19.75	-18.29	-18.60	1.391	1.67
1610	-17.45	-18.30	-18.37	-18.67	1.394	1.65
1609	-17.10	-17.21	-18.34	-18.66	1.552	1.65
1608	-16.49	-17.17	-18.31	-18.61	1.555	1.65
1607	-17.07	-16.81	-18.28	-18.58	1.713	1.64
1606	-17.96	-18.57	-18.24	-18.53	1.56	1.63
1605	-18.21	-19.46	-18.25	-18.52	2.032	1.62
1604	-18.72	-19.32	-18.16	-18.48	2.036	1.61
1603	-19.79	-20.47	-18.21	-18.42	1.804	1.61
1602	-20.44	-20.92	-18.21	-18.48	1.415	1.60
1601	-20.93	-20.81	-18.23	-18.44	1.496	1.60
1600	-18.79	-18.77	-18.26	-18.47	1.736	1.60
1599	-18.37	-18.97	-18.28	-18.51	2.055	1.60
1598	-17.52	-18.31	-18.22	-18.46	1.425	1.59
1597	-17.20	-18.18	-18.24	-18.50	1.587	1.59
1596	-16.59	-17.02	-18.33	-18.57	1.431	1.57
1595	-16.41	-16.65	-18.30	-18.55	1.434	1.56
1594	-16.88	-17.00	-18.37	-18.57	1.915	1.56
1593	-17.32	-17.36	-18.41	-18.62	1.119	1.57
1592	-17.40	-17.92	-18.43	-18.62	1.442	1.57
1591	-18.15	-18.16	-18.43	-18.64	1.444	1.57
1590	-18.35	-18.36	-18.31	-18.55	1.447	1.58
1589	-18.50	-18.88	-18.28	-18.52	1.933	1.56
1588	-20.13	-19.35	-18.25	-18.50	1.776	1.57
1587	-18.50	-19.24	-18.23	-18.50	2.102	1.57
1586	-19.77	-19.79	-18.22	-18.51	1.296	1.59
1585	-16.36	-17.38	-18.24	-18.50	1.461	1.59
1584	-16.13	-15.36	-18.30	-18.56	1.627	1.59
1583	-17.55	-17.82	-18.32	-18.58	1.45	1.59
1582	-17.89	-18.16	-18.37	-18.64	1.633	1.58

Year (AD)	Del 18-O (per mil)				Accumulation (m)	
	Raw Data*		49 Year Running mean		Raw Data*	49 Year Running mean
	Core 1	Summit	Core 1	Summit	Summit	Summit
1581	-18.60	-19.19	-18.37	-18.61	1.8	1.58
1580	-18.41	-17.64	-18.37	-18.59	1.476	1.57
1579	-20.62	-18.35	-18.35	-18.55	1.478	1.55
1578	-19.98	-22.17	-18.31	-18.50	1.646	1.55
1577	-19.96	-18.29	-18.30	-18.50	1.814	1.54
1576	-18.67	-20.05	-18.27	-18.43	1.818	1.56
1575	-18.50	-18.94	-18.22	-18.42	1.656	1.55
1574	-17.03	-17.30	-18.20	-18.41	1.327	1.54
1573	-19.62	-20.58	-18.21	-18.43	1.828	1.54
1572	-21.44	-21.13	-18.27	-18.46	1.166	1.54
1571	-15.57	-16.43	-18.33	-18.48	1.335	1.54
1570	-20.22	-18.32	-18.36	-18.49	1.505	1.53
1569	-20.00	-20.85	-18.37	-18.54	1.592	1.54
1568	-19.50	-19.17	-18.43	-18.56	1.427	1.56
1567	-18.65	-19.48	-18.44	-18.57	1.178	1.56
1566	-12.20	-13.88	-18.46	-18.57	1.686	1.55
1565	-17.21	-17.93	-18.47	-18.59	1.014	1.55
1564	-17.04	-16.98	-18.46	-18.59	1.524	1.54
1563	-18.02	-18.15	-18.38	-18.54	1.527	1.53
1562	-19.51	-20.27	-18.36	-18.52	2.04	1.52
1561	-18.52	-18.06	-18.31	-18.47	1.533	1.53
1560	-19.98	-20.23	-18.33	-18.49	1.536	1.53
1559	-17.71	-18.15	-18.38	-18.56	1.711	1.52
1558	-19.51	-19.45	-18.40	-18.54	1.2	1.53
1557	-17.62	-17.42	-18.43	-18.56	1.546	1.53
1556	-18.34	-18.41	-18.42	-18.54	1.377	1.52
1555	-17.98	-17.41	-18.40	-18.47	1.38	1.51
1554	-17.83	-17.87	-18.31	-18.45	1.383	1.51
1553	-19.74	-21.06	-18.27	-18.41	1.386	1.52
1552	-19.68	-17.31	-18.25	-18.39	2.084	1.51
1551	-16.07	-17.99	-18.22	-18.31	1.566	1.50
1550	-17.25	-18.63	-18.16	-18.26	1.221	1.49
1549	-17.97	-19.57	-18.08	-18.28	1.748	1.49
1548	-20.55	-19.25	-18.07	-18.22	1.401	1.47
1547	-19.37	-18.08	-17.96	-18.14	1.58	1.48
1546	-17.84	-17.15	-18.02	-18.18	1.056	1.47
1545	-17.51	-19.63	-17.93	-18.11	2.292	1.48
1544	-19.96	-18.21	-17.85	-18.01	1.767	1.47
1543	-18.00	-18.56	-17.80	-18.02	1.594	1.47
1542	-19.18	-18.02	-17.80	-18.01	1.242	1.47
1541	-18.92	-19.46	-17.91	-18.10	1.423	1.48
1540	-17.90	-18.65	-17.93	-18.10	1.07	1.47
1539	-16.16	-17.02	-17.96	-18.13	1.608	1.48
1538	-17.53	-18.31	-17.97	-18.16	1.433	1.48
1537	-17.27	-17.25	-17.96	-18.13	1.795	1.46

Year (AD)	Del 18-O (per mil)				Accumulation (m)	
	Raw Data*		49 Year Running mean		Raw Data*	49 Year Running mean
	Core 1	Summit	Core 1	Summit	Summit	Summit
1536	-17.36	-18.33	-17.96	-18.12	1.439	1.45
1535	-18.83	-18.79	-17.90	-18.04	1.262	1.46
1534	-18.31	-16.72	-17.87	-18.04	1.627	1.46
1533	-19.36	-19.15	-17.83	-17.99	1.63	1.46
1532	-18.15	-18.58	-17.82	-17.99	1.434	1.45
1531	-17.54	-14.27	-17.80	-17.99	1.092	1.46
1530	-16.11	-17.30	-17.78	-17.97	1.642	1.47
1529	-18.02	-19.81	-17.76	-17.95	2.011	1.47
1528	-18.90	-17.41	-17.70	-17.94	1.283	1.47
1527	-17.14	-16.08	-17.65	-18.00	1.102	1.45
1526	-15.53	-16.75	-17.71	-18.03	1.473	1.45
1525	-13.31	-18.30	-17.76	-17.98	1.107	1.46
1524	-18.97	-17.33	-17.79	-17.94	1.11	1.44
1523	-16.30	-17.44	-17.72	-17.94	1.483	1.44
1522	-18.42	-18.24	-17.68	-17.94	1.115	1.44
1521	-16.04	-15.05	-17.69	-17.97	1.863	1.45
1520	-15.72	-15.94	-17.71	-17.96	0.934	1.42
1519	-16.96	-19.61	-17.69	-17.94	1.311	1.41
1518	-18.93	-19.12	-17.71	-17.92	1.314	1.40
1517	-17.61	-18.01	-17.64	-17.88	2.051	1.40
1516	-18.08	-18.24	-17.60	-17.84	0.943	1.40
1515	-18.46	-18.42	-17.57	-17.79	1.701	1.39
1514	-18.70	-19.39	-17.59	-17.80	1.516	1.38
1513	-18.95	-19.05	-17.55	-17.78	1.33	1.37
1512	-18.65	-17.68	-17.53	-17.78	0.952	1.36
1511	-16.67	-16.32	-17.54	-17.75	1.909	1.35
1510	-16.42	-17.77	-17.50	-17.72	1.914	1.35
1509	-17.54	-17.37	-17.46	-17.74	1.151	1.36
1508	-17.07	-17.29	-17.41	-17.73	0.962	1.34
1507	-17.26	-18.13	-17.38	-17.73	1.929	1.34
1506	-17.38	-16.80	-17.40	-17.80	1.547	1.34
1505	-16.73	-16.94	-17.45	-17.82	1.745	1.33
1504	-16.78	-20.43	-17.44	-17.77	1.166	1.31
1503	-17.04	-20.26	-17.41	-17.77	1.364	1.30
1502	-19.31	-19.20	-17.43	-17.82	1.172	1.30
1501	-19.74	-16.30	-17.46	-17.86	1.762	1.30
1500	-19.47	-17.82	-17.56	-17.88	0.982	1.29
1499	-16.89	-19.04	-17.54	-17.92	1.575	1.30
1498	-17.39	-18.22	-17.60	-17.92	1.382	1.30
1497	-18.49	-18.66	-17.61	-17.93	1.385	1.30
1496	-18.32	-18.77	-17.65	-18.01	1.19	1.29
1495	-18.97	-17.49	-17.67	-18.06	1.193	1.30
1494	-18.94	-17.35	-17.70	-18.03	1.197	1.30
1493	-15.99	-16.33	-17.70	-18.02	0.8	1.30
1492	-16.83	-17.49	-17.70	-18.04	1.403	1.29

Year (AD)	Del 18-O (per mil)				Accumulation (m)	
	Raw Data*		49 Year Running mean		Raw Data*	49 Year Running mean
	Core 1	Summit	Core 1	Summit	Summit	Summit
1491	-16.16	-16.05	-17.71	-18.02	0.804	1.30
1490	-17.35	-17.66	-17.68	-18.03	1.008	1.29
1489	-15.74	-17.48	-17.67	-18.00	1.01	1.28
1488	-16.05	-16.92	-17.64	-17.99	1.216	1.28
1487	-17.83	-17.21	-17.63	-18.00	1.219	1.29
1486	-16.85	-16.99	-17.67	-18.03	1.222	1.28
1485	-16.64	-17.86	-17.72	-18.03	1.839	1.26
1484	-16.67	-18.42	-17.71	-18.03	1.024	1.26
1483	-16.87	-18.57	-17.75	-18.04	1.232	1.26
1482	-18.24	-17.71	-17.73	-18.06	1.236	1.25
1481	-18.80	-18.57	-17.73	-18.10	1.239	1.23
1480	-17.64	-17.36	-17.76	-18.19	0.828	1.22
1479	-17.06	-17.40	-17.79	-18.18	0.831	1.22
1478	-18.21	-18.53	-17.87	-18.17	1.249	1.22
1477	-17.28	-18.67	-17.86	-18.14	1.253	1.23
1476	-18.14	-19.21	-17.80	-18.15	0.837	1.21
1475	-17.98	-19.26	-17.75	-18.11	1.47	1.23
1474	-19.02	-17.53	-17.70	-18.08	1.263	1.23
1473	-19.03	-18.54	-17.71	-18.06	1.478	1.23
1472	-17.86	-19.05	-17.66	-18.03	1.27	1.22
1471	-16.81	-18.67	-17.63	-18.02	1.486	1.21
1470	-18.50	-17.99	-17.59	-18.04	1.278	1.21
1469	-19.03	-18.41	-17.57	-18.07	1.174	1.21
1468	-17.67	-19.24	-17.60	-18.10	1.392	1.23
1467	-18.40	-17.18	-17.63	-18.07	1.503	1.22
1466	-16.82	-18.73	-17.66	-18.08	1.292	1.24
1465	-18.33	-18.07	-17.63	-18.06	1.296	1.24
1464	-17.57	-18.40	-17.65	-18.06	1.3	1.25
1463	-17.98	-18.57	-17.65	-18.10	1.303	1.25
1462	-18.63	-17.76	-17.63	-18.15	1.307	1.26
1461	-18.79	-17.77	-17.65	-18.16	1.092	1.26
1460	-17.32	-17.26	-17.72	-18.21	0.876	1.25
1459	-18.76	-17.65	-17.75	-18.24	1.318	1.25
1458	-16.34	-19.20	-17.80	-18.23	1.102	1.25
1457	-17.72	-18.56	-17.83	-18.21	0.884	1.26
1456	-18.23	-21.58	-17.80	-18.17	1.108	1.26
1455	-17.86	-19.72	-17.78	-18.18	1.334	1.27
1454	-21.06	-20.11	-17.77	-18.21	1.338	1.28
1453	-19.00	-17.76	-17.74	-18.20	1.342	1.29
1452	-16.88	-16.49	-17.76	-18.17	1.099	1.29
1451	-16.76	-16.12	-17.73	-18.14	1.575	1.30
1450	-14.53	-17.47	-17.71	-18.08	1.579	1.30
1449	-17.95	-17.27	-17.69	-18.09	1.358	1.30
1448	-15.91	-17.24	-17.61	-18.11	0.908	1.29
1447	-17.07	-18.11	-17.59	-18.10	0.91	1.29

Year (AD)	Del 18-O (per mil)				Accumulation (m)	
	Raw Data*		49 Year Running mean		Raw Data*	49 Year Running mean
	Core 1	Summit	Core 1	Summit	Summit	Summit
1446	-16.93	-18.27	-17.63	-18.12	1.142	1.29
1445	-17.63	-19.25	-17.62	-18.12	1.374	1.30
1444	-17.63	-17.71	-17.63	-18.10	1.608	1.29
1443	-18.47	-15.92	-17.65	-18.08	1.152	1.29
1442	-17.50	-16.47	-17.65	-18.12	1.386	1.28
1441	-15.83	-16.48	-17.68	-18.08	1.159	1.29
1440	-16.63	-17.93	-17.64	-18.09	1.395	1.29
1439	-16.22	-18.79	-17.64	-18.09	1.632	1.28
1438	-16.73	-19.30	-17.65	-18.08	1.637	1.28
1437	-18.12	-17.67	-17.65	-18.03	1.173	1.29
1436	-19.84	-20.56	-17.64	-18.02	1.177	1.30
1435	-18.10	-19.60	-17.62	-18.02	1.18	1.31
1434	-19.55	-18.33	-17.58	-18.01	1.184	1.31
1433	-19.37	-16.54	-17.60	-17.98	1.425	1.31
1432	-17.33	-16.86	-17.60	-17.99	1.429	1.32
1431	-16.71	-17.84	-17.60	-17.92	1.195	1.33
1430	-16.76	-18.75	-17.64	-17.87	1.438	1.32
1429	-16.57	-17.90	-17.60	-17.82	1.683	1.31
1428	-18.61	-17.31	-17.52	-17.81	1.447	1.32
1427	-16.66	-17.75	-17.50	-17.83	1.451	1.31
1426	-16.70	-16.27	-17.49	-17.85	1.213	1.30
1425	-17.91	-18.14	-17.54	-17.85	1.217	1.30
1424	-15.53	-19.15	-17.52	-17.87	1.221	1.30
1423	-16.74	-18.68	-17.54	-17.90	1.224	1.31
1422	-16.53	-19.55	-17.56	-17.92	1.228	1.32
1421	-18.32	-18.21	-17.59	-17.94	1.725	1.33
1420	-19.50	-17.37	-17.61	-17.93	0.989	1.33
1419	-18.64	-18.51	-17.65	-17.92	1.24	1.32
1418	-18.19	-18.82	-17.66	-17.96	1.244	1.33
1417	-18.16	-16.91	-17.65	-17.99	1.497	1.33
1416	-16.40	-18.37	-17.69	-18.01	1.252	1.33
1415	-17.81	-18.37	-17.71	-18.05	1.004	1.32
1414	-18.29	-18.38	-17.75	-18.03	1.511	1.32
1413	-18.78	-15.40	-17.78	-18.01	1.769	1.32
1412	-18.49	-17.22	-17.78	-18.01	1.267	1.32
1411	-16.07	-16.97	-17.76	-17.97	1.271	1.32
1410	-17.06	-17.43	-17.75	-17.95	1.275	1.32
1409	-17.28	-17.61	-17.72	-17.96	1.279	1.32
1408	-17.72	-18.94	-17.71	-18.02	1.54	1.33
1407	-17.86	-18.32	-17.73	-18.01	1.545	1.33
1406	-20.07	-17.42	-17.76	-17.99	0.775	1.33
1405	-19.02	-17.45	-17.73	-17.96	1.036	1.32
1404	-15.15	-17.25	-17.73	-17.96	1.56	1.32
1403	-15.66	-17.39	-17.71	-17.95	0.782	1.31
1402	-16.47	-17.08	-17.73	-17.97	1.046	1.31

Year (AD)	Del 18-O (per mil)				Accumulation (m)	
	Raw Data*		49 Year Running mean		Raw Data*	49 Year Running mean
	Core 1	Summit	Core 1	Summit	Summit	Summit
1401	-16.78	-17.60	-17.74	-17.98	1.575	1.32
1400	-17.04	-18.40	-17.77	-17.93	1.316	1.33
1399	-17.10	-18.76	-17.79	-17.91	1.585	1.33
1398	-17.87	-18.67	-17.77	-17.90	1.325	1.34
1397	-18.39	-19.56	-17.77	-17.85	1.595	1.34
1396	-18.77	-18.51	-17.77	-17.81	1.333	1.33
1395	-19.68	-17.28	-17.71	-17.80	1.07	1.34
1394	-18.67	-17.97	-17.67	-17.74	1.61	1.34
1393	-17.38	-17.80	-17.65	-17.75	1.346	1.35
1392	-17.73	-17.58	-17.63	-17.76	1.323	1.34
1391	-17.49	-19.83	-17.67	-17.72	1.084	1.34
1390	-18.04	-17.87	-17.61	-17.68	1.631	1.34
1389	-18.20	-18.16	-17.57	-17.65	1.363	1.33
1388	-18.20	-17.93	-17.51	-17.67	1.094	1.32
1387	-18.98	-18.54	-17.48	-17.68	1.098	1.33
1386	-17.43	-18.64	-17.51	-17.65	1.349	1.31
1385	-18.39	-18.81	-17.50	-17.61	1.381	1.32
1384	-18.54	-19.47	-17.46	-17.61	1.663	1.32
1383	-18.54	-16.56	-17.42	-17.57	1.39	1.31
1382	-17.96	-16.69	-17.41	-17.54	1.116	1.30
1381	-15.29	-17.32	-17.34	-17.52	1.119	1.30
1380	-16.64	-17.74	-17.30	-17.48	1.684	1.32
1379	-17.56	-16.74	-17.31	-17.47	1.126	1.32
1378	-17.54	-19.07	-17.30	-17.47	1.413	1.34
1377	-17.28	-16.44	-17.32	-17.49	1.7	1.34
1376	-19.42	-15.90	-17.33	-17.50	1.422	1.34
1375	-16.45	-17.89	-17.37	-17.51	1.426	1.35
1374	-15.96	-18.62	-17.42	-17.52	1.717	1.35
1373	-18.60	-16.78	-17.46	-17.55	1.148	1.34
1372	-18.08	-16.38	-17.49	-17.50	1.152	1.34
1371	-16.52	-16.85	-17.53	-17.47	1.733	1.34
1370	-16.93	-15.81	-17.50	-17.47	1.159	1.35
1369	-16.93	-19.29	-17.47	-17.47	1.745	1.35
1368	-17.19	-17.07	-17.47	-17.47	1.167	1.34
1367	-18.74	-16.57	-17.48	-17.48	1.171	1.35
1366	-14.65	-16.57	-17.48	-17.47	0.881	1.35
1365	-16.26	-16.49	-17.51	-17.54	1.178	1.35
1364	-16.16	-16.71	-17.55	-17.60	1.182	1.36
1363	-16.75	-17.37	-17.60	-17.61	1.482	1.35
1362	-17.55	-15.64	-17.59	-17.58	0.595	1.36
1361	-16.73	-15.67	-17.58	-17.51	1.492	1.36
1360	-15.21	-17.57	-17.55	-17.42	1.497	1.35
1359	-15.51	-16.86	-17.49	-17.37	1.201	1.35
1358	-17.36	-16.86	-17.47	-17.39	0.904	1.35
1357	-16.93	-16.32	-17.46	-17.41	0.907	1.36

Year (AD)	Del 18-O (per mil)				Accumulation (m)	
	Raw Data*		49 Year Running mean		Raw Data*	49 Year Running mean
	Core 1	Summit	Core 1	Summit	Summit	Summit
1356	-16.93	-15.78	-17.50	-17.40	1.819	1.37
1355	-15.69	-16.78	-17.49	-17.38	1.521	1.36
1354	-15.32	-17.15	-17.52	-17.40	1.831	1.37
1353	-17.37	-18.12	-17.53	-17.39	1.224	1.37
1352	-17.32	-18.12	-17.56	-17.42	1.535	1.37
1351	-18.89	-18.88	-17.56	-17.49	1.848	1.37
1350	-19.37	-19.18	-17.57	-17.47	1.236	1.37
1349	-19.86	-20.01	-17.59	-17.44	1.24	1.35
1348	-19.85	-17.40	-17.54	-17.43	1.555	1.37
1347	-21.00	-17.14	-17.52	-17.45	1.248	1.37
1346	-18.15	-17.14	-17.51	-17.44	1.252	1.37
1345	-16.93	-17.75	-17.50	-17.46	1.57	1.37
1344	-17.72	-17.98	-17.51	-17.42	1.26	1.37
1343	-17.99	-17.98	-17.53	-17.43	1.58	1.37
1342	-17.85	-19.64	-17.50	-17.44	1.268	1.38
1341	-19.09	-21.24	-17.53	-17.45	1.59	1.40
1340	-20.44	-21.13	-17.53	-17.45	1.595	1.40
1339	-20.50	-18.16	-17.53	-17.43	0.64	1.40
1338	-18.32	-17.28	-17.52	-17.41	1.605	1.39
1337	-16.93	-14.88	-17.54	-17.48	1.61	1.41
1336	-17.39	-14.51	-17.53	-17.50	0.646	1.41
1335	-15.25	-17.32	-17.56	-17.48	1.944	1.40
1334	-17.45	-17.28	-17.63	-17.48	1.3	1.40
1333	-17.48	-17.56	-17.64	-17.51	1.304	1.42
1332	-17.28	-16.83	-17.66	-17.56	1.635	1.43
1331	-16.31	-16.83	-17.64	-17.60	1.313	1.42
1330	-18.87	-18.03	-17.67	-17.60	1.646	1.43
1329	-18.43	-18.27	-17.75	-17.58	1.321	1.43
1328	-18.33	-17.91	-17.79	-17.57	1.656	1.43
1327	-19.63	-19.60	-17.79	-17.56	1.661	1.43
1326	-17.04	-16.86	-17.79	-17.53	1.333	1.42
1325	-17.04	-16.86	-17.78	-17.49	1.003	1.42
1324	-15.80	-16.38	-17.76	-17.45	1.677	1.43
1323	-17.06	-17.21	-17.74	-17.48	1.346	1.43
1322	-16.34	-16.56	-17.70	-17.52	1.687	1.43
1321	-16.34	-16.56	-17.70	-17.55	1.32	1.44
1320	-17.41	-17.49	-17.71	-17.59	1.698	1.44
1319	-18.12	-17.44	-17.70	-17.62	1.022	1.44
1318	-17.23	-17.44	-17.70	-17.63	1.708	1.43
1317	-15.99	-16.81	-17.70	-17.61	2.056	1.44
1316	-16.25	-16.36	-17.68	-17.53	1.031	1.43
1315	-16.26	-16.17	-17.62	-17.45	1.379	1.41
1314	-16.26	-16.17	-17.59	-17.44	0.692	1.41
1313	-18.48	-18.85	-17.59	-17.45	1.734	1.40
1312	-16.26	-16.79	-17.62	-17.50	1.392	1.41

Year (AD)	Del 18-O (per mil)				Accumulation (m)	
	Raw Data*		49 Year Running mean		Raw Data*	49 Year Running mean
	Core 1	Summit	Core 1	Summit	Summit	Summit
1311	-16.86	-16.79	-17.64	-17.58	1.047	1.42
1310	-18.79	-16.65	-17.74	-17.62	1.4	1.40
1309	-18.09	-18.51	-17.77	-17.65	1.755	1.41
1308	-17.72	-18.44	-17.74	-17.66	1.408	1.41
1307	-16.09	-18.20	-17.74	-17.69	1.413	1.40
1306	-17.03	-16.68	-17.74	-17.72	1.771	1.39
1305	-19.40	-15.85	-17.68	-17.74	1.777	1.39
1304	-19.40	-18.03	-17.65	-17.79	1.425	1.38
1303	-17.17	-17.29	-17.63	-17.80	1.43	1.38
1302	-18.78	-17.41	-17.59	-17.71	1.434	1.37
1301	-19.00	-17.40	-17.65	-17.70	1.438	1.37
1300	-18.72	-18.10	-17.67	-17.68	1.443	1.39
1299	-18.90	-18.82	-17.74	-17.64	1.447	1.38
1298	-19.12	-19.08	-17.80	-17.64	1.451	1.38
1297	-18.04	-18.68	-17.87	-17.64	1.819	1.36
1296	-17.73	-19.50	-17.95	-17.65	1.46	1.36
1295	-17.23	-19.48	-17.96	-17.66	1.464	1.35
1294	-17.69	-18.75	-17.96	-17.68	1.101	1.37
1293	-18.00	-18.30	-18.01	-17.67	1.472	1.36
1292	-18.21	-17.44	-18.06	-17.70	0.923	1.35
1291	-17.19	-17.44	-18.10	-17.75	0.74	1.36
1290	-19.22	-17.36	-18.11	-17.83	0.743	1.36
1289	-18.32	-17.76	-18.11	-17.89	1.303	1.38
1288	-18.56	-17.59	-18.10	-17.87	1.681	1.38
1287	-18.22	-18.06	-18.16	-17.92	1.311	1.37
1286	-19.89	-19.55	-18.21	-17.99	1.127	1.38
1285	-19.04	-18.91	-18.23	-18.02	1.507	1.39
1284	-16.16	-17.93	-18.21	-18.02	1.511	1.39
1283	-17.19	-18.14	-18.15	-17.98	1.136	1.39
1282	-16.12	-18.14	-18.17	-17.98	0.76	1.39
1281	-15.99	-19.19	-18.16	-18.03	1.524	1.39
1280	-17.17	-20.74	-18.10	-18.10	1.146	1.39
1279	-17.54	-18.21	-18.03	-18.12	1.532	1.39
1278	-17.54	-15.44	-18.03	-18.14	1.153	1.39
1277	-19.70	-16.22	-17.99	-18.09	1.541	1.39
1276	-18.05	-16.17	-17.94	-18.06	1.932	1.39
1275	-19.63	-14.46	-17.94	-18.05	1.162	1.40
1274	-19.63	-17.07	-17.89	-18.02	1.165	1.40
1273	-20.08	-16.73	-17.79	-17.95	0.779	1.39
1272	-20.26	-16.73	-17.77	-17.91	1.172	1.38
1271	-17.83	-17.96	-17.79	-17.86	1.567	1.39
1270	-17.89	-18.38	-17.83	-17.81	1.571	1.39
1269	-20.00	-17.24	-17.87	-17.78	1.575	1.40
1268	-18.02	-18.32	-17.87	-17.78	1.579	1.40
1267	-18.58	-18.87	-17.92	-17.76	1.584	1.40

Year (AD)	Del 18-O (per mil)				Accumulation (m)	
	Raw Data*		49 Year Running mean		Raw Data*	49 Year Running mean
	Core 1	Summit	Core 1	Summit	Summit	Summit
1266	-16.40	-19.87	-17.99	-17.71	1.191	1.41
1265	-16.40	-19.30	-17.99	-17.71	1.592	1.44
1264	-17.82	-17.89	-18.00	-17.71	1.596	1.44
1263	-19.51	-18.97	-18.00	-17.72	1.2	1.45
1262	-19.13	-20.02	-17.96	-17.74	1.605	1.46
1261	-19.80	-18.35	-17.92	-17.76	1.609	1.47
1260	-17.09	-18.37	-17.88	-17.78	2.017	1.46
1259	-14.90	-16.79	-17.89	-17.82	1.213	1.46
1258	-17.18	-17.95	-17.90	-17.79	1.216	1.48
1257	-16.64	-19.40	-17.94	-17.80	2.033	1.50
1256	-16.29	-19.17	-17.99	-17.80	1.63	1.50
1255	-15.75	-19.05	-17.95	-17.74	1.594	1.50
1254	-17.28	-18.23	-17.90	-17.73	1.598	1.50
1253	-16.69	-14.74	-17.90	-17.77	1.232	1.52
1252	-16.83	-16.25	-17.85	-17.77	1.235	1.52
1251	-18.63	-17.31	-17.87	-17.81	2.064	1.52
1250	-16.36	-17.32	-17.86	-17.88	1.655	1.52
1249	-14.07	-15.99	-17.83	-17.91	0.83	1.51
1248	-17.18	-16.60	-17.77	-17.94	1.248	1.52
1247	-18.57	-17.19	-17.70	-17.93	2.085	1.54
1246	-19.46	-16.62	-17.63	-17.92	1.254	1.54
1245	-19.46	-17.66	-17.56	-17.92	1.676	1.54
1244	-18.31	-18.32	-17.50	-17.95	1.68	1.52
1243	-20.62	-16.31	-17.50	-17.96	0.842	1.53
1242	-20.33	-14.76	-17.49	-17.93	1.267	1.53
1241	-19.63	-17.56	-17.52	-17.89	2.116	1.55
1240	-18.54	-17.56	-17.59	-17.86	1.273	1.54
1239	-18.73	-18.44	-17.56	-17.83	2.126	1.53
1238	-16.01	-18.84	-17.51	-17.72	1.705	1.53
1237	-18.16	-20.38	-17.49	-17.61	1.709	1.53
1236	-16.95	-20.27	-17.46	-17.59	1.285	1.52
1235	-16.50	-19.53	-17.49	-17.59	1.288	1.50
1234	-17.92	-16.94	-17.55	-17.61	2.152	1.50
1233	-18.23	-18.42	-17.58	-17.62	1.726	1.50
1232	-18.23	-19.52	-17.64	-17.62	1.297	1.49
1231	-15.38	-17.76	-17.67	-17.63	1.517	1.49
1230	-14.97	-17.76	-17.67	-17.66	1.52	1.50
1229	-17.42	-16.96	-17.68	-17.64	2.177	1.51
1228	-17.37	-16.43	-17.74	-17.66	1.309	1.50
1227	-18.75	-18.04	-17.79	-17.65	1.75	1.50
1226	-19.30	-18.14	-17.76	-17.67	1.315	1.48
1225	-18.04	-18.14	-17.76	-17.71	0.879	1.49
1224	-17.52	-18.46	-17.83	-17.78	1.321	1.51
1223	-16.81	-16.16	-17.86	-17.80	1.766	1.52
1222	-14.19	-17.49	-17.87	-17.78	1.769	1.50

Year (AD)	Del 18-O (per mil)				Accumulation (m)	
	Raw Data*		49 Year Running mean		Raw Data*	49 Year Running mean
	Core 1	Summit	Core 1	Summit	Summit	Summit
1221	-14.60	-18.57	-17.85	-17.84	1.33	1.51
1220	-17.07	-18.57	-17.83	-17.87	0.889	1.51
1219	-17.77	-18.82	-17.83	-17.86	2.227	1.52
1218	-18.13	-17.44	-17.78	-17.87	1.339	1.53
1217	-18.13	-17.81	-17.73	-17.95	2.236	1.53
1216	-19.80	-17.81	-17.69	-17.97	0.896	1.52
1215	-16.34	-16.35	-17.67	-17.98	1.348	1.53
1214	-16.90	-13.85	-17.65	-17.96	1.351	1.51
1213	-18.22	-14.51	-17.72	-17.93	1.353	1.50
1212	-18.22	-17.47	-17.73	-17.87	1.356	1.49
1211	-18.66	-18.34	-17.74	-17.84	0.906	1.50
1210	-17.76	-17.65	-17.75	-17.82	0.908	1.52
1209	-18.65	-18.54	-17.74	-17.86	1.365	1.50
1208	-19.54	-19.41	-17.72	-17.86	1.824	1.50
1207	-17.68	-19.41	-17.71	-17.83	1.37	1.50
1206	-16.00	-20.57	-17.74	-17.84	2.289	1.50
1205	-17.88	-17.61	-17.77	-17.83	1.835	1.49
1204	-19.33	-15.55	-17.75	-17.85	0.919	1.48
1203	-19.33	-15.55	-17.78	-17.89	0.921	1.49
1202	-17.04	-18.44	-17.81	-17.92	1.384	1.50
1201	-16.61	-19.49	-17.82	-17.95	1.85	1.51
1200	-17.54	-19.10	-17.85	-17.96	1.853	1.51
1199	-18.63	-17.68	-17.85	-17.94	1.857	1.51
1198	-18.80	-16.24	-17.82	-17.97	0.93	1.51
1197	-18.48	-19.55	-17.89	-17.97	1.864	1.50
1196	-18.63	-18.97	-17.96	-17.94	1.868	1.50
1195	-18.28	-17.85	-17.95	-17.91	1.872	1.52
1194	-18.28	-16.70	-17.95	-17.90	1.406	1.49
1193	-17.68	-18.66	-17.94	-17.90	1.409	1.50
1192	-17.68	-18.59	-17.92	-17.88	1.882	1.49
1191	-17.68	-18.23	-17.89	-17.86	1.414	1.50
1190	-17.68	-17.35	-17.93	-17.87	1.37	1.50
1189	-19.51	-17.35	-17.96	-17.93	0.947	1.52
1188	-18.59	-17.41	-17.96	-17.98	1.422	1.52
1187	-17.31	-18.93	-17.96	-18.04	1.9	1.52
1186	-17.31	-18.76	-17.94	-18.08	1.903	1.55
1185	-17.12	-18.79	-17.91	-18.13	1.43	1.56
1184	-17.29	-18.17	-17.88	-18.14	1.433	1.57
1183	-17.93	-18.17	-17.88	-18.11	1.435	1.56
1182	-16.93	-18.56	-17.89	-18.04	1.677	1.56
1181	-16.27	-16.80	-17.93	-17.94	1.2	1.54
1180	-16.32	-18.17	-17.92	-17.93	1.443	1.54
1179	-19.07	-18.40	-17.88	-17.98	1.927	1.56
1178	-20.27	-19.61	-17.82	-18.01	1.931	1.57
1177	-19.80	-19.70	-17.79	-18.00	1.934	1.58

Year (AD)	Del 18-O (per mil)				Accumulation (m)	
	Raw Data*		49 Year Running mean		Raw Data*	49 Year Running mean
	Core 1	Summit	Core 1	Summit	Summit	Summit
1176	-19.15	-18.22	-17.79	-17.97	0.969	1.57
1175	-17.99	-17.70	-17.78	-17.94	1.455	1.55
1174	-15.17	-17.56	-17.75	-17.94	1.458	1.55
1173	-17.58	-17.56	-17.69	-17.96	1.46	1.57
1172	-17.84	-17.13	-17.68	-17.94	1.463	1.55
1171	-16.95	-17.16	-17.66	-17.93	1.465	1.54
1170	-17.68	-18.32	-17.62	-17.94	0.979	1.53
1169	-17.69	-17.15	-17.59	-17.97	1.96	1.53
1168	-17.01	-17.05	-17.58	-17.97	1.472	1.54
1167	-18.42	-16.96	-17.54	-17.97	1.475	1.53
1166	-18.42	-16.59	-17.52	-17.96	1.477	1.55
1165	-18.19	-17.07	-17.53	-17.95	2.466	1.55
1164	-18.28	-16.65	-17.49	-17.94	0.988	1.55
1163	-17.90	-20.50	-17.48	-17.97	1.484	1.55
1162	-17.90	-20.37	-17.48	-17.96	2.478	1.53
1161	-16.25	-20.24	-17.49	-17.96	1.489	1.54
1160	-17.43	-19.04	-17.49	-17.96	1.491	1.54
1159	-19.24	-17.57	-17.50	-17.97	1.493	1.54
1158	-18.05	-15.97	-17.50	-17.98	1.496	1.53
1157	-18.29	-15.97	-17.47	-17.97	0.999	1.53
1156	-17.40	-16.83	-17.50	-17.99	2	1.54
1155	-17.40	-18.15	-17.54	-17.98	2.003	1.54
1154	-16.19	-17.26	-17.54	-17.94	1.505	1.53
1153	-15.69	-17.95	-17.52	-17.86	1.507	1.51
1152	-16.35	-17.95	-17.47	-17.79	1.509	1.51
1151	-17.39	-17.67	-17.43	-17.75	1.007	1.53
1150	-16.85	-17.35	-17.41	-17.74	2.018	1.53
1149	-15.98	-17.35	-17.47	-17.76	1.516	1.53
1148	-17.96	-18.47	-17.41	-17.71	1.012	1.55
1147	-17.49	-18.48	-17.40	-17.73	1.52	1.55
1146	-16.65	-18.32	-17.44	-17.74	1.522	1.55
1145	-16.65	-18.32	-17.46	-17.73	1.016	1.56
1144	-17.02	-18.53	-17.47	-17.72	2.035	1.55
1143	-15.95	-18.80	-17.47	-17.72	1.528	1.56
1142	-16.92	-17.78	-17.44	-17.72	2.041	1.56
1141	-17.97	-16.90	-17.42	-17.73	1.533	1.55
1140	-17.38	-16.90	-17.39	-17.72	1.023	1.54
1139	-18.07	-18.67	-17.35	-17.74	1.537	1.55
1138	-17.54	-18.67	-17.31	-17.68	1.026	1.56
1137	-17.54	-18.78	-17.26	-17.63	2.054	1.54
1136	-17.26	-18.78	-17.25	-17.59	1.543	1.53
1135	-17.80	-18.57	-17.22	-17.58	1.545	1.53
1134	-17.82	-18.57	-17.15	-17.59	1.031	1.54
1133	-15.38	-17.99	-17.11	-17.61	1.549	1.54
1132	-17.95	-17.99	-17.09	-17.63	1.55	1.55

Year (AD)	Del 18-O (per mil)				Accumulation (m)	
	Raw Data*		49 Year Running mean		Raw Data*	49 Year Running mean
	Core 1	Summit	Core 1	Summit	Summit	Summit
1131	-18.28	-17.58	-17.08	-17.65	1.552	1.54
1130	-19.19	-16.14	-17.05	-17.66	1.554	1.53
1129	-19.19	-16.14	-17.04	-17.68	1.038	1.53
1128	-17.55	-16.12	-17.07	-17.70	1.558	1.54
1127	-17.09	-16.12	-17.10	-17.71	2.08	1.52
1126	-17.09	-17.09	-17.08	-17.71	1.562	1.52
1125	-17.89	-18.50	-17.07	-17.72	1.564	1.51
1124	-14.91	-15.41	-17.15	-17.74	2.035	1.51
1123	-17.21	-17.84	-17.19	-17.73	1.568	1.52
1122	-18.75	-17.84	-17.24	-17.75	1.569	1.52
1121	-18.75	-17.59	-17.30	-17.76	1.571	1.53
1120	-18.12	-17.04	-17.36	-17.73	1.573	1.54
1119	-16.86	-17.04	-17.38	-17.68	1.575	1.52
1118	-17.35	-17.04	-17.42	-17.67	1.577	1.53
1117	-17.35	-16.80	-17.43	-17.68	1.052	1.52
1116	-16.55	-16.80	-17.43	-17.68	2.107	1.51
1115	-16.55	-17.43	-17.45	-17.68	1.582	1.53
1114	-15.70	-17.72	-17.46	-17.63	1.584	1.52
1113	-15.70	-17.72	-17.45	-17.58	1.585	1.53
1112	-15.76	-18.41	-17.45	-17.58	1.058	1.52
1111	-15.76	-18.41	-17.46	-17.57	1.589	1.52
1110	-16.05	-18.37	-17.46	-17.57	2.121	1.52
1109	-16.05	-16.74	-17.48	-17.56	1.061	1.54
1108	-17.05	-16.74	-17.55	-17.53	1.594	1.54
1107	-17.05	-18.22	-17.57	-17.51	1.595	1.54
1106	-15.68	-18.22	-17.59	-17.50	1.597	1.54
1105	-15.68	-18.67	-17.59	-17.52	1.599	1.54
1104	-17.50	-18.67	-17.57	-17.54	1.601	1.54
1103	-17.50	-18.67	-17.57	-17.55	0.801	1.53
1102	-16.53	-17.66	-17.59	-17.55	1.069	1.54
1101	-16.53	-17.66	-17.59	-17.52	1.338	1.54
1100	-19.92	-18.20	-17.58	-17.47	1.607	1.52
1099	-19.92	-18.20	-17.66	-17.46	1.609	1.50
1098	-19.92	-19.17	-17.69	-17.41	1.61	1.50
1097	-19.57	-19.17	-17.69	-17.37	1.612	1.50
1096	-19.57	-16.51	-17.61	-17.35	1.613	1.49
1095	-17.79	-16.51	-17.54	-17.32	1.077	1.49
1094	-17.80	-18.22	-17.56	-17.30	2.155	1.48
1093	-17.80	-18.22	-17.56	-17.30	1.618	1.48
1092	-17.80	-16.87	-17.57	-17.31	1.08	1.51
1091	-18.40	-16.87	-17.61	-17.29	1.621	1.50
1090	-18.40	-16.27	-17.61	-17.25	1.082	1.49
1089	-17.40	-16.27	-17.66	-17.26	1.624	1.49
1088	-17.40	-18.54	-17.70	-17.26	1.626	1.48
1087	-17.66	-18.54	-17.75	-17.20	1.627	1.51

Year (AD)	Del 18-O (per mil)				Accumulation (m)	
	Raw Data*		49 Year Running mean		Raw Data*	49 Year Running mean
	Core 1	Summit	Core 1	Summit	Summit	Summit
1086	-17.66	-18.22	-17.81	-17.19	1.628	1.51
1085	-18.82	-18.22	-17.86	-17.18	1.63	1.50
1084	-18.82	-16.69	-17.92	-17.21	1.632	1.50
1083	-19.13	-17.02	-17.96	-17.28	1.633	1.50
1082	-19.13	-17.02	-17.96	-17.29	1.634	1.50
1081	-19.13	-17.20	-17.98	-17.30	1.636	1.49
1080	-18.41	-17.20	-18.03	-17.30	1.092	1.49
1079	-17.67	-16.63	-18.04	-17.30	1.092	1.49
1078	-17.67	-15.80	-18.05	-17.29	2.187	1.52
1077	-17.36	-15.80	-18.04	-17.30	1.642	1.52
1076	-17.36	-15.80	-18.03	-17.32	0.548	1.52
1075	-18.74	-15.13	-17.95	-17.32	1.096	1.52
1074	-18.74	-15.13	-17.87	-17.33	1.646	1.51
1073	-18.85	-16.29	-17.79	-17.31	1.647	1.50
1072	-14.82	-16.29	-17.75	-17.30	1.099	1.49
1071	-14.82	-15.92	-17.70	-17.36	1.65	1.49
1070	-17.38	-15.92	-17.68	-17.41	1.101	1.49
1069	-17.38	-17.05	-17.66	-17.39	1.653	1.48
1068	-18.27	-17.28	-17.64	-17.38	2.205	1.48
1067	-18.27	-15.62	-17.64	-17.40	1.656	1.48
1066	-16.70	-15.62	-17.62	-17.42	1.105	1.48
1065	-17.93	-18.00	-17.60	-17.45	1.658	1.49
1064	-17.93	-18.00	-17.62	-17.49	1.106	1.48
1063	-17.93	-15.54	-17.63	-17.49	2.491	1.48
1062	-18.75	-17.88	-17.64	-17.52	1.385	1.48
1061	-18.75	-17.88	-17.61	-17.56	1.664	1.48
1060	-19.02	-17.88	-17.55	-17.59	1.11	1.48
1059	-19.02	-20.46	-17.50	-17.65	1.611	1.48
1058	-16.77	-18.59	-17.48	-17.70	1.668	1.48
1057	-16.77	-18.59	-17.44	-17.75	1.113	1.47
1056	-18.04	-18.64	-17.40	-17.76	1.67	1.47
1055	-18.04	-18.64	-17.38	-17.77	1.672	1.49
1054	-18.04	-18.22	-17.38	-17.79	2.231	1.49
1053	-16.11	-18.42	-17.36	-17.83	1.06	1.47
1052	-16.11	-18.42	-17.36	-17.86	1.117	1.47
1051	-15.92	-18.42	-17.38	-17.89	1.677	1.48
1050	-15.92	-18.42	-17.34	-17.94	1.119	1.49
1049	-15.92	-18.55	-17.35	-17.99	1.12	1.48
1048	-17.44	-18.55	-17.36	-18.06	1.121	1.48
1047	-17.44	-19.20	-17.38	-18.13	1.682	1.50
1046	-16.79	-19.20	-17.44	-18.17	1.122	1.49
1045	-16.79	-17.26	-17.43	-18.21	1.685	1.50
1044	-16.79	-17.65	-17.45	-18.22	1.686	1.49
1043	-17.60	-17.65	-17.46	-18.18	1.125	1.48
1042	-17.60	-17.82	-17.44	-18.21	1.689	1.49

Year (AD)	Del 18-O (per mil)				Accumulation (m)	
	Raw Data*		49 Year Running mean		Raw Data*	49 Year Running mean
	Core 1	Summit	Core 1	Summit	Summit	Summit
1041	-17.60	-17.82	-17.45	-18.23	1.127	1.49
1040	-18.27	-18.58	-17.47	-18.21	1.128	1.48
1039	-17.68	-18.58	-17.47	-18.20	1.693	1.49
1038	-18.13	-19.94	-17.45	-18.25	1.694	1.47
1037	-16.32	-19.80	-17.43	-18.26	1.695	1.46
1036	-16.03	-19.80	-17.42	-18.27	1.697	1.45
1035	-16.03	-19.56	-17.42	-18.26	1.698	1.45
1034	-18.41	-19.56	-17.43	-18.21	1.699	1.44
1033	-17.17	-19.56	-17.45	-18.20	1.134	1.42
1032	-17.17	-17.75	-17.44	-18.20	1.702	1.42
1031	-17.15	-17.60	-17.40	-18.19	1.703	1.42
1030	-17.85	-17.60	-17.38	-18.20	1.136	1.41
1029	-16.88	-17.60	-17.37	-18.21	1.137	1.40
1028	-17.43	-17.47	-17.40	-18.23	1.707	1.42
1027	-17.89	-17.47	-17.42	-18.24	1.139	1.43
1026	-17.22	-17.54	-17.48	-18.26	1.71	1.42
1025	-19.06	-17.54	-17.53	-18.23	1.141	1.43
1024	-19.15	-19.77	-17.58	-18.20	1.713	1.42
1023	-16.00	-19.77	-17.60	-18.18	1.714	1.42
1022	-17.57	-17.73	-17.63	-18.10	1.144	1.44
1021	-17.22	-17.73	-17.67	-18.09	1.717	1.44
1020	-18.23	-17.73	-17.67	-18.12	1.145	1.44
1019	-18.72	-15.10	-17.69	-18.10	1.719	1.44
1018	-17.28	-16.96	-17.70	-18.08	2.294	1.44
1017	-17.28	-16.96	-17.69	-18.04	1.148	1.43
1016	-18.59	-17.08	-17.68	-18.00	1.149	1.43
1015	-18.07	-17.08	-17.65	-17.95	1.725	1.43
1014	-16.89	-18.27	-17.65	-17.90	1.151	1.42
1013	-18.14	-18.27	-17.65	-17.86	1.152	1.42
1012	-18.14	-18.27	-17.68	-17.81	1.153	1.41
1011	-19.12	-17.44	-17.70	-17.77	1.154	1.40
1010	-19.12	-18.22	-17.71	-17.72	1.155	1.40
1009	-18.10	-18.22	-17.67	-17.67	0.578	1.39
1008	-16.21	-18.22	-17.66	-17.61	1.157	1.39
1007	-16.21	-18.38	-17.69	-17.59	1.736	1.37
1006	-16.74	-18.85	-17.72	-17.59	1.158	1.36
1005	-17.57	-18.85	-17.71	-17.59	1.739	1.37
1004	-17.50	-19.45	-17.74	-17.59	1.741	1.38
1003	-17.47	-19.10	-17.75	-17.59	1.742	1.37
1002	-18.61	-19.10	-17.72	-17.59	1.163	1.37
1001	-18.43	-17.16	-17.73	-17.61	1.745	1.38
1000	-18.43	-17.16	-17.70	-17.63	0.582	1.38
999	-18.43	-17.16	-17.67	-17.60	1.165	1.37
998	-18.71	-15.65	-17.70	-17.56	2.333	1.36
997	-18.71	-18.73	-17.70	-17.53	1.167	1.37

Year (AD)	Del 18-O (per mil)				Accumulation (m)	
	Raw Data*		49 Year Running mean		Raw Data*	49 Year Running mean
	Core 1	Summit	Core 1	Summit	Summit	Summit
996	-17.09	-18.73	-17.75	-17.49	1.753	1.36
995	-17.57	-16.56	-17.74	-17.46	1.754	1.37
994	-18.27	-16.56	-17.70	-17.52	1.171	1.37
993	-16.94	-15.91	-17.72	-17.54	1.113	1.37
992	-16.94	-15.91	-17.76	-17.56	1.173	1.39
991	-16.94	-16.09	-17.74	-17.59	1.174	1.39
990	-17.69	-16.09	-17.70	-17.58	1.175	1.38
989	-17.97	-17.79	-17.69	-17.55	1.764	1.38
988	-17.97	-17.79	-17.69	-17.54	1.177	1.38
987	-17.01	-17.42	-17.70	-17.52	1.178	1.39
986	-16.54	-17.42	-17.67	-17.53	1.769	1.40
985	-16.54	-16.79	-17.65	-17.52	1.18	1.40
984	-16.36	-16.79	-17.63	-17.49	1.182	1.41
983	-18.78	-16.79	-17.62	-17.47	0.591	1.41
982	-18.46	-17.40	-17.62	-17.46	1.184	1.40
981	-17.65	-17.65	-17.60	-17.43	1.777	1.39
980	-18.18	-17.65	-17.59	-17.41	1.779	1.38
979	-17.85	-17.45	-17.59	-17.38	1.187	1.38
978	-16.84	-17.45	-17.59	-17.36	1.188	1.38
977	-17.49	-18.60	-17.57	-17.33	1.784	1.38
976	-17.49	-18.60	-17.54	-17.35	1.191	1.37
975	-17.55	-18.09	-17.51	-17.41	1.192	1.39
974	-17.72	-18.09	-17.47	-17.47	1.193	1.39
973	-17.72	-16.11	-17.43	-17.55	1.792	1.36
972	-19.31	-16.11	-17.42	-17.57	1.196	1.35
971	-17.69	-16.16	-17.42	-17.52	1.795	1.35
970	-17.15	-17.85	-17.41	-17.52	1.797	1.33
969	-18.21	-17.85	-17.41	-17.56	2.099	1.33
968	-18.96	-18.20	-17.44	-17.61	2.101	1.34
967	-17.57	-18.20	-17.48	-17.63	1.202	1.34
966	-16.35	-16.77	-17.52	-17.66	1.203	1.34
965	-16.35	-16.77	-17.52	-17.70	1.205	1.34
964	-17.97	-17.67	-17.53	-17.70	1.206	1.34
963	-18.71	-17.67	-17.54	-17.71	1.811	1.34
962	-17.89	-17.69	-17.57	-17.74	1.209	1.34
961	-17.89	-17.69	-17.62	-17.76	1.21	1.32
960	-17.17	-17.07	-17.66	-17.80	1.211	1.32
959	-15.89	-17.07	-17.68	-17.83	1.213	1.32
958	-15.89	-17.69	-17.65	-17.83	1.214	1.35
957	-15.89	-17.69	-17.63	-17.82	0.608	1.35
956	-17.11	-17.69	-17.64	-17.81	1.521	1.34
955	-17.80	-18.12	-17.61	-17.82	1.523	1.33
954	-17.09	-18.12	-17.58	-17.84	1.83	1.33
953	-17.59	-17.72	-17.59	-17.86	1.221	1.33
952	-17.04	-17.72	-17.60	-17.84	1.223	1.32

Year (AD)	Del 18-O (per mil)				Accumulation (m)	
	Raw Data*		49 Year Running mean		Raw Data*	49 Year Running mean
	Core 1	Summit	Core 1	Summit	Summit	Summit
951	-17.04	-20.13	-17.62	-17.81	1.224	1.31
950	-16.27	-20.13	-17.64	-17.80	1.226	1.31
949	-17.18	-19.60	-17.66	-17.81	1.227	1.33
948	-18.16	-19.60	-17.67	-17.87	0.614	1.31
947	-16.89	-16.56	-17.63	-17.92	1.538	1.31
946	-16.89	-16.56	-17.65	-17.97	0.924	1.30
945	-18.42	-18.29	-17.65	-17.98	1.233	1.30
944	-18.42	-18.29	-17.67	-17.98	1.235	1.28
943	-18.90	-17.36	-17.64	-17.98	1.236	1.27
942	-18.90	-17.36	-17.62	-17.97	1.238	1.27
941	-17.53	-17.85	-17.63	-17.96	1.24	1.26
940	-18.53	-17.85	-17.64	-17.94	1.862	1.28
939	-18.53	-18.61	-17.65	-17.93	1.243	1.29
938	-18.53	-18.61	-17.64	-17.91	1.245	1.28
937	-19.27	-18.61	-17.63	-17.90	0.623	1.29
936	-18.24	-18.40	-17.65	-17.89	1.248	1.29
935	-17.38	-18.40	-17.69	-17.90	1.25	1.30
934	-17.23	-16.88	-17.74	-17.91	1.877	1.30
933	-17.76	-16.95	-17.78	-17.91	1.253	1.31
932	-17.76	-16.95	-17.82	-17.92	1.255	1.33
931	-17.10	-18.43	-17.82	-17.92	1.257	1.32
930	-16.13	-18.43	-17.81	-17.94	1.259	1.32
929	-17.25	-18.43	-17.84	-17.96	1.26	1.31
928	-17.96	-17.23	-17.85	-17.96	1.199	1.32
927	-18.69	-17.23	-17.89	-17.97	0.632	1.32
926	-18.54	-17.77	-17.93	-17.92	1.266	1.31
925	-18.49	-18.70	-17.97	-17.90	1.901	1.31
924	-18.12	-18.70	-17.97	-17.89	1.269	1.31
923	-17.55	-18.74	-17.96	-17.88	0.954	1.32
922	-18.62	-18.74	-17.97	-17.93	1.273	1.31
921	-17.21	-18.04	-17.98	-17.99	1.594	1.32
920	-18.99	-18.04	-17.95	-17.98	1.277	1.34
919	-17.75	-17.97	-17.93	-17.99	1.919	1.34
918	-16.49	-17.97	-17.92	-18.01	0.961	1.34
917	-16.84	-16.13	-17.91	-18.04	0.962	1.34
916	-17.01	-16.13	-17.92	-18.03	1.928	1.35
915	-18.29	-16.78	-17.90	-18.01	1.545	1.34
914	-18.29	-16.78	-17.88	-17.99	1.289	1.33
913	-17.49	-17.25	-17.88	-17.95	1.937	1.35
912	-18.85	-17.35	-17.87	-17.95	1.293	1.38
911	-18.85	-17.35	-17.86	-17.95	1.619	1.37
910	-18.68	-17.62	-17.88	-17.94	0.973	1.38
909	-17.67	-17.62	-17.85	-17.96	1.95	1.37
908	-17.90	-18.07	-17.82	-17.98	1.302	1.37
907	-16.90	-18.07	-17.81	-18.00	1.304	1.38

Year (AD)	Del 18-O (per mil)				Accumulation (m)	
	Raw Data*		49 Year Running mean		Raw Data*	49 Year Running mean
	Core 1	Summit	Core 1	Summit	Summit	Summit
906	-17.49	-19.03	-17.83	-17.98	1.633	1.38
905	-18.45	-19.03	-17.87	-17.97	1.308	1.39
904	-18.18	-17.93	-17.87	-17.97	1.638	1.38
903	-18.88	-17.93	-17.85	-18.00	0.985	1.38
902	-18.88	-17.93	-17.82	-17.99	0.986	1.40
901	-18.35	-19.10	-17.80	-17.98	1.317	1.40
900	-17.54	-19.10	-17.79	-17.94	0.99	1.38
899	-17.54	-19.08	-17.79	-17.91	0.992	1.38
898	-17.23	-19.08	-17.77	-17.87	1.324	1.38
897	-17.26	-19.08	-17.74	-17.82	1.327	1.38
896	-17.35	-17.85	-17.74	-17.79	1.993	1.37
895	-17.35	-18.74	-17.72	-17.75	1.664	1.38
894	-18.08	-18.74	-17.72	-17.76	1	1.37
893	-18.71	-18.51	-17.76	-17.77	1.336	1.38
892	-17.74	-17.27	-17.78	-17.83	1.673	1.39
891	-17.74	-17.27	-17.79	-17.89	1.341	1.38
890	-17.71	-17.27	-17.78	-17.92	1.008	1.38
889	-18.46	-16.71	-17.78	-17.95	2.019	1.38
888	-18.46	-18.70	-17.75	-17.97	2.023	1.38
887	-18.04	-18.21	-17.71	-17.99	1.013	1.38
886	-18.04	-18.21	-17.65	-18.01	1.692	1.37
885	-16.14	-17.90	-17.61	-18.00	1.356	1.38
884	-16.14	-17.90	-17.59	-17.99	1.359	1.36
883	-17.16	-17.90	-17.59	-17.97	1.361	1.37
882	-18.32	-17.62	-17.58	-17.94	1.364	1.37
881	-17.97	-17.62	-17.56	-17.90	1.708	1.36
880	-17.05	-18.60	-17.53	-17.86	1.027	1.36
879	-17.29	-18.60	-17.54	-17.85	1.029	1.36
878	-17.29	-17.01	-17.54	-17.86	1.718	1.38
877	-17.29	-17.01	-17.51	-17.86	1.377	1.40
876	-17.98	-16.95	-17.49	-17.84	0.69	1.40
875	-17.98	-16.95	-17.48	-17.82	1.382	1.41
874	-17.03	-16.95	-17.48	-17.79	1.039	1.42
873	-17.03	-16.36	-17.49	-17.77	1.041	1.42
872	-16.98	-16.36	-17.51	-17.74	1.391	1.42
871	-18.03	-16.36	-17.52	-17.74	1.742	1.40
870	-18.07	-18.46	-17.53	-17.71	1.396	1.39
869	-18.07	-18.46	-17.52	-17.69	1.399	1.39
868	-17.94	-19.01	-17.51	-17.67	1.402	1.39
867	-17.65	-19.01	-17.51	-17.71	1.405	1.39
866	-17.68	-18.22	-17.50	-17.75	1.408	1.38
865	-18.09	-18.22	-17.53	-17.78	1.411	1.39
864	-16.44	-18.25	-17.53	-17.80	2.12	1.39
863	-16.62	-18.25	-17.54	-17.77	1.062	1.39
862	-16.01	-18.25	-17.57	-17.75	1.348	1.40

Year (AD)	Del 18-O (per mil)				Accumulation (m)	
	Raw Data*		49 Year Running mean		Raw Data*	49 Year Running mean
	Core 1	Summit	Core 1	Summit	Summit	Summit
861	-16.76	-17.25	-17.54	-17.73	1.067	1.39
860	-16.76	-17.25	-17.55	-17.72	1.069	1.38
859	-17.65	-16.74	-17.57	-17.72	1.785	1.39
858	-16.52	-16.74	-17.58	-17.71	1.431	1.39
857	-16.52	-17.20	-17.57	-17.74	1.076	1.40
856	-17.14	-17.20	-17.57	-17.78	1.437	1.39
855	-18.61	-17.20	-17.58	-17.79	1.44	1.40
854	-18.74	-18.56	-17.59	-17.78	2.165	1.41
853	-17.51	-17.97	-17.62	-17.80	1.808	1.42
852	-17.15	-17.97	-17.63	-17.82	1.449	1.41
851	-17.15	-17.97	-17.61	-17.84	1.452	1.44
850	-17.72	-17.97	-17.60	-17.86	1.455	1.43
849	-17.72	-17.74	-17.60	-17.85	1.459	1.44
848	-17.87	-17.74	-17.61	-17.86	1.096	1.46
847	-17.87	-17.74	-17.61	-17.87	1.099	1.46
846	-17.87	-17.62	-17.61	-17.84	1.101	1.46
845	-18.00	-17.62	-17.60	-17.78	1.103	1.46
844	-18.00	-17.62	-17.60	-17.76	1.474	1.47
843	-17.59	-19.10	-17.60	-17.74	1.477	1.48
842	-17.61	-19.10	-17.60	-17.71	1.11	1.49
841	-18.80	-19.10	-17.60	-17.71	1.484	1.49
840	-18.80	-17.32	-17.60	-17.70	1.859	1.49
839	-18.80	-17.32	-17.66	-17.69	1.863	1.47
838	-19.42	-17.32	-17.72	-17.65	1.493	1.49
837	-16.73	-17.32	-17.74	-17.61	1.122	1.49
836	-16.73	-17.49	-17.75	-17.62	1.125	1.50
835	-16.73	-17.49	-17.75	-17.63	1.879	1.50
834	-17.76	-17.49	-17.72	-17.65	1.13	1.50
833	-17.76	-19.35	-17.74	-17.67	1.887	1.49
832	-18.02	-19.35	-17.75	-17.67	1.134	1.49
831	-17.75	-19.35	-17.76	-17.67	1.516	1.49
830	-17.75	-17.87	-17.73	-17.66	1.899	1.48
829	-18.88	-17.92	-17.71	-17.63	1.903	1.44
828	-17.69	-17.92	-17.71	-17.61	1.144	1.44
827	-17.10	-17.92	-17.72	-17.59	1.911	1.43
826	-17.10	-17.92	-17.73	-17.56	1.149	1.44
825	-17.27	-16.72	-17.74	-17.53	1.535	1.44
824	-17.27	-16.72	-17.76	-17.50	1.923	1.44
823	-17.25	-16.72	-17.77	-17.50	1.156	1.45
822	-17.74	-15.34	-17.78	-17.49	1.931	1.46
821	-17.74	-15.34	-17.76	-17.50	1.548	1.47
820	-17.92	-17.64	-17.73	-17.50	1.939	1.47
819	-17.92	-17.64	-17.71	-17.48	1.555	1.47
818	-17.98	-17.86	-17.71	-17.44	1.948	1.46
817	-17.59	-17.86	-17.71	-17.40	1.561	1.46

Year (AD)	Del 18-O (per mil)				Accumulation (m)	
	Raw Data*		49 Year Running mean		Raw Data*	49 Year Running mean
	Core 1	Summit	Core 1	Summit	Summit	Summit
816	-18.10	-17.86	-17.68	-17.37	1.173	1.47
815	-19.49	-17.86	-17.64	-17.39	1.176	1.46
814	-19.49	-16.23	-17.61	-17.40	2.356	1.47
813	-17.05	-16.23	-17.56	-17.43	1.181	1.47
812	-17.05	-17.77	-17.59	-17.46	1.577	1.47
811	-16.60	-17.77	-17.61	-17.48	1.185	1.47
810	-16.60	-17.77	-17.62	-17.47	1.425	1.47
809	-17.08	-17.77	-17.62	-17.46	0.952	1.49
808	-17.08	-17.06	-17.62	-17.44	1.431	1.48
807	-17.58	-17.06	-17.61	-17.41	1.354	1.48
806	-17.58	-17.06	-17.61	-17.39	0.718	1.48
805	-17.57	-17.02	-17.60	-17.43	0.48	1.47
804	-17.57	-17.02	-17.54	-17.47	1.763	1.45
803	-17.54	-17.02	-17.49	-17.49	1.044	1.46
802	-17.54	-16.47	-17.48	-17.51	1.769	1.46
801	-18.48	-16.47	-17.47	-17.51	1.37	1.46
800	-18.48	-16.47	-17.46	-17.53	1.534	1.47
799	-18.48	-17.45	-17.47	-17.54	1.618	1.46
798	-18.48	-17.45	-17.48	-17.55	1.54	1.45
797	-16.71	-17.77	-17.48	-17.58	1.542	1.43
796	-16.71	-17.77	-17.47	-17.62	1.057	1.42
795	-16.62	-16.92	-17.45	-17.62	1.548	1.42
794	-17.70	-16.92	-17.47	-17.62	0.898	1.42
793	-17.70	-16.92	-17.48	-17.62	1.39	1.42
792	-17.11	-18.06	-17.49	-17.60	1.72	1.42
791	-17.11	-18.06	-17.48	-17.58	1.723	1.44
790	-17.22	-18.06	-17.44	-17.56	2.137	1.45
789	-17.22	-18.67	-17.41	-17.55	1.235	1.43
788	-17.87	-18.67	-17.42	-17.54	1.237	1.43
787	-17.87	-18.67	-17.43	-17.50	1.239	1.42
786	-17.39	-16.97	-17.45	-17.46	2.068	1.41
785	-17.39	-16.97	-17.46	-17.45	2.071	1.42
784	-17.80	-18.10	-17.46	-17.44	1.245	1.44
783	-17.80	-18.10	-17.47	-17.47	1.163	1.44
782	-17.54	-18.10	-17.46	-17.49	1.498	1.44
781	-17.54	-19.99	-17.44	-17.52	1.25	1.43
780	-15.59	-19.99	-17.42	-17.55	1.085	1.44
779	-15.59	-18.90	-17.42	-17.58	1.672	1.44
778	-16.60	-18.90	-17.42	-17.60	1.674	1.45
777	-16.60	-17.88	-17.41	-17.64	1.257	1.43
776	-16.60	-17.88	-17.39	-17.67	2.266	1.44
775	-17.88	-17.03	-17.37	-17.70	1.177	1.45
774	-17.76	-17.03	-17.35	-17.71	1.01	1.44
773	-17.76	-17.03	-17.34	-17.72	0.842	1.43
772	-16.95	-17.03	-17.38	-17.73	1.012	1.43

Year (AD)	Del 18-O (per mil)				Accumulation (m)	
	Raw Data*		49 Year Running mean		Raw Data*	49 Year Running mean
	Core 1	Summit	Core 1	Summit	Summit	Summit
771	-16.95	-17.75	-17.39	-17.74	1.689	1.42
770	-18.82	-17.75	-17.41	-17.76	1.691	1.40
769	-18.82	-17.75	-17.43	-17.78	1.862	1.41
768	-17.76	-16.94	-17.45	-17.80	1.525	1.42
767	-17.76	-16.94	-17.48	-17.80	2.12	1.41
766	-17.68	-16.94	-17.50	-17.27	1.953	1.39
765	-17.68	-15.76	-17.52	-17.33	1.19	1.40
764	-17.66	-15.76	-17.54	-17.37	1.361	1.37
763	-17.66	-15.76	-17.55	-17.41	1.021	1.38
762	-17.66	-15.76	-17.56	-17.45	0.852	1.38
761	-17.06	-17.27	-17.57	-17.46	1.705	1.38
760	-17.06	-17.27	-17.58	-17.48	1.877	1.37
759	-17.34	-18.37	-17.58	-17.50	1.281	1.35
758	-17.34	-18.37	-17.58	-17.56	1.794	1.21
757	-16.34	-18.37	-17.58	-17.60	0.086	1.15
756	-16.94	-18.37	-17.57	-17.64	1.026	1.23
755	-17.49	-18.38	-17.61	-18.38	1.54	1.04
754	-17.49	-18.38	-17.65	-18.27	1.712	1.40
753	-17.21	-18.38	-17.67	-18.16	0.856	1.54
752	-17.21	-17.84	-17.69	-18.06	1.885	1.49
751	-17.44	-17.84	-17.69	-18.01	1.714	1.37
750	-17.44	-17.84	-17.66	-17.97	1.286	1.51
749	-18.42	-18.16	-17.65	-18.03	1.115	1.25
748	-18.42	-18.16	-17.66	-18.10	1.543	1.05
747	-17.43	-18.16	-17.69	-18.10	0.6	1.05
746	-17.43	-18.16	-17.72	-18.04	0.686	1.17
745	-18.58	-17.86	-17.71	-17.96	1.286	0.86
744	-18.58	-17.86	-17.69	-17.86	1.715	1.715
743	-18.58		-17.69			
742	-18.29		-17.68			
741	-18.29		-17.66			
740	-18.31		-17.64			
739	-18.31		-17.64			
738	-18.14		-17.64			
737	-18.14		-17.64			
736	-17.77		-17.67			
735	-17.77		-17.68			
734	-17.77		-17.69			
733	-17.39		-17.71			
732	-17.39		-17.74			
731	-17.41		-17.77			
730	-17.41		-17.79			
729	-17.57		-17.81			
728	-17.57		-17.83			
727	-16.48		-17.85			

Year (AD)	Del 18-O (per mil)				Accumulation (m)	
	Raw Data*		49 Year Running mean		Raw Data*	49 Year Running mean
	Core 1	Summit	Core 1	Summit	Summit	Summit
726	-16.48		-17.85			
725	-17.35		-17.86			
724	-18.41		-17.84			
723	-18.41		-17.83			
722	-18.41		-17.83			
721	-18.00		-17.83			
720	-18.00		-17.82			
719	-17.67		-17.82			
718	-17.67		-17.83			
717	-16.59		-17.82			
716	-16.59		-17.81			
715	-17.54		-17.79			
714	-17.54		-17.77			
713	-18.13		-17.76			
712	-18.13		-17.76			
711	-17.89		-17.76			
710	-17.89		-17.75			
709	-17.90		-17.75			
708	-17.90		-17.75			
707	-18.56		-17.74			
706	-18.56		-17.74			
705	-18.56		-17.74			
704	-18.01		-17.73			
703	-18.01		-17.70			
702	-17.66		-17.70			
701	-17.66		-17.70			
700	-17.80		-17.67			
699	-17.80		-17.62			
698	-17.31		-17.58			
697	-17.31		-17.53			
696	-18.22		-17.50			
695	-18.76		-17.48			
694	-18.76		-17.46			
693	-17.88		-17.45			
692	-17.88		-17.46			
691	-17.45		-17.46			
690	-17.45		-17.46			
689	-17.45		-17.46			
688	-17.89		-17.44			
687	-17.89		-17.43			
686	-17.52		-17.43			
685	-17.52		-17.41			
684	-17.31		-17.39			
683	-17.31		-17.37			
682	-17.31		-17.34			

Year (AD)	Del 18-O (per mil)				Accumulation (m)	
	Raw Data*		49 Year Running mean		Raw Data*	49 Year Running mean
	Core 1	Summit	Core 1	Summit	Summit	Summit
681	-17.09		-17.31			
680	-17.09		-17.30			
679	-16.49		-17.30			
678	-16.49		-17.29			
677	-16.08		-17.29			
676	-16.08		-17.28			
675	-16.17		-17.27			
674	-16.17		-17.25			
673	-16.26		-17.26			
672	-16.26		-17.27			
671	-16.87		-17.27			
670	-16.87		-17.26			
669	-17.03		-17.25			
668	-17.03		-17.26			
667	-17.03		-17.25			
666	-17.41		-17.26			
665	-17.31		-17.26			
664	-17.31		-17.26			
663	-17.69		-17.24			
662	-17.69		-17.22			
661	-17.04		-17.22			
660	-17.04		-17.21			
659	-16.99		-17.21			
658	-16.99		-17.21			
657	-16.99		-17.22			
656	-17.95		-17.24			
655	-17.95		-17.26			
654	-17.61		-17.29			
653	-17.61		-17.31			
652	-17.32		-17.34			
651	-17.18		-17.37			
650	-17.18		-17.39			
649	-17.78		-17.42			
648	-17.78		-17.44			
647	-18.24		-17.45			
646	-18.24		-17.45			
645	-18.16		-17.47			
644	-18.16		-17.48			
643	-17.75		-17.50			
642	-17.75		-17.51			
641	-17.32		-17.52			
640	-17.32		-17.53			
639	-17.11		-17.55			
638	-17.11		-17.54			
637	-17.20		-17.53			

Year (AD)	Del 18-O (per mil)				Accumulation (m)	
	Raw Data*		49 Year Running mean		Raw Data*	49 Year Running mean
	Core 1	Summit	Core 1	Summit	Summit	Summit
636	-17.20		-17.53			
635	-17.18		-17.53			
634	-17.18		-17.54			
633	-18.14		-17.54			
632	-18.00		-17.55			
631	-18.00		-17.54			
630	-18.00		-17.54			
629	-17.29		-17.53			
628	-17.59		-17.53			
627	-17.59		-17.53			
626	-17.34		-17.54			
625	-17.34		-17.54			
624	-17.34		-17.53			
623	-16.95		-17.52			
622	-16.95		-17.50			
621	-17.55		-17.48			
620	-17.77		-17.47			
619	-17.77		-17.47			
618	-17.69		-17.48			
617	-17.90		-17.46			
616	-17.90		-17.46			
615	-17.90		-17.44			
614	-17.28		-17.43			
613	-17.15		-17.41			
612	-17.15		-17.39			
611	-17.15		-17.37			
610	-17.30		-17.35			
609	-17.30		-17.33			
608	-17.25		-17.31			
607	-17.70		-17.30			
606	-17.70		-17.28			
605	-17.33		-17.27			
604	-17.44		-17.26			
603	-17.44		-17.26			
602	-17.40		-17.25			
601	-17.40		-17.25			
600	-17.40		-17.25			
599	-17.28		-17.26			
598	-17.24		-17.27			
597	-17.24		-17.29			
596	-17.82		-17.29			
595	-18.01		-17.29			
594	-18.01		-17.29			
593	-17.12		-17.29			
592	-17.12		-17.28			

Year (AD)	Del 18-O (per mil)				Accumulation (m)	
	Raw Data*		49 Year Running mean		Raw Data*	49 Year Running mean
	Core 1	Summit	Core 1	Summit	Summit	Summit
591	-16.42		-17.28			
590	-16.42		-17.27			
589	-16.42		-17.28			
588	-16.21		-17.29			
587	-16.21		-17.30			
586	-16.22		-17.31			
585	-16.22		-17.32			
584	-17.19		-17.32			
583	-17.19		-17.33			
582	-17.20		-17.32			
581	-17.20		-17.32			
580	-17.20		-17.33			
579	-17.26		-17.34			
578	-17.26		-17.36			
577	-17.26		-17.37			
576	-17.42		-17.39			
575	-17.69		-17.40			
574	-17.69		-17.42			
573	-17.69		-17.44			
572	-17.69		-17.46			
571	-17.69		-17.47			
570	-17.69		-17.45			
569	-17.69		-17.44			
568	-17.69		-17.43			
567	-17.69		-17.43			
566	-17.69		-17.44			
565	-17.69		-17.45			
564	-17.69		-17.47			
563	-17.69		-17.49			
562	-17.58		-17.52			
561	-17.58		-17.55			
560	-17.31		-17.59			
559	-17.57		-17.60			
558	-17.57		-17.63			
557	-17.73		-17.65			
556	-17.79		-17.67			
555	-17.79		-17.69			
554	-18.20		-17.71			
553	-18.20		-17.72			
552	-18.08		-17.74			
551	-18.22		-17.75			
550	-18.25		-17.75			
549	-18.25		-17.76			
548	-18.25		-17.76			
547	-17.89		-17.76			

Year (AD)	Del 18-O (per mil)				Accumulation (m)	
	Raw Data*		49 Year Running mean		Raw Data*	49 Year Running mean
	Core 1	Summit	Core 1	Summit	Summit	Summit
546	-17.29		-17.77			
545	-17.29		-17.77			
544	-16.90		-17.78			
543	-16.90		-17.78			
542	-16.90		-17.79			
541	-17.20		-17.79			
540	-17.32		-17.79			
539	-17.32		-17.79			
538	-17.57		-17.78			
537	-17.57		-17.77			
536	-18.04		-17.76			
535	-18.04		-17.76			
534	-18.30		-17.76			
533	-18.30		-17.77			
532	-18.30		-17.77			
531	-18.19		-17.77			
530	-18.19		-17.78			
529	-17.97		-17.77			
528	-17.97		-17.77			
527	-17.84		-17.77			
526	-17.84		-17.76			
525	-17.98		-17.75			
524	-17.98		-17.73			
523	-17.70		-17.71			
522	-17.88		-17.70			
521	-17.88		-17.70			
520	-18.01		-17.70			
519	-18.01		-17.70			
518	-17.97		-17.69			
517	-17.97		-17.69			
516	-17.52		-17.68			
515	-17.52		-17.66			
514	-17.14		-17.66			
513	-17.14		-17.66			
512	-17.28		-17.66			
511	-17.28		-17.66			
510	-17.68		-17.66			
509	-17.68		-17.66			
508	-17.93		-17.65			
507	-17.93		-17.64			
506	-17.93		-17.64			
505	-17.99		-17.63			
504	-17.99		-17.63			
503	-18.21		-17.62			
502	-17.98		-17.62			

Year (AD)	Del 18-O (per mil)				Accumulation (m)	
	Raw Data*		49 Year Running mean		Raw Data*	49 Year Running mean
	Core 1	Summit	Core 1	Summit	Summit	Summit
501	-17.61		-17.61			
500	-17.34		-17.60			
499	-17.34		-17.59			
498	-17.34		-17.60			
497	-17.22		-17.59			
496	-17.01		-17.61			
495	-17.01		-17.62			
494	-16.63					
493	-16.63					
492	-16.70					
491	-16.70					
490	-17.23					
489	-17.23					
488	-17.87					
487	-17.87					
486	-18.16					
485	-18.16					
484	-17.97					
483	-17.97					
482	-18.02					
481	-17.76					
480	-17.76					
479	-17.76					
478	-17.47					
477	-17.49					
476	-17.49					
475	-17.77					
474	-17.77					
473	-17.77					
472	-18.49					
471	-18.49					
470	-18.49					

* Adapted after http://www.ngdc.noaa.gov/paleo/icecore/trop/quelccaya/quelccaya_data.html

APPENDIX D

Speleothem Isotopic Data

LOS2 Untuned Isotopic Data

Sample Number	Distance from Base (mm)	Del 13-C (per mil)		Del 18-O (per mil)	
		Raw Data	5- Point Running Mean	Raw Data	5-Point Running Mean
LOS2 A1	0.0				
LOS2 A2	1.5	-8.36	-8.36	-3.64	-3.64
LOS2 A3	3.0	-8.20	-8.32	-3.65	-3.61
LOS2 A4	4.5	-8.40	-8.49	-3.55	-3.62
LOS2 A5	6.5	-8.64	-8.62	-3.56	-3.67
LOS2 A6	7.0	-8.82	-8.78	-3.70	-3.75
LOS2 A7	9.0	-9.02	-8.82	-3.88	-3.84
LOS2 A8	10.5	-9.00	-8.59	-4.06	-3.71
LOS2 A9	12.0	-8.60	-8.40	-4.00	-3.67
LOS2 A10	13.5	-7.52	-8.01	-2.93	-3.55
LOS2 A11	15.0	-7.87	-7.46	-3.47	-3.28
LOS2 B1	17.5	-7.06	-7.26	-3.31	-3.16
LOS2 B2	19.0	-6.27	-7.29	-2.69	-3.27
LOS2 B3	20.0	-7.57	-7.40	-3.40	-3.22
LOS2 B4	22.0	-7.69	-7.30	-3.45	-3.19
LOS2 B5	23.0	-8.40	-7.75	-3.23	-3.50
LOS2 B6	25.0	-6.59	-7.74	-3.16	-3.57
LOS2 B7	26.0	-8.51	-7.79	-4.28	-3.59
LOS2 B8	27.5	-7.49	-7.53	-3.71	-3.67
LOS2 B9	29.0	-7.97	-7.70	-3.55	-3.67
LOS2 B10	30.5	-7.11	-7.57	-3.67	-3.48
LOS2 B11	32.0	-7.42	-7.40	-3.16	-3.31
LOS2 B12	33.0	-7.85	-7.62	-3.30	-3.39
LOS2 C1	34.5	-6.66	-7.92	-2.85	-3.34
LOS2 C2	36.0	-9.06	-8.02	-3.98	-3.37
LOS2 C3	37.5	-8.62	-8.12	-3.42	-3.33
LOS2 C4	39.0	-7.90	-8.53	-3.31	-3.50
LOS2 C5	40.5	-8.33	-8.07	-3.08	-3.37
LOS2 C6	41.5	-8.75	-8.23	-3.71	-3.54
LOS2 C7	42.5	-6.73	-8.43	-3.31	-3.68
LOS2 C8	43.5	-9.43	-8.43	-4.28	-3.78
LOS2 C9	45.0	-8.90	-8.55	-4.00	-3.86
LOS2 C10	46.0	-8.33	-8.63	-3.61	-3.77
LOS2 C11	47.5	-9.37	-8.43	-4.10	-3.54
LOS2 D1	50.0	-7.13	-8.48	-2.83	-3.43
LOS2 D2	51.0	-8.44	-8.56	-3.16	-3.33
LOS2 D3	52.5	-9.15	-8.17	-3.45	-3.07
LOS2 D4	54.0	-8.72	-7.98	-3.10	-3.18
LOS2 D5	55.0	-7.44	-8.06	-2.83	-3.29
LOS2 D6	56.5	-6.14	-7.71	-3.38	-3.20
LOS2 D7	57.5	-8.83	-7.49	-3.71	-3.20
LOS2 D8	59.0	-7.40	-7.39	-2.99	-3.26

Sample Number	Distance from Base (mm)	Del 13-C (per mil)		Del 18-0 (per mil)	
		Raw Data	5- Point Running Mean	Raw Data	5-Point Running Mean
LOS2 D9	60.5	-7.62	-7.35	-3.11	-3.12
LOS2 D10	62.0	-6.96	-7.01	-3.09	-3.07
LOS2 D11	63.5	-5.96	-7.00	-2.68	-3.17
LOS2 E2	67.5	-7.09	-7.09	-3.47	-3.24
LOS2 E3	68.5	-7.38	-7.26	-3.52	-3.31
LOS2 E4	70.0	-8.04	-7.49	-3.44	-3.40
LOS2 E5	71.0	-7.81	-7.52	-3.44	-3.34
LOS2 E6	72.5	-7.11	-7.55	-3.14	-3.24
LOS2 E7	73.5	-7.27	-7.47	-3.15	-3.23
LOS2 E8	74.5	-7.50	-7.26	-3.00	-3.18
LOS2 E9	75.5	-7.63	-7.09	-3.40	-3.19
LOS2 E10	77.0	-6.75	-6.95	-3.18	-3.18
LOS2 E11	78.5	-6.29	-6.79	-3.23	-3.15
LOS2 E12	79.5	-6.60	-6.62	-3.11	-3.12
LOS2 F1	81.0	-6.70	-6.90	-2.81	-3.16
LOS2 F2	82.5	-6.78	-7.20	-3.26	-3.26
LOS2 F4	84.5	-8.16	-7.37	-3.40	-3.31
LOS2 F5	85.5	-7.79	-7.59	-3.71	-3.40
LOS2 F6	87.0	-7.45	-7.77	-3.40	-3.44
LOS2 F7	88.0	-7.77	-7.83	-3.26	-3.45
LOS2 F8	90.0	-7.66	-7.97	-3.43	-3.42
LOS2 F9	91.0	-8.49	-8.39	-3.46	-3.57
LOS2 F10	92.0	-8.47	-8.93	-3.58	-3.83
LOS2 F11	93.5	-9.57	-9.36	-4.10	-4.00
LOS2 F12	95.0	-10.46	-9.41	-4.58	-4.09
LOS2 G2	97.0	-9.83	-9.47	-4.29	-4.18
LOS2 G3	99.0	-8.73	-9.10	-3.90	-4.04
LOS2 G4	100.0	-8.78	-8.61	-4.01	-3.86
LOS2 G5	101.5	-7.71	-8.39	-3.41	-3.77
LOS2 G6	103.0	-8.00	-8.09	-3.68	-3.64
LOS2 G7	104.0	-8.73	-7.84	-3.84	-3.46
LOS2 G8	106.5	-7.24	-8.02	-3.24	-3.50
LOS2 G9	107.0	-7.51	-8.01	-3.12	-3.36
LOS2 G10	108.5	-8.62	-7.88	-3.63	-3.28
LOS2 G11	109.5	-7.96	-8.18	-2.94	-3.39
LOS2 G12	111.0	-8.09	-8.25	-3.46	-3.40
LOS2 H1	113.0	-8.72	-8.06	-3.80	-3.32
LOS2 H2	114.0	-7.89	-7.82	-3.19	-3.31
LOS2 H3	115.0	-7.66	-7.57	-3.20	-3.17
LOS2 H4	117.0	-6.76	-7.06	-2.92	-2.96
LOS2 H5	118.0	-6.82	-6.96	-2.75	-2.98
LOS2 H6	119.5	-6.15	-6.78	-2.77	-2.93
LOS2 H7	120.5	-7.40	-6.79	-3.28	-2.94
LOS2 H8	122.0	-6.77	-6.67	-2.92	-2.96

Sample Number	Distance from Base (mm)	Del 13-C (per mil)		Del 18-0 (per mil)	
		Raw Data	5- Point Running Mean	Raw Data	5-Point Running Mean
LOS2 H9	123.0	-6.80	-6.64	-2.98	-2.94
LOS2 H10	124.5	-6.22	-6.44	-2.84	-2.73
LOS2 H11	126.0	-6.03	-6.65	-2.66	-2.71
LOS2 H12	127.0	-6.38	-6.77	-2.23	-2.68
LOS2 I1	129.0	-7.83	-6.83	-2.82	-2.60
LOS2 I2	130.0	-7.42	-7.19	-2.84	-2.67
LOS2 I3	131.5	-6.48	-7.10	-2.43	-2.73
LOS2 I4	132.5	-7.84	-7.22	-3.02	-2.86
LOS2 I5	134.0	-5.94	-7.62	-2.51	-3.06
LOS2 I6	135.5	-8.40	-8.21	-3.47	-3.33
LOS2 I7	136.5	-9.44	-8.39	-3.86	-3.49
LOS2 I8	137.5	-9.43	-8.38	-3.81	-3.72
LOS2 I9	138.5	-8.74	-8.36	-3.79	-3.61
LOS2 I10	139.5	-5.88	-8.13	-3.69	-3.52
LOS2 I12	143.0	-8.31	-7.90	-2.91	-3.49
LOS2 J1	145.0	-8.27	-7.62	-3.39	-3.46
LOS2 J2	146.0	-8.28	-8.00	-3.67	-3.38
LOS2 J3	147.0	-7.34	-7.70	-3.65	-3.43
LOS2 J4	148.5	-7.79	-7.37	-3.27	-3.36
LOS2 J5	150.0	-6.79	-7.03	-3.16	-3.25
LOS2 J6	151.0	-6.65	-6.85	-3.06	-3.14
LOS2 J7	152.0	-6.55	-6.55	-3.14	-3.05
LOS2 J8	153.5	-6.48	-6.47	-3.06	-3.01
LOS2 J9	154.5	-6.27	-6.39	-2.81	-2.86
LOS2 J10	156.0	-6.41	-6.43	-2.99	-2.75
LOS2 J11	157.5	-6.26	-6.42	-2.28	-2.68
LOS2 J12	158.5	-6.71	-6.30	-2.62	-2.67
LOS2 K1	160.0	-6.45	-6.12	-2.72	-2.60
LOS2 K2	161.0	-5.65	-6.26	-2.73	-2.72
LOS2 K3	162.5	-5.53	-6.07	-2.64	-2.61
LOS2 K4	164.0	-6.97	-5.99	-2.87	-2.58
LOS2 K5	165.0	-5.75	-5.78	-2.08	-2.42
LOS2 K6	166.0	-6.03	-5.70	-2.59	-2.29
LOS2 K7	167.5	-4.60	-5.40	-1.93	-2.17
LOS2 K9	169.5	-5.16	-4.72	-1.98	-1.99
LOS2 K11	172.0	-5.49	-4.64	-2.28	-1.90
LOS2 K12	173.5	-2.33	-4.31	-1.16	-1.80
LOS2 L1	175.0	-5.64	-4.24	-2.14	-1.79
LOS2 L2	176.5	-2.93	-4.24	-1.42	-1.77
LOS2 L3	177.0	-4.81	-5.00	-1.98	-1.97
LOS2 L4	178.0	-5.51	-5.21	-2.18	-2.02
LOS2 L5	179.0	-6.11	-5.97	-2.12	-2.24
LOS2 L6	180.5	-6.71	-5.96	-2.38	-2.26
LOS2 L7	182.0	-6.74	-6.12	-2.56	-2.30

Sample Number	Distance from Base (mm)	Del 13-C (per mil)		Del 18-0 (per mil)	
		Raw Data	5- Point Running Mean	Raw Data	5-Point Running Mean
LOS2 L8	183.0	-4.74	-6.63	-2.06	-2.56
LOS2 L9	184.0	-6.32	-6.90	-2.40	-2.68
LOS2 L11	186.5	-8.63	-7.19	-3.42	-2.76
LOS2 L12	187.5	-8.06	-7.93	-2.98	-2.90
LOS2 M1	189.5	-8.22	-8.33	-2.96	-3.00
LOS2 M2	191.0	-8.41	-8.30	-2.72	-2.92
LOS2 M3	192.5	-8.33	-8.45	-2.90	-3.00
LOS2 M4	193.5	-8.46	-8.49	-3.04	-3.06
LOS2 M5	194.5	-8.83	-8.38	-3.36	-3.06
LOS2 M6	196.0	-8.42	-7.88	-3.28	-2.91
LOS2 M7	197.0	-7.84	-7.31	-2.69	-2.75
LOS2 M8	198.5	-5.84	-6.54	-2.19	-2.44
LOS2 M9	199.5	-5.61	-6.03	-2.21	-2.19
LOS2 M10	201.0	-5.02	-5.56	-1.84	-2.05
LOS2 M11	202.5	-5.84	-5.65	-2.05	-2.09
LOS2 N1	205.0	-5.50	-5.97	-1.97	-2.26
LOS2 N2	206.5	-6.29	-6.10	-2.36	-2.39
LOS2 N3	207.0	-7.18	-6.09	-3.08	-2.45
LOS2 N4	209.0	-5.68	-6.23	-2.48	-2.56
LOS2 N5	210.0	-5.78	-5.90	-2.38	-2.45
LOS2 N6	211.5	-6.23	-6.23	-2.49	-2.49
Hendy Test Samples					
LOS2 A1 Hendy		-7.42		-3.43	
LOS2 A2 Hendy		-8.24		-3.49	
LOS2 A3 Hendy		-8.48		-3.65	
LOS2 A4 Hendy		-8.49		-3.65	
LOS2 A5 Hendy		-8.28		-3.62	
LOS2 A6 Hendy		-8.13		-3.29	

LOS2 Tuning With Quelccaya Summit

Year (AD) (Tuned)	LOS2		Summit	
	Del 18-O (per mil) 5-Point Mean	Del 13-C (per mil) 5-Point Mean	Del 18-O (per mil) 49-Year Mean	Accumulation (m) 49-Year Mean
729				
742	-3.64	-8.36	-17.86	
755	-3.61	-8.32	-18.01	1.27
768	-3.62	-8.49	-17.68	1.41
785	-3.67	-8.62	-17.46	1.43
789	-3.75	-8.78	-17.55	1.43
806	-3.84	-8.82	-17.43	1.47
819	-3.71	-8.59	-17.46	1.46
832	-3.67	-8.40	-17.66	1.49
844	-3.55	-8.01	-17.77	1.47
857	-3.28	-7.46	-17.75	1.39
879	-3.16	-7.26	-17.87	1.37
892	-3.27	-7.29	-17.84	1.38
900	-3.22	-7.40	-17.94	1.39
917	-3.19	-7.30	-18.01	1.34
926	-3.50	-7.75	-17.93	1.31
943	-3.57	-7.74	-17.97	1.28
951	-3.59	-7.79	-17.82	1.32
964	-3.67	-7.53	-17.70	1.34
977	-3.67	-7.70	-17.37	1.38
987	-3.48	-7.57	-17.53	1.39
997	-3.31	-7.40	-17.53	1.36
1004	-3.39	-7.62	-17.59	1.37
1014	-3.34	-7.92	-17.90	1.42
1024	-3.37	-8.02	-18.19	1.43
1034	-3.33	-8.12	-18.23	1.44
1045	-3.50	-8.53	-18.18	1.49
1055	-3.37	-8.07	-17.78	1.48
1061	-3.54	-8.23	-17.56	1.48
1068	-3.68	-8.43	-17.40	1.48
1075	-3.78	-8.43	-17.32	1.51
1085	-3.86	-8.55	-17.21	1.50
1090	-3.77	-8.63	-17.27	1.49
1097	-3.54	-8.43	-17.38	1.50
1109	-3.43	-8.48	-17.55	1.53
1114	-3.33	-8.56	-17.63	1.52
1122	-3.07	-8.17	-17.75	1.52
1129	-3.18	-7.98	-17.68	1.53
1134	-3.29	-8.06	-17.59	1.54
1141	-3.20	-7.71	-17.73	1.55
1146	-3.20	-7.49	-17.73	1.55
1153	-3.26	-7.39	-17.86	1.52

Year (AD) (Tuned)	LOS2		Summit	
	Del 18-O (per mil) 5-Point Mean	Del 13-C (per mil) 5-Point Mean	Del 18-O (per mil) 49-Year Mean	Accumulation (m) 49-Year Mean
1160	-3.12	-7.35	-17.97	1.54
1168	-3.07	-7.01	-17.97	1.53
1175	-3.17	-7.00	-17.95	1.56
1194	-3.24	-7.09	-17.90	1.50
1199	-3.31	-7.26	-17.95	1.51
1207	-3.40	-7.49	-17.84	1.50
1212	-3.34	-7.52	-17.88	1.50
1219	-3.24	-7.55	-17.86	1.52
1224	-3.23	-7.47	-17.76	1.50
1229	-3.18	-7.26	-17.65	1.50
1233	-3.19	-7.09	-17.62	1.50
1241	-3.18	-6.95	-17.89	1.54
1248	-3.15	-6.79	-17.92	1.52
1253	-3.12	-6.62	-17.76	1.52
1260	-3.16	-6.90	-17.79	1.46
1267	-3.26	-7.20	-17.75	1.41
1277	-3.31	-7.37	-18.10	1.39
1282	-3.40	-7.59	-18.00	1.39
1289	-3.44	-7.77	-17.87	1.37
1294	-3.45	-7.83	-17.67	1.36
1304	-3.42	-7.97	-17.77	1.38
1309	-3.57	-8.39	-17.65	1.41
1314	-3.83	-8.93	-17.45	1.41
1321	-4.00	-9.36	-17.55	1.44
1328	-4.09	-9.41	-17.57	1.43
1338	-4.18	-9.47	-17.44	1.40
1347	-4.04	-9.10	-17.44	1.37
1351	-3.86	-8.61	-17.46	1.37
1358	-3.77	-8.39	-17.39	1.35
1364	-3.64	-8.09	-17.59	1.35
1368	-3.46	-7.84	-17.47	1.35
1379	-3.50	-8.02	-17.47	1.33
1382	-3.36	-8.01	-17.54	1.31
1388	-3.28	-7.88	-17.66	1.33
1392	-3.39	-8.18	-17.74	1.35
1399	-3.40	-8.25	-17.91	1.33
1408	-3.32	-8.06	-18.00	1.33
1412	-3.31	-7.82	-18.00	1.32
1416	-3.17	-7.57	-18.02	1.33
1425	-2.96	-7.06	-17.86	1.30
1429	-2.98	-6.96	-17.83	1.32
1436	-2.93	-6.78	-18.02	1.30
1440	-2.94	-6.79	-18.08	1.29
1447	-2.96	-6.67	-18.11	1.29

Year (AD) (Tuned)	LOS2		Summit	
	Del 18-O (per mil) 5-Point Mean	Del 13-C (per mil) 5-Point Mean	Del 18-O (per mil) 49-Year Mean	Accumulation (m) 49-Year Mean
1451	-2.94	-6.64	-18.13	1.30
1458	-2.73	-6.44	-18.23	1.25
1464	-2.71	-6.65	-18.07	1.25
1469	-2.68	-6.77	-18.07	1.22
1477	-2.60	-6.83	-18.16	1.22
1482	-2.67	-7.19	-18.07	1.25
1488	-2.73	-7.10	-18.00	1.29
1493	-2.86	-7.22	-18.03	1.30
1499	-3.06	-7.62	-17.91	1.30
1506	-3.33	-8.21	-17.78	1.34
1510	-3.49	-8.39	-17.74	1.35
1516	-3.72	-8.38	-17.84	1.39
1523	-3.61	-8.36	-17.94	1.44
1529	-3.52	-8.13	-17.96	1.47
1551	-3.49	-7.90	-18.32	1.50
1564	-3.46	-7.62	-18.57	1.54
1570	-3.38	-8.00	-18.50	1.54
1576	-3.43	-7.70	-18.45	1.55
1586	-3.36	-7.37	-18.50	1.58
1595	-3.25	-7.03	-18.56	1.56
1602	-3.14	-6.85	-18.45	1.60
1608	-3.05	-6.55	-18.62	1.65
1617	-3.01	-6.47	-18.54	1.69
1624	-2.86	-6.39	-18.65	1.73
1633	-2.75	-6.43	-18.42	1.73
1643	-2.68	-6.42	-18.51	1.83
1649	-2.67	-6.30	-18.62	1.82
1659	-2.60	-6.12	-18.53	1.79
1665	-2.72	-6.26	-18.70	1.75
1674	-2.61	-6.07	-18.75	1.70
1684	-2.58	-5.99	-19.01	1.68
1690	-2.42	-5.78	-18.80	1.62
1696	-2.29	-5.70	-18.81	1.58
1706	-2.17	-5.40	-18.56	1.49
1719	-1.99	-4.72	-18.70	1.47
1734	-1.90	-4.64	-18.70	1.42
1744	-1.80	-4.31	-18.75	1.38
1753	-1.79	-4.24	-18.88	1.35
1763	-1.77	-4.24	-18.70	1.30
1766	-1.97	-5.00	-18.93	1.29
1772	-2.02	-5.21	-18.70	1.26
1779	-2.24	-5.97	-18.81	1.26
1788	-2.26	-5.96	-18.71	1.24
1798	-2.30	-6.12	-19.04	1.27

Year (AD) (Tuned)	LOS2		Summit	
	Del 18-O (per mil) 5-Point Mean	Del 13-C (per mil) 5-Point Mean	Del 18-O (per mil) 49-Year Mean	Accumulation (m) 49-Year Mean
1804	-2.56	-6.63	-18.82	1.26
1810	-2.68	-6.90	-18.72	1.27
1826	-2.76	-7.19	-18.55	1.26
1832	-2.90	-7.93	-18.55	1.27
1845	-3.00	-8.33	-18.16	1.32
1854	-2.92	-8.30	-18.38	1.37
1864	-3.00	-8.45	-18.32	1.43
1870	-3.06	-8.49	-18.48	1.46
1877	-3.06	-8.38	-18.38	1.49
1886	-2.91	-7.88	-18.30	1.51
1892	-2.75	-7.31	-18.22	1.52
1902	-2.44	-6.54	-17.98	1.55
1908	-2.19	-6.03	-18.01	1.54
1918	-2.05	-5.56	-17.54	1.52
1927	-2.09	-5.65	-17.53	1.54
1943	-2.26	-5.97	-17.35	1.54
1952	-2.39	-6.10	-17.44	1.50
1956	-2.45	-6.09	-17.39	1.48
1968	-2.56	-6.23	-17.42	1.44
1984	-2.45	-5.90		1.521
1993	-2.49	-6.23		

AB1 Isotopic Data

Sample Number	Distance From Base (mm)	Del 13-C (per mil)		Del 18-O (per mil)	
		Raw Data	5 Point Running Mean	Raw Data	5 Point Running Mean
AB1 E2	1.9	-2.65	-2.65	-2.37	-2.37
AB1 A5	4.9	-2.64	-2.73	-2.06	-1.98
AB1 E5	5.1	-2.91	-3.22	-1.53	-2.09
AB1 A6	5.9	-3.85	-3.43	-1.90	-2.15
AB1 E6	6.3	-4.36	-3.59	-2.25	-2.34
AB1 A9	9.6	-3.39	-3.65	-2.92	-2.56
AB1 E7	10	-3.45	-3.68	-2.86	-2.81
AB1 A10	10.8	-3.72	-3.71	-3.00	-3.00
AB1 E8	11.5	-3.08	-3.67	-2.90	-3.06
AB1 A11	12	-4.79	-3.48	-3.55	-2.94
AB1 E9	13	-4.18	-3.20	-3.54	-2.71
AB1 E11	15.2	-1.62	-3.02	-1.84	-2.47
AB1 E12	16	-1.89	-2.98	-1.59	-2.24
AB1 F1	16.5	-2.56	-3.13	-1.91	-2.11
AB1 F2	17.2	-4.51	-3.34	-2.31	-2.09
AB1 B4	17.9	-4.37	-3.46	-2.28	-2.15
AB1 B5	18.9	-3.86	-3.32	-2.43	-2.17
AB1 F3	19.5	-2.72	-3.10	-1.95	-2.15
AB1 B6	20.1	-1.15	-3.03	-1.92	-2.15
AB1 F4	20.5	-3.07	-3.23	-2.15	-2.21
AB1 B7	21.1	-3.89	-3.67	-2.27	-2.31
AB1 F5	21.7	-4.71	-4.15	-2.53	-2.48
AB1 B8	22.3	-5.34	-4.48	-2.73	-2.64
AB1 F6	22.8	-4.31	-4.46	-2.60	-2.72
AB1 B9	23.5	-4.56	-4.20	-3.21	-2.67
AB1 F7	23.9	-4.15	-3.86	-2.90	-2.51
AB1 B10	24.8	-2.62	-3.59	-2.05	-2.30
AB1 F8	25.1	-3.26	-3.38	-1.81	-2.07
AB1 B11	25.9	-3.45	-3.30	-1.64	-1.90
AB1 F9	26.3	-3.39	-3.30	-1.85	-1.83
AB1 B12	27.2	-3.03	-3.35	-1.82	-1.91
AB1 F10	27.5	-3.82	-3.33	-1.91	-2.08
AB1 C1	28.4	-3.17	-3.41	-1.98	-2.34
AB1 C2	29.1	-3.01	-3.43	-2.81	-2.54
AB1 C3	30	-3.67	-3.44	-3.08	-2.71
AB1 F12	30.9	-4.33	-3.43	-3.27	-2.80
AB1 C4	31.3	-2.55	-3.45	-2.30	-2.82
AB1 G1	31.3	-3.23	-3.53	-2.63	-2.81
AB1 C5	32.4	-4.09	-3.77	-3.20	-2.86
AB1 G2	32.4	-2.84	-4.18	-2.30	-3.00
AB1 C6	33.4	-5.36	-4.39	-3.57	-3.02
AB1 G3	33.7	-5.89	-4.40	-3.49	-2.93

Sample Number	Distance From Base (mm)	Del 13-C (per mil)		Del 18-0 (per mil)	
		Raw Data	5 Point Running Mean	Raw Data	5 Point Running Mean
AB1 C7	34.4	-5.04	-4.11	-3.17	-2.71
AB1 G4	34.8	-2.14	-3.74	-1.78	-2.49
AB1 C8	35.3	-3.11	-3.34	-1.92	-2.27
AB1 G5	35.7	-2.65	-3.34	-2.07	-2.23
AB1 C9	36.1	-2.76	-3.71	-2.07	-2.38
AB1 G6	36.8	-4.95	-4.36	-2.73	-2.68
AB1 C10	37.1	-5.35	-4.94	-3.11	-2.97
AB1 C11	38.1	-5.53	-5.37	-3.30	-3.19
AB1 C12	39.1	-6.73	-5.53	-3.87	-3.26
AB1 D1	40.2	-4.95	-5.61	-3.21	-3.36
AB1 D2	41.5	-5.14	-5.14	-3.00	-3.00

APPENDIX E

Carbon 14 Calibration

OxCal radiocarbon calibration results. The radiocarbon date (on the vertical axis) is plotted against a calibration curve (based on dendrochronological records) to give the calibrated date.

APPENDIX F

Speleothem Crystal Measurements

LOS2 AND AB1 CRYSTAL MEASUREMENTS

Thin Section Number	Layer Number	Layer Interval (mm)		Crystal Length (mm)	Crystal Width (mm)	Crystal Roundness	Average Crystal Length (mm)	Standard Deviation	Average Crystal Width (mm)	Standard Deviation	Average Crystal Roundness	Standard Deviation
		Bottom	Top									
AB1-1	1.00	0.00	1.31	0.50	0.63	0.79	0.63	0.14	0.61	0.12	1.03	0.17
				0.68	0.54	1.25						
				0.54	0.54	1.00						
				0.59	0.54	1.08						
				0.86	0.81	1.06						
AB1-1	2.00	1.31	1.44	0.09	0.05	2.00	0.08	0.04	0.06	0.02	1.30	0.45
				0.05	0.05	1.00						
				0.09	0.09	1.00						
				0.14	0.09	1.50						
				0.05	0.05	1.00						
AB1-1	3.00	1.44	5.76	0.18	0.14	1.33	0.19	0.04	0.18	0.03	1.07	0.23
				0.18	0.18	1.00						
				0.23	0.23	1.00						
				0.23	0.18	1.25						
				0.14	0.18	0.75						
AB1-1	4.00	5.76	11.66	1.62	0.63	2.57	1.61	0.41	0.65	0.27	2.66	0.53
				1.89	0.99	1.91						
				1.13	0.36	3.13						
				2.12	0.86	2.47						
				1.31	0.41	3.22						
AB1-1	5.00	11.66	14.67	0.54	0.36	1.50	0.71	0.22	0.43	0.15	1.79	0.87
				0.59	0.45	1.30						
				0.54	0.41	1.33						
				0.90	0.27	3.33						
				0.99	0.68	1.47						
AB1-1	6.00	14.67	18.00	0.99	0.36	2.75	1.18	0.33	0.39	0.04	3.01	0.50
				1.04	0.36	2.88						
				1.76	0.45	3.90						

Thin Section Number	Layer Number	Layer Interval (mm)		Crystal Length (mm)	Crystal Width (mm)	Crystal Roundness	Average Crystal Length (mm)	Standard Deviation	Average Crystal Width (mm)	Standard Deviation	Average Crystal Roundness	Standard Deviation
		Bottom	Top									
				0.99	0.36	2.75						
				1.13	0.41	2.78						
AB1-2	1.00	18.00	21.96	0.86	0.32	2.71	0.77	0.14	0.28	0.07	2.82	0.46
				0.77	0.36	2.13						
				0.54	0.18	3.00						
				0.90	0.32	2.86						
				0.77	0.23	3.40						
AB1-2	2.00	21.96	29.12	1.31	0.54	2.42	1.31	0.37	0.38	0.16	3.75	0.96
				1.35	0.32	4.29						
				1.13	0.32	3.57						
				0.90	0.18	5.00						
				1.89	0.54	3.50						
AB1-2	3.00	29.12	30.78	0.90	0.23	4.00	0.86	0.24	0.23	0.06	3.82	0.88
				0.99	0.23	4.40						
				0.45	0.18	2.50						
				1.08	0.32	3.43						
				0.86	0.18	4.75						
AB1-2	4.00	30.78	37.08	1.80	0.54	3.33	0.72	0.66	0.27	0.19	2.44	0.59
				0.86	0.41	2.11						
				0.50	0.18	2.75						
				0.27	0.14	2.00						
				0.18	0.09	2.00						
AB1-2	5.00	37.08	42.75	0.68	0.32	2.14	0.60	0.23	0.28	0.13	2.30	0.89
				0.41	0.18	2.25						
				0.77	0.50	1.55						
				0.32	0.18	1.75						
				0.86	0.23	3.80						
LOS2-1	1.00	0.00	4.68	0.36	0.24	1.50	0.53	0.10	0.32	0.14	1.91	0.91
				0.54	0.54	1.00						
				0.60	0.27	2.22						

Thin Section Number	Layer Number	Layer Interval (mm)		Crystal Length (mm)	Crystal Width (mm)	Crystal Roundness	Average Crystal Length (mm)	Standard Deviation	Average Crystal Width (mm)	Standard Deviation	Average Crystal Roundness	Standard Deviation
		Bottom	Top									
				0.60	0.18	3.33						
				0.54	0.36	1.50						
LOS2-1	2.00	4.68	9.33	1.86	0.78	2.38	2.03	0.79	0.76	0.54	3.97	3.80
				2.22	1.65	1.35						
				1.86	0.72	2.58						
				3.21	0.30	10.70						
				1.02	0.36	2.83						
LOS2-1	3.00	9.33	13.44	0.45	0.45	1.00	0.73	0.40	0.34	0.17	2.35	0.93
				0.36	0.15	2.40						
				0.63	0.27	2.33						
				0.87	0.24	3.63						
				1.35	0.57	2.37						
LOS2-1	4.00	13.44	30.36	0.24	0.24	1.00	0.38	0.13	0.27	0.08	1.56	0.84
				0.36	0.30	1.20						
				0.30	0.30	1.00						
				0.45	0.15	3.00						
				0.57	0.36	1.58						
LOS2-2	1.00	30.36	39.33	1.14	0.54	2.11	0.77	0.44	0.38	0.20	2.00	0.51
				0.36	0.15	2.40						
				1.17	0.60	1.95						
				0.93	0.39	2.38						
				0.24	0.21	1.14						
LOS2-2	2.00	39.33	44.64	0.21	0.18	1.17	0.24	0.15	0.15	0.06	1.54	0.52
				0.36	0.21	1.71						
				0.42	0.18	2.33						
				0.12	0.12	1.00						
				0.09	0.06	1.50						
LOS2-2	3.00	44.64	48.63	0.81	0.12	6.75	0.90	0.39	0.20	0.12	5.12	1.89
				1.50	0.21	7.14						
				0.99	0.39	2.54						

Thin Section Number	Layer Number	Layer Interval (mm)		Crystal Length (mm)	Crystal Width (mm)	Crystal Roundness	Average Crystal Length (mm)	Standard Deviation	Average Crystal Width (mm)	Standard Deviation	Average Crystal Roundness	Standard Deviation
		Bottom	Top									
				0.75	0.18	4.17						
				0.45	0.09	5.00						
LOS2-2	4.00	48.63	57.48	3.45	0.66	5.23	1.90	1.21	0.37	0.23	4.98	0.58
				1.95	0.36	5.42						
				2.67	0.54	4.94						
				0.96	0.18	5.33						
				0.48	0.12	4.00						
LOS2-3	1.00	57.48	69.48	1.62	0.18	9.00	1.51	0.21	0.18	0.03	8.44	0.46
				1.26	0.15	8.40						
				1.68	0.21	8.00						
				1.32	0.15	8.80						
				1.68	0.21	8.00						
LOS2-3	2.00	69.48	69.84	0.36	0.18	2.00	0.66	0.23	0.20	0.04	3.34	1.35
				0.84	0.21	4.00						
				0.51	0.27	1.89						
				0.90	0.18	5.00						
				0.69	0.18	3.83						
LOS2-3	3.00	69.84	72.69	0.24	0.09	2.67	0.34	0.16	0.13	0.03	2.65	0.98
				0.42	0.12	3.50						
				0.12	0.12	1.00						
				0.39	0.12	3.25						
				0.51	0.18	2.83						
LOS2-4	1.00	72.69	76.35	0.87	0.18	4.83	0.89	0.32	0.18	0.03	5.18	2.13
				1.02	0.15	6.80						
				1.17	0.21	5.57						
				0.36	0.21	1.71						
				1.05	0.15	7.00						
LOS2-4	2.00	76.35	77.16	0.09	0.06	1.50	0.17	0.06	0.13	0.04	1.34	0.24
				0.18	0.15	1.20						
				0.12	0.12	1.00						

Thin Section Number	Layer Number	Layer Interval (mm)		Crystal Length (mm)	Crystal Width (mm)	Crystal Roundness	Average Crystal Length (mm)	Standard Deviation	Average Crystal Width (mm)	Standard Deviation	Average Crystal Roundness	Standard Deviation
		Bottom	Top									
				0.21	0.15	1.40						
				0.24	0.15	1.60						
LOS2-4	3.00	77.16	79.59	0.66	0.21	3.14	0.64	0.28	0.17	0.06	3.61	0.88
				0.57	0.18	3.17						
				0.72	0.15	4.80						
				1.02	0.24	4.25						
				0.24	0.09	2.67						
LOS2-4	4.00	79.59	80.52	0.51	0.12	4.25	0.47	0.10	0.10	0.02	4.65	0.68
				0.60	0.12	5.00						
				0.48	0.09	5.33						
				0.33	0.09	3.67						
				0.45	0.09	5.00						
LOS2-4	5.00	80.52	81.39	0.09	0.09	1.00	0.20	0.15	0.14	0.06	1.31	0.36
				0.15	0.12	1.25						
				0.45	0.24	1.88						
				0.21	0.15	1.40						
				0.09	0.09	1.00						
LOS2-4	6.00	81.39	83.58	0.84	0.12	7.00	0.67	0.37	0.13	0.03	5.55	3.57
				0.90	0.09	10.00						
				1.05	0.15	7.00						
				0.36	0.18	2.00						
				0.21	0.12	1.75						
LOS2-4	7.00	83.58	93.63	1.38	0.15	9.20	1.69	0.26	0.21	0.13	10.71	6.10
				1.53	0.09	17.00						
				1.80	0.33	5.45						
				1.68	0.36	4.67						
				2.07	0.12	17.25						
LOS2-5	1.00	93.63	97.89	1.23	0.33	3.73	1.00	0.27	0.22	0.08	4.75	1.21
				0.72	0.12	6.00						
				1.29	0.21	6.14						

Thin Section Number	Layer Number	Layer Interval (mm)		Crystal Length (mm)	Crystal Width (mm)	Crystal Roundness	Average Crystal Length (mm)	Standard Deviation	Average Crystal Width (mm)	Standard Deviation	Average Crystal Roundness	Standard Deviation
		Bottom	Top									
				1.05	0.27	3.89						
				0.72	0.18	4.00						
LOS2-5	2.00	97.89	98.49	0.42	0.36	1.17	0.37	0.09	0.23	0.10	1.88	0.91
				0.42	0.15	2.80						
				0.45	0.24	1.88						
				0.24	0.30	0.80						
				0.33	0.12	2.75						
LOS2-5	3.00	98.49	105.78	0.30	0.06	5.00	0.23	0.05	0.07	0.01	3.53	0.96
				0.18	0.06	3.00						
				0.18	0.06	3.00						
				0.24	0.06	4.00						
				0.24	0.09	2.67						
LOS2-5	4.00	105.78	109.41	0.24	0.12	2.00	0.25	0.12	0.16	0.06	1.53	0.54
				0.18	0.12	1.50						
				0.24	0.24	1.00						
				0.45	0.21	2.14						
				0.12	0.12	1.00						
LOS2-5	5.00	109.41	120.24	1.02	0.24	4.25	0.64	0.43	0.19	0.07	3.70	3.47
				1.14	0.12	9.50						
				0.54	0.24	2.25						
				0.36	0.24	1.50						
				0.12	0.12	1.00						
LOS2-6	1.00	120.24	130.29	0.90	0.09	10.00	0.74	0.21	0.13	0.04	6.15	2.26
				0.90	0.15	6.00						
				0.51	0.12	4.25						
				0.87	0.18	4.83						
				0.51	0.09	5.67						
LOS2-6	2.00	130.29	137.88	0.27	0.18	1.50	0.20	0.08	0.16	0.04	1.32	0.52
				0.30	0.15	2.00						
				0.12	0.09	1.33						

Thin Section Number	Layer Number	Layer Interval (mm)		Crystal Length (mm)	Crystal Width (mm)	Crystal Roundness	Average Crystal Length (mm)	Standard Deviation	Average Crystal Width (mm)	Standard Deviation	Average Crystal Roundness	Standard Deviation
		Bottom	Top									
				0.12	0.21	0.57						
				0.18	0.15	1.20						
LOS2-6	3.00	137.88	141.48	0.24	0.06	4.00	0.23	0.03	0.16	0.07	1.85	1.23
				0.21	0.12	1.75						
				0.27	0.21	1.29						
				0.18	0.15	1.20						
				0.24	0.24	1.00						
LOS2-7	1.00	141.48	145.68	0.36	0.18	2.00	0.49	0.21	0.16	0.07	3.33	1.11
				0.81	0.27	3.00						
				0.36	0.12	3.00						
				0.60	0.12	5.00						
				0.33	0.09	3.67						
LOS2-7	2.00	145.68	150.36	0.36	0.21	1.71	0.31	0.08	0.19	0.02	1.59	0.37
				0.36	0.21	1.71						
				0.27	0.18	1.50						
				0.36	0.18	2.00						
				0.18	0.18	1.00						
LOS2-7	3.00	150.36	156.99	0.69	0.12	5.75	0.58	0.13	0.16	0.04	3.73	1.19
				0.63	0.18	3.50						
				0.57	0.21	2.71						
				0.66	0.18	3.67						
				0.36	0.12	3.00						
LOS2-7	4.00	156.99	162.09	0.42	0.15	2.80	0.61	0.19	0.20	0.05	3.02	0.36
				0.90	0.27	3.33						
				0.60	0.18	3.33						
				0.45	0.18	2.50						
				0.66	0.21	3.14						
LOS2-8	1.00	162.09	169.50	0.54	0.21	2.57	1.40	0.66	0.25	0.17	7.25	6.20
				2.16	0.12	18.00						
				1.95	0.54	3.61						

Thin Section Number	Layer Number	Layer Interval (mm)		Crystal Length (mm)	Crystal Width (mm)	Crystal Roundness	Average Crystal Length (mm)	Standard Deviation	Average Crystal Width (mm)	Standard Deviation	Average Crystal Roundness	Standard Deviation
		Bottom	Top									
				1.20	0.21	5.71						
				1.14	0.18	6.33						
LOS2-8	2.00	169.50	173.04	1.11	0.06	18.50	1.06	0.10	0.10	0.03	12.17	4.45
				1.11	0.09	12.33						
				0.90	0.15	6.00						
				1.14	0.09	12.67						
				1.02	0.09	11.33						
LOS2-8	3.00	173.04	179.34	0.03	0.03	1.00	0.03	0.00	0.03	0.00	1.00	0.00
				0.03	0.03	1.00						
				0.03	0.03	1.00						
				0.03	0.03	1.00						
				0.03	0.03	1.00						
LOS2-9	1.00	179.34	186.24	0.90	0.42	2.14	0.53	0.42	0.23	0.12	2.74	2.73
				0.30	0.33	0.91						
				0.51	0.24	2.13						
				0.90	0.12	7.50						
				1.38	0.15	9.20						
LOS2-9	2.00	186.24	187.53	0.57	0.09	6.33	0.88	0.23	0.12	0.02	7.22	0.75
				0.78	0.12	6.50						
				0.90	0.12	7.50						
				1.20	0.15	8.00						
				0.93	0.12	7.75						
LOS2-9	3.00	187.53	190.71	1.29	0.15	8.60	1.51	0.20	0.14	0.03	10.98	3.25
				1.35	0.15	9.00						
				1.65	0.18	9.17						
				1.77	0.15	11.80						
				1.47	0.09	16.33						
LOS2-9	4.00	190.71	194.55	2.25	0.12	18.75	2.27	0.20	0.11	0.03	21.75	3.82
				2.01	0.09	22.33						
				2.22	0.09	24.67						

Thin Section Number	Layer Number	Layer Interval (mm)		Crystal Length (mm)	Crystal Width (mm)	Crystal Roundness	Average Crystal Length (mm)	Standard Deviation	Average Crystal Width (mm)	Standard Deviation	Average Crystal Roundness	Standard Deviation
		Bottom	Top									
				2.34	0.09	26.00						
				2.55	0.15	17.00						
LOS2-9	5.00	194.55	198.09	1.68	0.12	14.00	1.67	0.32	0.10	0.04	18.09	5.55
				1.38	0.06	23.00						
				1.68	0.15	11.20						
				2.19	0.12	18.25						
				1.44	0.06	24.00						
LOS2-9	6.00	198.09	211.50	1.50	0.24	6.25	1.41	0.58	0.23	0.09	6.90	2.91
				0.81	0.36	2.25						
				1.05	0.12	8.75						
				1.35	0.18	7.50						
				2.34	0.24	9.75						