

**DISSOLUTION OF OPHIUROID OSSICLES (*OPHIONOTUS VICTORIAE*)
IN EXPLORERS COVE, ANTARCTICA: IMPLICATIONS FOR
THE ANTARCTIC FOSSIL RECORD**

By

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To my Family and my Best Friend for their unconditional love, support, and putting up
with me traveling around the world to following my passions.

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CHAPTER I

INTRODUCTION

Brittlestars have been members of the unusual Antarctic epibenthic communities for at least the past 35 million years, since the opening of the Drake Passage (~34mya) and the cooling (~41mya) resulting from the formation of the Antarctic circumpolar current (Aronson et al., 1997; Aronson et al., 2009; Blake and Aronson, 1998; Brandt, 2005; Clarke et al., 2004; Ivany et al., 2008). Despite the extremely cold temperatures and sea-ice covered waters, epibenthic communities developed their unique ecological structure in Antarctica. These benthic communities include scallops, sponges, bryozoans, asteroids and ophiuroids (brittlestars) as dominant epifauna; epifauna probably became dominant because of the lack of shell-crushing predators such as durophagous (skeleton- breaking) fish and crabs, telosts, and decapods and other fast moving predators. These predators became extinct in Antarctica presumably due to physiological constraints amplified by rapid temperature transitions from the cooling initiated by the formation of the Antarctic circumpolar current (Aronson et al., 2009; Brandt, 2005; Clarke et al., 2004; Cummings et al., 2006; Fell, 1961; Moya et al., 2003). These organisms live in the openness of the seafloor, similar to that of deep water communities where fast moving predators are scarce and ophiuroids have the potential to be abundant (Dayton, 1990; Dayton et al., 1994; Dearborn et al., 1996; Fell, 1961; Moya et al., 2003).

The history of benthic community development and fluctuation over the Cenozoic will provide the baseline by which to understand reactions to large events such as climate change. The fossil and sediment record should record the responses to those changes. Without an

accessible Cenozoic rock record in Antarctica, effort has been put forth to analyze the sedimentological records for reconstructing the Cenozoic history. Drilling initiatives have retrieved over 6,100 meters of sediment cores from the Ross Sea (MIS-ANDRILL 1B, MSSTS - 1, Dry Valley Drilling Project (DVDP) cores (e.g., 8-12), Cape Roberts Project (CRP) core, (CIROS) cores (e.g. 1 and 2), and Operation Deep Freeze) for a variety of characteristics of the sediment cores, including the presence of macro- and micro-fossils. These sediment cores would be perfect records to study the development and evolution of the brittle star communities, except for the fact that of the 6,100 meters recovered, only a one thin layer contained disarticulated ophiuroid ossicles (Barrett, 1986; Chapman-Smith, 1981; Kaharoeddin, et al., 1988; Pyne et al., 1985; Robinson et al. 1987; Scherer et al., 2007; Taviani and Beu, 2003; Webb and Wren 1975).

Historically ophiuroids have been present in Antarctic waters for millions of years (Blake and Aronson, 1998; Brandt, 2005). The lack of ossicles raises questions about the taphonomic processes in this area. How do taphonomic processes affect the preservation of skeletal material in Antarctic waters?

As concern about climate change grows, there is a corresponding need to understand climate change of the past (Andersson et al., 2008; Aronson and Blake, 2001; Aronson et al., 2009; McClintock et al., 2009; Schubert et al., 2006), primarily as interpreted from the recovered cores. Observation and experimentation on present Antarctic faunas will yield key paleoenvironmental clues that may not be reflected in the sedimentological characteristics; for example, faunas under the ice shelves where nutrients are brought in by advection are depauperate, whereas those under multi-year ice are relatively diverse and abundant (Dayton, 1990; Dayton et al., 1994; Thrush et al., 2006). For the use of information about ancient benthic

communities to be maximized in reconstructions of Cenozoic environments and climate, the effects of taphonomic processes must be delineated.

I investigated the fate of the skeletal components of an abundant Antarctic ophiuroid, *Ophionotus victoriae* in Explorers Cove (Fig. 1). The goals were to assess the rate of soft tissue decay and to determine whether or not *O. victoriae* ossicles are affected by chemical dissolution and physical breakage over a short (2 year) experimental period. The secondary goals were to evaluate the abundance of ossicles in the short cores retrieved from Explorers Cove, determine whether or not ossicles would lose weight over a short (1 month) experimental period, and determine if the digestive processes of a predatory ophiuroid damaged the ossicles. Taphonomic processes were assessed through a series of *in situ* and laboratory experiments.

Study Site
 Explorers Cove
 (77 ° 34.51'S, 163 °
 31.79'E, Fig. 1) is
 located on the west side
 of McMurdo Sound, at
 the mouth of the Taylor
 Valley. This side of
 McMurdo Sound has
 extensive multi-year sea-
 ice (Dayton and Oliver,
 1977) that breaks out

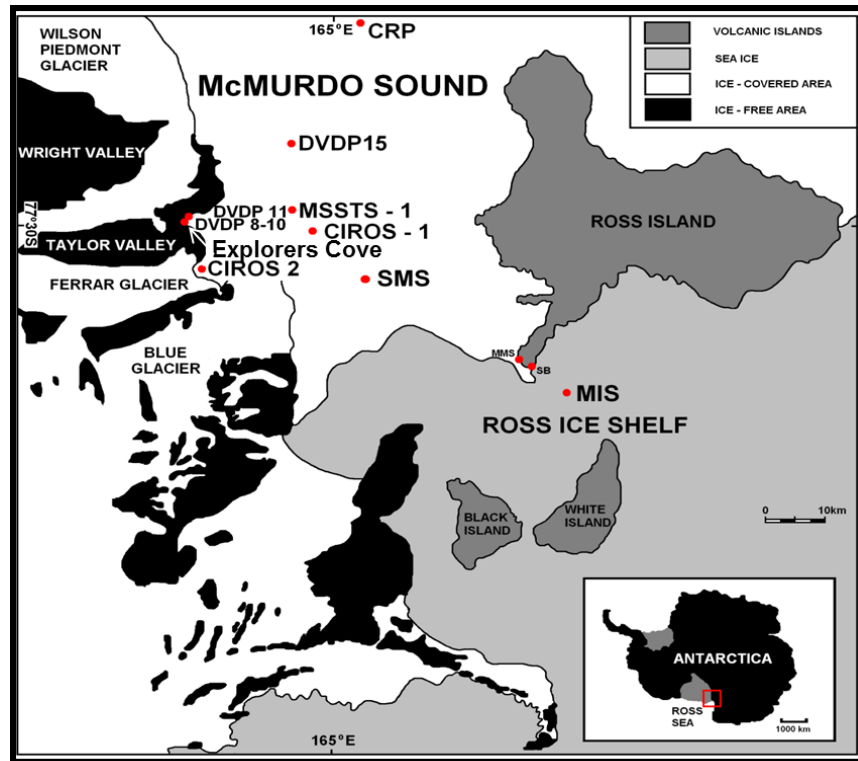


FIGURE 1- Map of McMurdo Sound with north to the top. Explorers Cove is an arm of New Harbor just off shore of the Taylor Valley. Red dots indicate locations of cores of Cenozoic deposits retrieved from McMurdo Sound over the last 50 years.

once every 5 to 7 years (Gooday et al., 1996); Explorers Cove was last ice free during the austral summer 1999-2000. Primary productivity is limited by the light limitations of the multi-year sea-ice and by nutrient-poor currents that flow northward from under the Ross Ice Shelf (Cummings et al., 2006; Dayton and Oliver, 1977). Measured current velocities in Explorers Cove are consistently very low (1.2 to 4.6cm/sec; Cummings et al., 2006; Norkko, et al. 2002) and divers report perceiving no current. The episodic primary productivity is dominated by algae and microbes in a near shore moat formed in summer when grounded sea ice melts and by algae during years of sea ice melting (Gooday et al., 1996; Stockton, 1984; Thrush et al., 2006).

The substrate of Explorers Cove is fine to medium grained sand that is poorly sorted and contains few out-sized clasts (Murray et al., 2009; Murray et al., 2011 submitted). Even though the sediment is coarse the sedimentation rate has been estimated to be 4.3mm per year for the past 5,800 years (Gooday et al., 1996). Currents are minimal, yet sediment is re-suspended frequently by the swimming and clapping movements of the Antarctic scallop (*Adamussium colbecki*), which is the most abundant epifaunal animal in Explorers Cove (McClintock et al., 2010; Norkko et al., 2002; Stockton, 1984). The second most abundant epifaunal animal is the bush sponge *Homaxinella balfourensis*, which attaches to hard substrates, including scallop shells, and the third most abundant is the brittle star, *Ophionotus victoriae*, (Cummings et al., 2006; Norkko et al., 2002). Other epifaunal organisms include the nemertean, *Parborlasia corrugatus*; the brittle star, *Ophiosparte gigas*; the sea star, *Diplasterias brucei*; the heart urchin *Abatus nimrodi*; and the pencil urchin, *Ctenocidaris perrieri* (Norkko et al., 2002) few of which have been documented in the sediment cores (Barrett, 1986; Chapman-Smith, 1981; Kaharoeddin, et al., 1988; Pyne et al., 1985; Robinson et al. 1987; Scherer et al., 2007; Taviani and Beu, 2003; Wren and Webb 1975).

The epifauna-dominated benthic community of Explorers Cove has been compared to that of the deep sea (Dayton and Oliver, 1977; Gooday et al., 1996). Explorers Cove and the deep sea share quiet water conditions, consistently frigid water temperatures (in Explorers Cove, the water is -1.9°C) as well as limited and episodic nutrient pulses. The abundant *O. victoriae* resembles the life style of deep-sea ophiuroids (Dayton and Oliver, 1977) and the large agglutinated foraminifera that occur in shallow water in Explorers Cove are more common in deep-sea areas (Gooday et al., 1996). Similar to deep-water communities Explorers Cove is an isolated ecosystem in that the benthic community is forced to rely on the bits of food that episodically fall from above and scavenge for the detritus.

Brittlestar Biology

Ophionotus victoriae (Fig. 2), is an endemic circumpolar species of Antarctica found at depths from 5m to 1,266m living on diverse substrates, and is an opportunist generalist when it comes to feeding (Fell, 1961; Morris, 2001; Moya et al., 2003; Warner, 1982). *O. victoriae* is a dominant component of the megafauna wherever it lives (Fell 1961; Moya et al., 2003), including Explorers Cove where it is the third most abundant large, epifaunal animal (Norkko et al., 2002).



FIGURE 2- *Ophionotus victoriae* standing on seafloor in Explorers Cove, Antarctica.

The ophiuroid skeleton is composed of articulated calcite ossicles which disarticulate soon after death (Allison, 1990; Barrett, 1986; Brett et al., 1997; Byrne, 1994; Donovan, 1991;

Hyman, 1955; Kidwell and Baumiller, 1990; Lewis, 1987, 1986; Schafer, 1972). The internal skeleton contains over 1,500 ossicles of various shapes and sizes held together by muscle, mutable connective tissue, and dermis ligamentous tissue (Byrne, 1994). All ossicles are composed of high-magnesium calcite which is a metastable form of calcite and is secreted intracellularly in the sclerocytes (Byrne, 1994; Märkel and Röser, 1985; Tucker, 1991). The metastable state does not explain why the ossicles are not seen in the sediment cores, because the process of recrystallization occurs over thousands to hundreds of thousands of years after burial and at depth. According to Twitchett et al. (2005), disarticulated ossicles in the sedimentary record usually have syntaxial overgrowths. Ossicles may be altered within the sub-fossil record such as cores from Explorers Cove, but they have the potential to be preserved and especially to be seen in the sub-fossil record of the sediment cores.

Although all types of ossicles may become a part of the fossil record, the vertebral ossicles (Fig. 3) are most likely to be preserved and have been reported by Mallikarjuna, et al. (1999) and Štorc and Žitt (2008) from other areas. They are the abundant ossicle with at least 400 vertebral ossicles per individual and more if autonomy occurs during their life time (Clark et al., 2007;

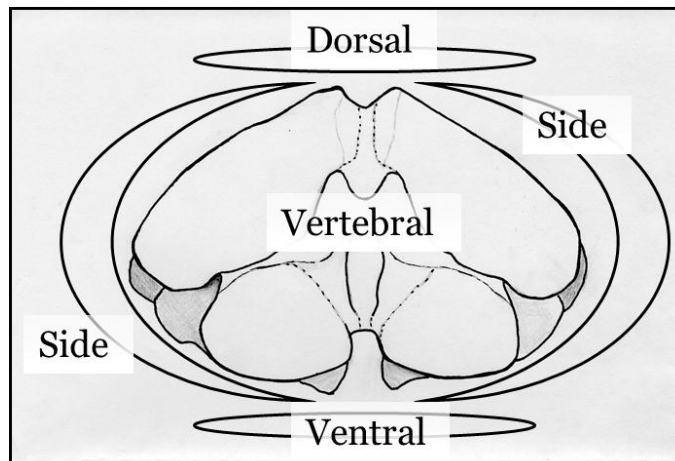


FIGURE 3- A diagram showing the position of ossicles within the cross sectional area of a brittlestar leg.

Hyman, 1955; Wilkie and Emson, 1987). Also, other than the 10 jaw ossicles the vertebral ossicles are the thickest (personal observation). Thicker ossicles are assumed to have the highest preservation potential.

The vertebral ossicles also allow for a wide range of biomechanical movements of the legs. Each vertebral ossicle serves as a joint or hinge point of movement (LeClair and LaBarbera, 1997). With vertebral ossicles throughout each arm, the legs are capable of a variety of movements. For example brittle stars can make an arm loop to assist in feeding, a swimming stroke for propulsion, repetitive sawing motions and a curled grip are used to hold and cut food boluses during ingestion, and some raise their arms for suspension feeding and to assist in the dispersal of larvae (Fratt and Dearborn, 1984; LeClair and LaBarbera, 1997; Warner, 1982; Woodley, 1975; personal observation). These complex movements are only possible by the presence of the vertebral ossicles within the arms.

Each ossicle is composed of a stereom structure with a mesh like appearance and is composed of trabeculae (rods of solid calcite) and intertrabeculae spaces (pore space) (Hyman, 1955). The distal side of each vertebral ossicle (which will be referred to as ossicles) (Fig. 4A) has several components to it: the Upper Fossae is an area that usually holds muscle tissue and mutable collagenous tissue (MCT); the Lower Fossae is an area where connective tissue also resides; the Margins are the outermost layers at the edge of the fossae regions; the Knob is the

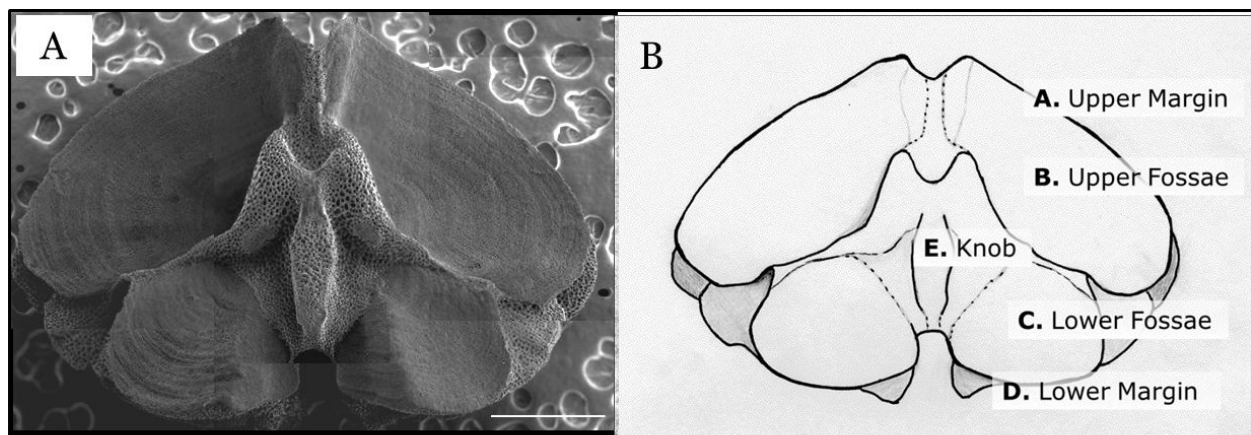


FIGURE 4- The distal side of a vertebral ossicle. A) Composite SEM images. White line is 750 μ m. B) Diagram indicating various parts of the ossicle.

central hinge point in movement and experiences the most friction from movement (Fig. 4B) (Byrne, 1994; LeClair, 1995). The stereom at the margins and the fossae have a lower trabecular to intertrabecular ratios. The Knob on the other hand has a higher trabecular to intertrabecular ratio (personal observations from SEM images) and will be the focus of imagery to show damage features.

CHAPTER II

METHODS

Motivation

Brittlestar ossicles are absent from the sediment cores in Explorers Cove. Because there is no literature on brittlestar taphonomy in Explorers Cove, we chose to conduct a series of *in situ* experiments to assess the taphonomic processes. Sediment cores were searched for ossicles to determine ossicle abundance and microstructural features of damage. The soft tissue decay rate was narrowed by two, two year *in situ* experiments (Pole and Aquarium), a one month *in situ* experiment (Hanging Bag), and through observation after dissections. Changes in weight and porosity of the whole ossicle, and the surface area of the distal side were measured to determine loss of ossicle material lost through breakage and dissolution. A semi-qualitative scale of dissolution was created to assess the type and amount of dissolution seen on the microstructural scale.

Sediment Search

Thirty centimeter long cores were collected by SCUBA divers, frozen and sent to Vanderbilt. They were then divided into ~30 one cm samples. Each sample was sieved and separated into grains larger than or smaller than 250 μ . The grains larger than 250 μ were examined under a dissecting light microscope (Wild M4A TYP 376788; Heerbrugg, Switzerland). A fine paint brush removed any items that were not sediment grains and placed these items on a micropaleontology slide for observation.

Decay and Dissolution Experiments

In November 2008, specimens of *O. victoriae* were collected from 9m-18m by SCUBA divers in Explorers Cove, Antarctica, were frozen immediately and divided for either the Pole or Aquarium experiments. For the Pole experiments, a frozen brittle star was placed in a bag composed of nylon (mesh size ~1mm); the bags were suspended from PVC pipe pole 15 to 40 cm above the sediment-water interface (SWI). Each pole had several bags. Overall there were 54 bags deployed. For the Aquarium experiments brittle stars were placed on top of stratified sediment in 7 aquaria (11cm x 3.6cm x 15cm). On the 11x15cm sides of the aquaria there are three holes (2.5cm diameter) covered with mesh to allow the movement of water, oxygen, nutrients, and organisms through the sediment within the aquaria. Both the Aquarium and Pole experiments were placed on the seafloor in Explorers Cove (Fig. 1) by divers at 9m or 18m water's depth in November 2008 and were recovered in October 2010.

Before placement within the mesh bags, some of the brittle stars were treated with bleach or peroxide in an effort to free the ossicles from the soft tissue. Results from soft tissue decay experiments (Walker, unpublished) showed that peroxide and bleach accelerated the removal of soft tissue and damaged ossicles, only untreated brittle stars were analyzed after collection.

Nineteen frozen Antarctic brittle stars collected during the 2008 season were transported to and stored in a freezer at Vanderbilt University. Due to mechanical malfunction the brittle stars thawed. Upon removal from the freezer the soft tissue readily fell away from the hard tissues (which will be referred to ossicles). The retrieved ossicles were rinsed with deionized water, dried, and subsequently used as the pristine (control) ossicles for comparison to ossicles from the Pole and Aquarium experiments. They also became the ossicles used in the Hanging Bag experiment.

To constrain the rate of dissolution, the *in situ* Hanging Bag experiment was deployed for one month in November 2010. In this experiment pristine proximal vertebral ossicles were isolated, weighed on a Mettler Toledo's UMX2 Ultra-microbalance, placed in mesh bags and hung 1.5m above the seafloor and exposing pristine ossicles to normal bottom water conditions. Five sets of 7 pristine ossicles were each placed in a polyester 300mesh bag. The bags were separated from one another by blasting wire and were suspended by a rope that was attached to the building through a hole in the ice. The entire apparatus was weighted down by a canvas bag of rocks attached to the blasting wire.

For comparison with the Hanging Bag experiment, nine sets of six pristine, weighed ossicles were sewn into of polyester 300mesh bags and stored in a refrigerator for 240 days, at an average temperature of 1° C. Filtered water (NANOpure ultrapure water system; Barnstead) was mixed with Instant Ocean, to create a salinity of 35ppt.

During recovery of the Pole, Aquarium, and Hanging Bag experiments in November 2010, the divers also scooped ossicles off the SWI, some of which was ossicle rich and also collected four live *O. gigas* that appeared to have distended discs. All four of the *O. gigas* were dissected, so the stomach contents could be examined. Each dissection took place shortly after death. The disc was cut with a No. 22 scalpel blade or a pair of fine dissection scissors. The top portion was removed to reveal the stomach contents. Large chunks were removed by tweezers and finer or gelatinous material was removed by irrigation. Ossicles were positively identified using a light microscope, rinsed, and packaged for examination under the scanning electron microscope (SEM: Hitachi S-4200) at Vanderbilt University.

Identifying and classifying damage

To facilitate identification of microstructural features caused by physical breakage or chemical dissolution ossicles were subjected to the following treatments: pristine ossicles as well as freshly broken calcite pieces were submerged in 3.5% hydrochloric acid for 8 seconds, 6.15% sodium hypochlorite (household bleach) for 27 hours, or 3% dihydrogen dioxygen (household hydrogen peroxide) for 27 hours; they were also broken by applying pressure. All treated samples were then imaged under 1,500x, 800x, 100x, and 40x magnification on the SEM. Each vertebral ossicle was individually mounted on a stub using a fine brush, and sputter-coated with gold in a vacuum. The images of treated ossicles were compared to images of pristine ossicles and calcite. The calcite showed the same patterns of dissolution as the microstructural damage seen on the ossicles.

SEM Analysis

To evaluate and characterize dissolution and microstructural damage on the ossicles from the *in situ* dissolution and decay experiments, each ossicle was imaged with the SEM. Every ossicle was examined at five locations on the distal side as labeled in Figure 4B. Each location was imaged at 3,000x, 1,500x, 800x, 400x, and 100x. At 3,000x and 1,500x the microstructural damage was characterized as chemical or physical. The lower magnifications showed whether or not the damage type was localized, spotty, or widespread. All characterizations were compared to pristine ossicles. Pristine ossicles were never exposed to additional chemicals during the decay process.

Silhouette Area Loss

Calculating the surface area of the ossicle is incredibly complex, because of the intricate relief patterns. Rather than using the surface area, we used the silhouette area to determine the percentage of physical breakage endured. To calculate the percentage of physical breakage, we estimated how much silhouette area should be present and compared it to how much silhouette area is present.

To determine how much silhouette area should be present, we measured the vertical central axis lengths on the distal side of 20 pristine ossicles and compared it to the distal silhouette area. When plotted against one another the regression line gives the relationship between the axial length and silhouette area. The equation of this relationship allowed us to calculate the original silhouette area of damaged ossicles. The vertical central axis was chosen because it is the most protected, thickest and last to be altered through the breakage process (Walker, unpublished). The length was measured on a printed image of the whole ossicle. To determine the silhouette area, I used a paper proxy assuming the weight and thickness of the paper is held constant. First I found the ratio between the weight and the area of a small square of paper. The silhouette area for each ossicle was then cut-out and weighed. The weight and the ratio were then used to determine the initial area of the ossicle.

Based on inspection of a plot of silhouette area A versus axis length l , I assume a relation between these, of the form

$$A = al^m \quad (1)$$

Taking the logarithm of (1),

$$\log A = \log a + m \log l \quad (2)$$

which has the form of a linear equation

$$y = b + mx \quad (3)$$

with $y = \log A$, $b = \log a$ and $x = \log l$ linear regression gives estimates of b and m . Because A has units of $[L^2]$ and l has units of $[L]$ it is desirable if $m = 2$ wherein a is dimensionless. In my calculation $m = 1.63$, which suggests it approximately represents an allometric relationship with appropriate dimensions, although here it is used purely as an empirical curve to relate A and l . This technique was used to obtain the final area. To find the area loss I subtracted the final area from the initial area, divided by the initial area and multiplied by 100. The percentages were then comparable between ossicles.

X-ray Tomography

To determine the porosity of the ossicles, 24 samples were imaged at the GeoSoilEnvironCARS beamline (sector 13) of the Advanced Proton Source (APS) at Argonne National Laboratory in Chicago, IL. X-ray tomography was used because it is a nondestructive way to create three dimensional (3D) map of the linear attenuation coefficient (for details, see Landis and Keane, 2010; Rivers et al., 1999) that can be used to calculate the total volume of the ossicles. For imaging, four ossicles were stacked in a plastic pipette tip, separated by foam and enclosed with scotch tape. The vials were placed on a rotating stage; a radiograph was taken at every 0.25° step, with a total of 720 radiographs taken for each tomogram. Tomograms were obtained at 19keV with resulting cubic volume elements (voxels) of 6.1 or 8.9 micrometers in each linear dimension. Reconstructions were performed using ‘tomo_display’ (Rivers and Gualda, 2009).

IDL routines implemented in ‘vol_tools’ (Rivers and Gualda, 2009) and Blob_3D (Ketchum, 2005) were used for image processing. The routine ‘vol_detect’ of ‘vol_tools’ was

used to compute the volume of each ossicle, inclusive of its pores; it uses a morphological close algorithm to select both ossicle and pore voxels and separate from surrounding air voxels, resulting in the total volume of the ossicle. Using the mass of each ossicle as measured with a precision scale, the ossicle density can be calculated by the ossicles mass by the total volume.

Knowledge of calcite density allows calculations of the pore volume:

$$TotalVolume(Voxel^3 = cm^3) - \frac{OssicleMass(g)}{CalciteDensity(\frac{g}{cm^3})} = PoreVolume(cm^3) \quad (4)$$

CHAPTER III

RESULTS

SEM Analysis

Ossicles from the experiments revealed a variety of microstructural dissolution patterns. To evaluate the intensity of dissolution I created a scale from 0 (no dissolution) to 7 (extensive dissolution) (Fig. 5, 6). Chemical dissolution was characterized at each of the five locations (Fig. 4B) using the 8 levels on the qualitative scale. The highest level of chemical dissolution typically occurred on the Knob (Location E in Fig. 4B), where the stereom struts are widest and the dissolution features are most easily seen.

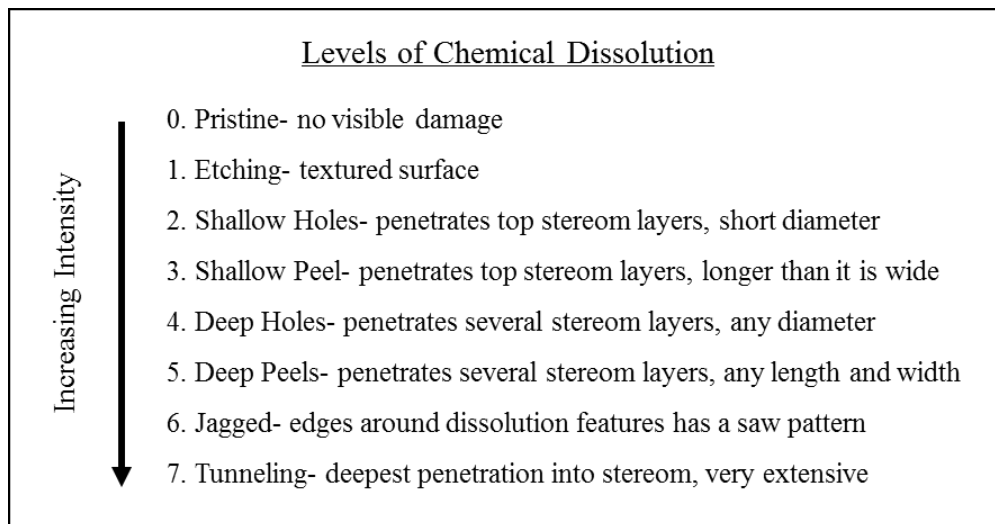


FIGURE 5- Quantitative Scale based on observations from SEM imagery.

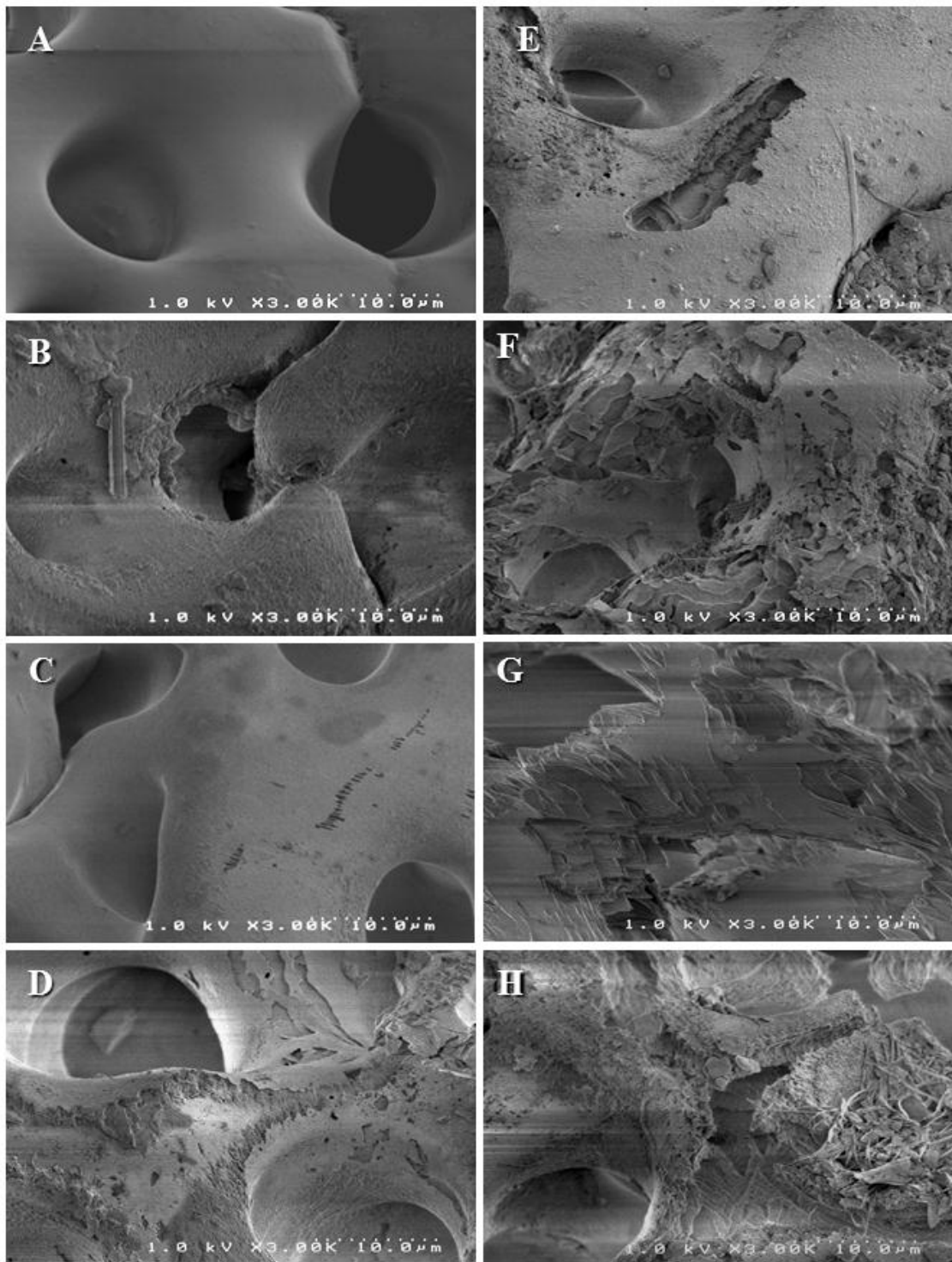


FIGURE 6- SEM images demonstrate the quantitative scale of chemical dissolution. All images are at 3,000 magnification. A) Pristine #0. B) Etching #1. C) Shallow Holes #2. D) Shallow Peel #3. E) Deep Hole #4. F) Deep Peel #5. G) Jagged Edges #6. H) Deep Tunneling #7. # = levels of dissolution as described in Figure 5.

In situ Experiments

Decay and Ossicle recovery

After two years on or near the seafloor, no soft tissue remained on any ophiuroids and ossicle dissolution had begun as seen through our analyses. Dissolution can only occur after all soft tissue has been completely removed from the ossicles exposing the surface of the stereom structure to taphonomic processes. Ossicles were recovered from 35 of the 54 mesh bags in the Pole experiments and from 3 of the 7 Aquarium experiments. Seven mesh bags from the Pole experiment and from one Aquarium had holes in the mesh casing presumably produced by scavengers. Some ossicles may have been lost due to these holes, but the ossicles recovered from the experiments are assumed to not have been altered or ingested.

Chemical Dissolution

The Kruskal-Wallis H-test (Johnson, 2005) shows that ossicles from Aquarium and Pole experiments are all statistically different in levels of chemical dissolution seen from the pristine ossicles ($H=30$, $df=2$, $p>0.001$).

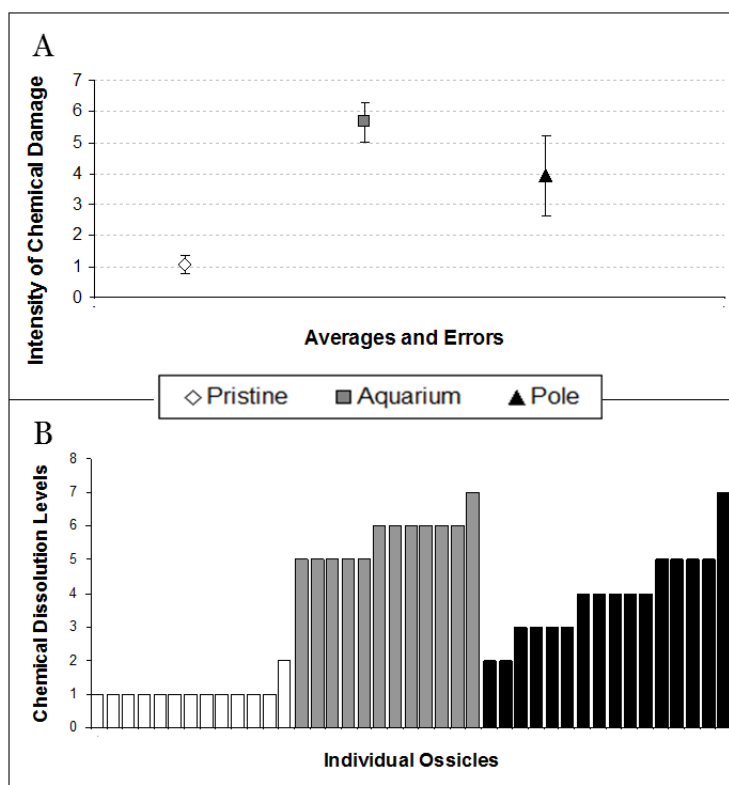


FIGURE 7- The highest level of chemical dissolution sustained on ossicles in different treatments. A) The means and errors for each grouping. Pristine mean= 1.08 ± 0.28 , Aquarium mean= 5.67 ± 0.65 , and Pole mean= 3.94 ± 1.9 . B) Highest level of dissolution seen on each ossicle examined.

Chemical dissolution was assessed by recording the highest level seen anywhere on the ossicle. Both Aquarium and Pole ossicles had higher mean levels of dissolution than the pristine ossicles (Fig. 7A). Ossicles from the Aquarium consistently showed the highest maximum levels of dissolution (Fig. 7B). Pole ossicles had the highest level of dissolution, but also had the widest range of maximum dissolution levels (Fig. 7B). The Knobs consistently had the highest levels of dissolution, although high levels of dissolution could occur at other locations as well (Fig. 4B).

Ossicles scooped off the sediment surface showed a range of macroscopic physical breakage and microscopic chemical damage. These ossicles showed either high amounts of physical loss and high levels of chemical dissolution, appeared to be pristine, or some combination of chemical and physical damage. Post-mortem transport is most likely the cause of the variety of amounts and types of damage seen in the scopes, but there is insufficient information to reconstruct their post-mortem transport.

Silhouette Area loss

The silhouette area loss on the ossicles from the Pole and Aquarium experiments have means statistically different

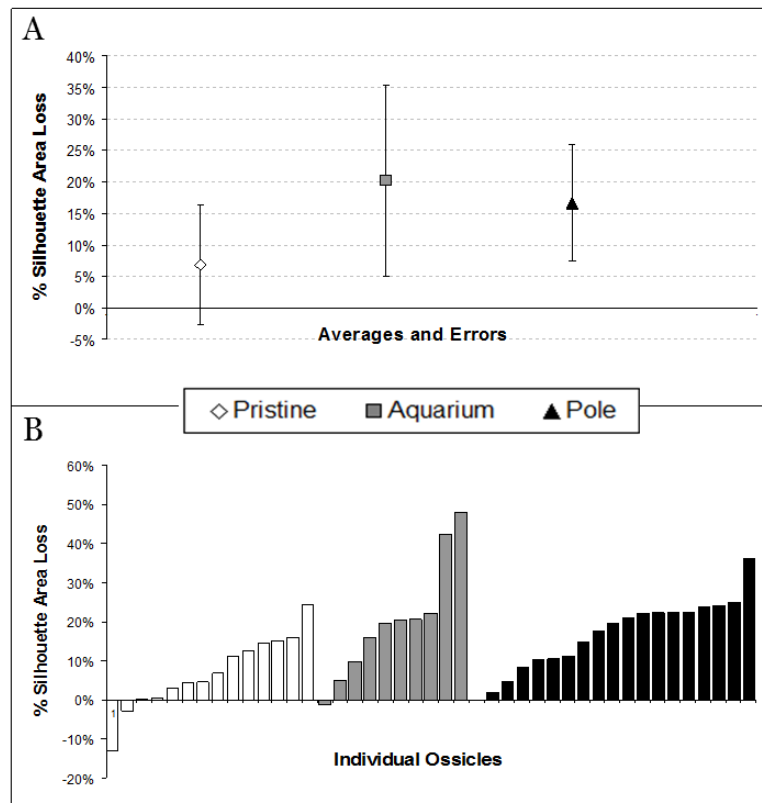


FIGURE 8- Estimated percentage of silhouette area (S.A.) lost for all ossicles. A) The means and errors for each grouping. Pristine mean=6.9% ± 9.5%, Aquarium mean=20.2% ± 15.2%, and Pole mean=16.7% ± 9.2% B) S.A. loss for each ossicle.

(Kruskal-Wallis H-test, $H=6.90$, $df=2$, $p>0.05$) from the pristine ossicles (Fig. 8). The variation, however, is high and cannot be contributed to differences in the incurred damage, but to the method of estimation.

Porosity

The ossicles from the Pole experiments have the highest mean percent porosity (77.7%) of all the experimental ossicles (Fig. 9).

Rate of Dissolution

Ossicles from the Hanging Bag experiment lost between 0.07wt% and 1.31wt% over the course of the 27-day experiment (mean= 0.74wt%).

Assuming this range of rates is constant, complete ossicle dissolution will occur between 6 and 110 years.

Ossicles from the Hanging Bag experiment had levels of silhouette area loss and chemical dissolution similar to the Pristine ossicles.

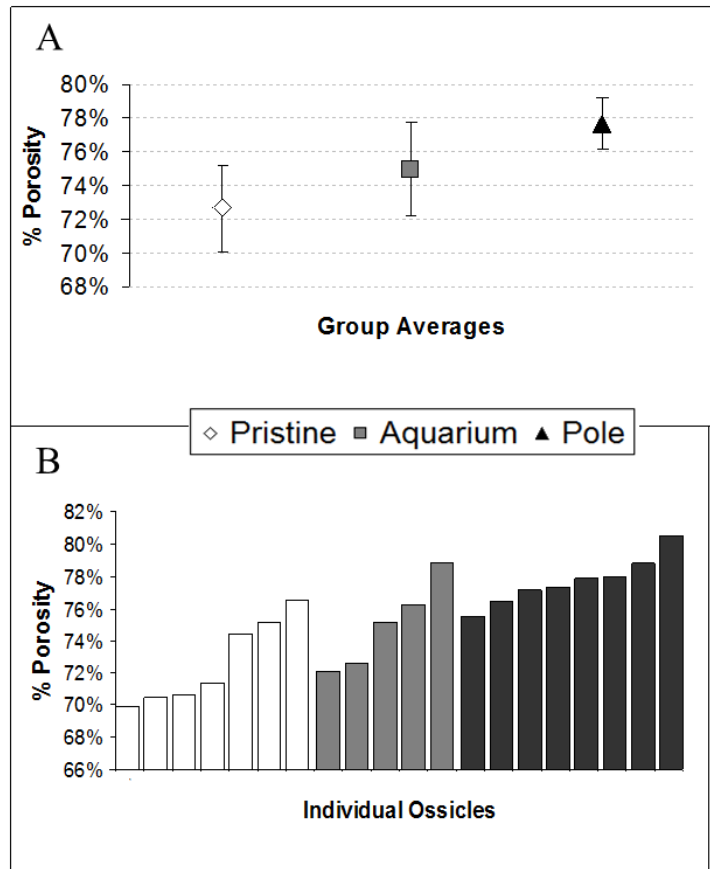


FIGURE 9- The percent porosity found through X-ray tomography analysis and subsequent IDL software analysis. A) The means for each group. Pristine mean= $73.8\% \pm 0.04\%$, Aquarium mean= $74.4\% \pm 0.02\%$, and Pole mean= $77.7\% \pm 0.02\%$. B) Percent porosity for each ossicle analyzed.

The Water-bath experiment, in the laboratory, yielded rates that were much slower than the Hanging Bag experiment. The ossicles lost between 0.11wt% and 4.62wt % which calculates over 6,000 years for complete ossicle dissolution to occur.

Laboratory Investigations

Sediment Search

From the 7,775 cm³ of core sediment searched a total of 11 ossicles were recovered. The single vertebral ossicle was recovered at 6cm below the SWI and 3 were recovered from 1cm, 3

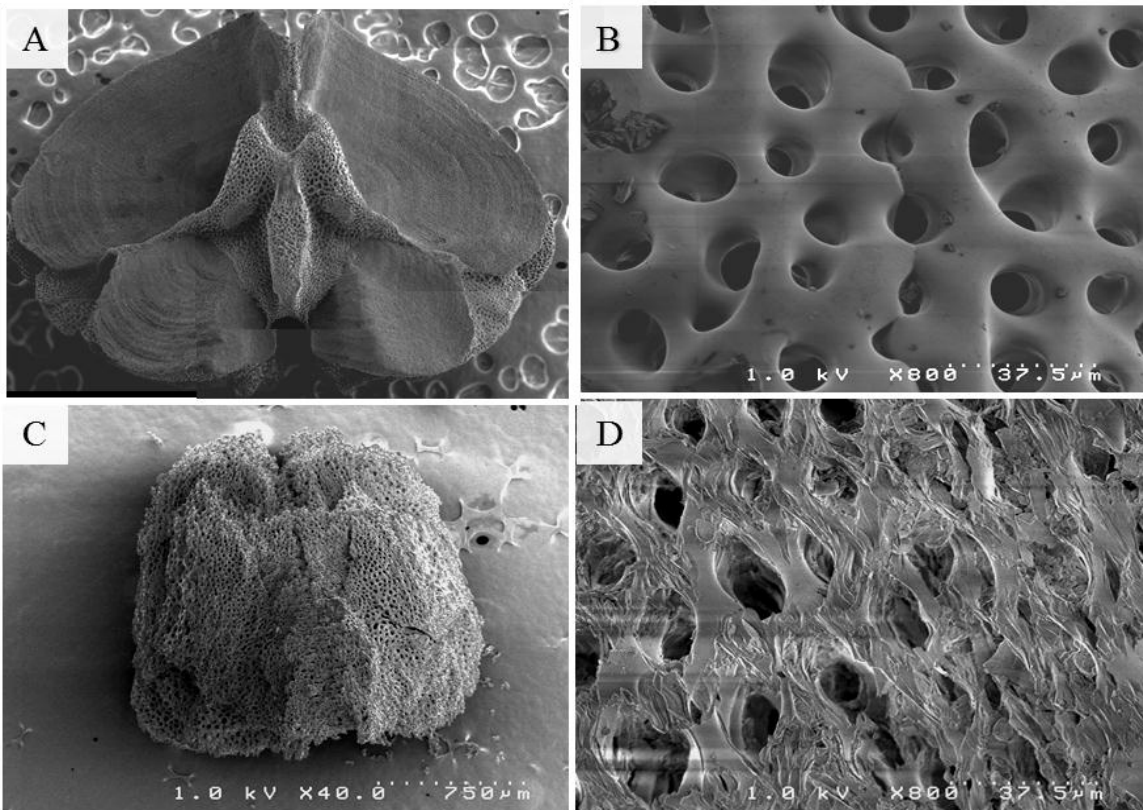


FIGURE 10- SEM images of vertebral ossicles. A) Pristine vertebral ossicle imaged at 40x. B) Stereom structure of the pristine vertebral ossicle at the knob location (Fig. 4) imaged at 800x. C) Highly degraded ossicle found in the sediment core imaged at 40x. D) Stereom of the highly dissolved ossicle at knob location (Fig. 4) imaged at 800x.

were recovered from 2cm, and 5 were recovered from 6cm in addition to the vertebral ossicle. The vertebral ossicle is highly degraded; missing the outermost morphological components typically seen on the distal side, such as the upper and lower fossae as well as the prominent Knob feature and central relief seen on the central axis (Fig. 10A and 10C). Only remnants of these features remain (Fig. 10C). Figure 10D illustrates the unusual microstructural pattern of dissolution which is not seen in any of the ossicles recovered from the experiments, scoops from the sediment surface, or removed from the stomach contents of *O. gigas*. X-ray tomography yielded 78 vol % porosity for this ossicle, which is comparable to the ossicles recovered from the Pole experiments (~77 vol % porosity).

Dissections

Three of the six dissected *O. gigas* contained *O. victoriae* ossicles. The ossicles were removed from the stomach contents and cleaned; no other types of stomach contents were analyzed. The dissections that yielded *O. victoriae* ossicles came from three different locations. The *O. gigas* from Double Curtain was ingesting legs from the carcass of an *O. victoriae*. The central disc and other legs were laying on the SWI with soft tissue intact. The vertebral ossicles recovered from the stomach, only had microscopic traces of soft tissue remaining. The ossicle from this dissection is designated as a partially consumed.

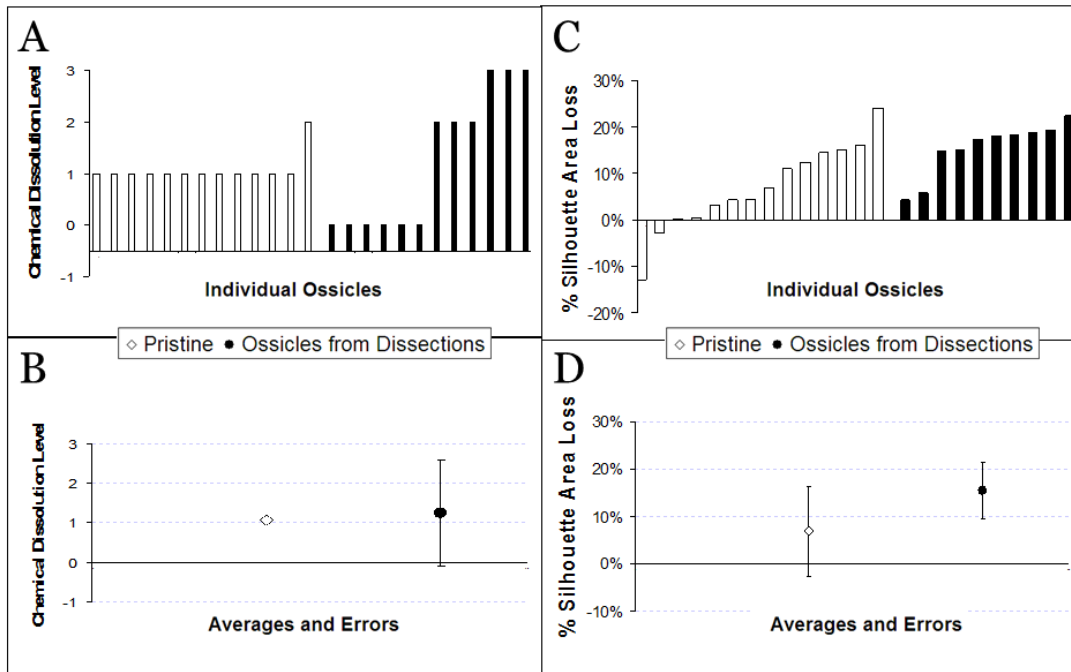


FIGURE 11- Comparisons between Pristine ossicles and ossicles recovered from the dissections. A) Maximum level of dissolution observed on pristine ossicles and those recovered during the dissection of *O. gigas*. B) The means and errors of the chemical dissolution. C) Silhouette area lost on pristine ossicles and ossicles from the dissections. D) The means and errors of the silhouette area lost.

The *O. gigas* from Herbertson had an entire *O. victoriae* in their stomach with some soft tissue still intact. We assume that this specimen was inside *O. gigas* longer than the one from Double Curtain because there were no *O. victoriae* parts or pieces on the ground next to *O. gigas*. The *O. gigas* taken from Wales Delta had vertebral ossicles in its stomach only with microscopic pieces of soft tissue remaining on the ossicle. We assume *O. victoriae* from the Wales Delta dissection was the stomach the longest, because there is a lack of any visible soft tissue and lack of other parts on the seafloor nearby. Ossicles from both the Herbertson and Wales Delta locations are considered completely consumed.

All ossicles removed from the dissections had 0 through 3 levels of chemical dissolution (Fig. 11A) and minimal physical breakage. Using the Mann-Whitney U-test, I compared the level of chemical dissolution and silhouette area loss of all ossicles found in the guts to the

pristine ossicles (Fig. 11). Neither the silhouette area loss ($Z=-0.15$, $p<0.05$) nor the chemical dissolution levels ($Z=0$, $p<0.05$) were significantly different.

Forced Ossicle Damage (SEM assessment)

Effects of the physical breakage were observed at both the macroscopic and microscopic levels. On the macroscopic level after physical breakage ossicles lost stereom area from both the upper and lower fossae and if it was broken completely through the stereom in one horizontal plane, it was broken across the middle of the distal side. SEM microscopy revealed flat fractured surfaces across the middle of the trabecular where the stereom was broken. Macroscopically ossicles from the peroxide and bleach treatments looked unaltered, yet microscopically they showed pitting or shallow holes. Ossicles in the HCL treatment exhibited a greatly reduced silhouette area macroscopically and commonly showed thinning of stereom struts on the microscopic scale. Results from these experiments provided the basis for distinguishing between chemical and physical damage in the ossicles recovered from the *in situ* experiments from Explorers Cove and assisted in the ordering and creation of the semi-qualitative dissolution scale (Fig. 5).

CHAPTER IV

DISCUSSION

The prediction that ossicles from *O. victoriae* would dissolve under natural conditions in Explorers Cove was correct. In all three *in situ* experiments (Pole, Aquarium, Hanging Bag) the ossicles showed greater amounts and types of damage compared to the pristine ossicles. Damage is occurring at a relatively rapid rate despite the fact all ossicles were in water less than 30m deep, which is presumably well above the carbonate compensation depth (CCD). The CCD is not well constrained for Explorers Cove, but in the Ross Sea it is at 500m (Kenneth, 1966) and between 250m-3700m in the Weddell Sea (Anderson, 1975), where *O. victoriae* also is a major component of the epibenthos (Dayton, 1990, 1994; Manjon-Cabeza and Ramos, 2003).

Dissolution has been documented at high latitudes on the shallow seafloor in the North Sea on biogenic carbonates (Alexandersson, 1978, 1976, 1975), on the coastal platforms near northern Norway on forams (Freiwald, 1995), and in the water column at every 500m down to 3,500m water depth in the Drake Passage on echinoderms and other calcifiers (Henrich and Wefer, 1986). However none of these studies constrained a rate of dissolution at the SWI or document dissolution in shallow, multi-year sea-ice covered environments. Dissolution has also been documented at lower latitudes in the Gulf of Mexico on bivalve and gastropod shells (Cai et al., 2006), on Bahamas Bank carbonate sediment grains (Hu and Burdige, 2008), in Australia on skeletal carbonate sediment micro-bored by algal (Tudhope and Risk, 1985) and on corals by fungi (Aline, 2008). Carbonates dissolve more easily into the warm waters of the tropics for several reasons. For example, tropical waters are usually shallow which means the organisms are

in the photic zone where biological activity is high and recycling of nutrients is common. Also, in shallow water carbonate skeletons are within wave base and are exposed to damage during storms, both types of wave energy can physically breakdown the carbonates. All of these experiments have not been *in situ* experiments in extremely high latitudes and underneath the sea-ice, which are the conditions that make our study unique.

Visible Degradation

Chemical

The 7 levels of chemical dissolution (Fig. 5, 6) are the only patterns seen in the ossicles recovered from the *in situ* experiments. Dissolution features on ossicles recovered from *in situ* experiments reflect only the range of dissolution sustained over the course of the 2 year experiments. The most intense levels of dissolution are commonly seen on the Knob (Fig. 4B, location E), which morphologically has the widest trabeculae and smallest pore diameters. The 7 levels of dissolution all occur during the initial 2 years, but different patterns of dissolution could occur after longer exposure. For example, none of the descriptions reflect the dissolution pattern seen in the vertebral ossicle recovered from the sediment core. The highly dissolved ossicle from the core is assumed to have been exposed to degradational processes near the sediment surface for longer than 2 years, because it has sustained greater chemical dissolution, has lost the marginal areas, and has reduced central features, including the Knob area. Because the silhouette area estimations require the presence of the central features, it was impossible to calculate an initial silhouette area with the greatly reduced features. However, the ossicle clearly has lost

significant amounts of the marginal area. To our knowledge, such intense physical and chemical degradation of an echinoderm ossicle has not previously been reported or illustrated.

Silhouette Area

Analysis of silhouette area loss over the initial two years of decay only shows removal from the fossae regions (Fig. 4). Ossicle morphology plays a central role in the pattern of silhouette area loss (Henrich and Wefer, 1986). The lower fossa protrudes from the main plane of the distal side, resulting in the lower half exposed as a thin sheet that is easily broken. Also the margins around the upper fossae are thin protrusions that are easily broken after removal from the protective soft tissue. These thin areas are the first to be lost.

Porosity

Assuming the highly dissolved ossicle was exposed longer than 2 years, we expected this ossicle to have the most intense micro- and macro- damage, and thus to have the greatest percent porosity (Alexandersson, 1978). In contrast to our expectations, the degraded ossicle had a comparable percent porosity to the Pole experiments, which were determined to have the least amount of damage than other experiments exposed for 2 years. In this case longevity of exposure to taphonomic processes does not correlate to increased percentages in porosity. Percent volume porosity is an inadequate estimator for quantifying amounts of internal degradation in ophiuroid ossicles. This could be true because the natural variation in the porous stereom structure exerts strong control over ossicle porosity making the original porosity difficult to assess accurately.

Lamination

Several levels of dissolution show lamination within the ‘solid’ structure. This is manifested through peeling layers and a step-wise descent into holes, which suggests a weakness within trabeculae. Several flat surfaces identified under the SEM (Fig. 12) exhibited a very faint, yet distinguishable micron thick lamination pattern. The lamination could be conchoidal fracture surfaces, but they are seen in the peeling patterns and down hole in some of the holes that

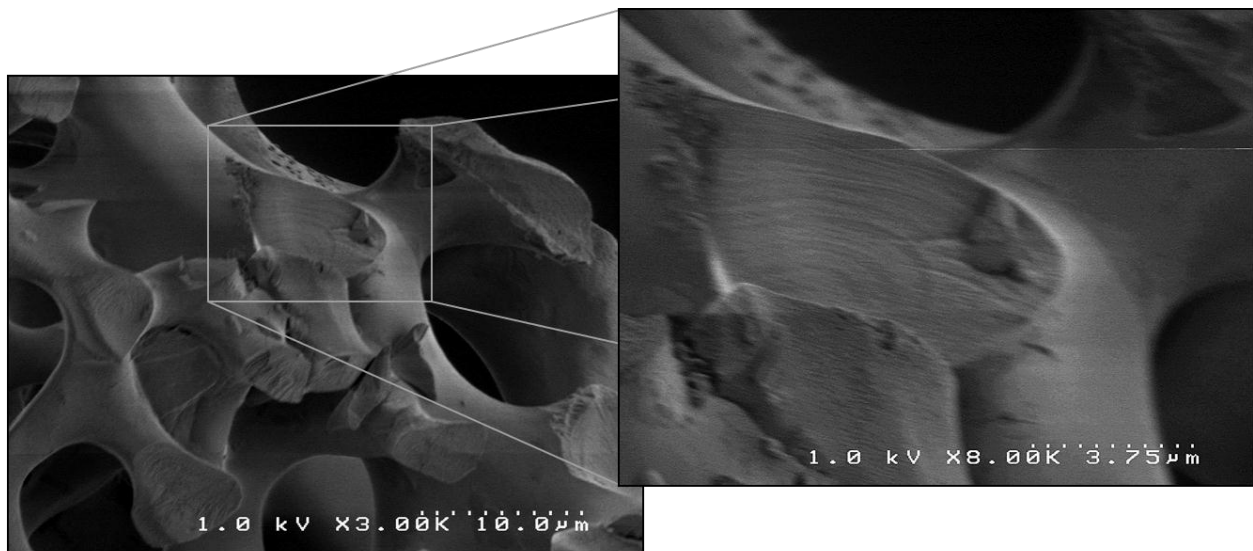


FIGURE 12- SEM images of the flat surfaces revealed by the removal of stereom material. A) 3,000 magnification showing several examples of internal lamination. B) 8,000 magnification show a zoomed in example of the internal laminations.

penetrate deep into the trabeculae. This internal pattern was also seen in an echinoid ossicle in the Drake Passage experiments conducted by Henrich and Wefer (1986).

During the initial growth of an ossicle, it expands in the direction of all three axes, implying that calcite is added to the ossicle through time (Clark, 1914). Calcite is secreted in the sclerocytes cells which are attached to the skeleton (Byrne, 1994, Märkel and Röser, 1985). The layering pattern made from calcite secretion could represent the pattern of biomineralization by which the brittlestar orients the microcrystalline additions of calcite (Byrne, 1994; Imai, 2007;

Märkel and Röser, 1985; Wray, 1999). The peeling pattern would then represent destruction occurring in the reverse order in which it was created.

Rate of Degradation

Complete soft tissue decay occurred in much less than two years, although the exact mechanism for soft tissue decay or removal is unclear. Schäfer (1972) suggests that ophiuroid soft tissue decay occurs in less than 15 hours whereas Allison (1990) suggests that decay begins within 48 days. In either case ossicles, from the scarified ophiuroids in the experiments were most likely disarticulated and exposed for most of the 2 years.

The Hanging Bag results, based on the one month weight loss experiment, imply the ossicles will take between 6 and 110 years to completely dissolve assuming a constant rate of degradation. This is a very rapid rate and suggests nearly instantaneous dissolution relative to geologic time and may even be an underestimation the rate of dissolution. The Hanging Bag experiments are similar to the Pole experiments in that they are elevated off the SWI. Ossicles elevated off the SWI in the Pole experiments sustained less damage over the two years than the ossicles at the SWI in the aquaria. This discrepancy suggests that the rate of dissolution at the SWI may be higher than our calculated rate. Complete dissolution in or at the SWI may occur in less than the range of 6 to 110 years.

Controls on rate of degradation

Overall greater levels of chemical dissolution and greater percentages of physical loss are seen in the Aquarium experiments than the Pole experiments. The main difference between the two experimental designs is proximity to the SWI, which indicates more rapid degradation by

taphonomic processes at the SWI. This could be due to decomposition of organic matter at the SWI and a very slow current that may not replenish oxygen to those areas. This could also be due to the biological interactions within the sediments, where microbial and infaunal respiration alters the pore water chemistry by increasing the CO₂ concentrations which drops the pH and increases calcite solubility (Boudreau and Canfield, 1993; Jones et al., 1985; Walters et al., 2003). The pore water chemistry at the SWI and in the top few centimeters of sediment has a significant effect on the rate of dissolution, because it becomes a micro-environment very different from what is occurring in the water column above and deep within the sediment core below.

This micro-environment in the upper part of the sediment column where the pore water chemistry can effect and alter biogenic grains is called the taphonomically active zone (TAZ) (Davies et al., 1989). Microbial respiration can decrease the pH, disrupting the chemical equilibrium state and pushing the buffering system to dissolve CaCO₃ (Jones et al., 1985; Walters et al., 2003). Also depending on the pore water chemistry, byproducts from oxidation can alter the calcite-saturation point and increase dissolution (Boudreau and Canfield, 1993; Jones et al., 1985; Walters et al., 1993). The longer the exposure in the TAZ the greater the extent of damage will be, due to continued exposure to dissolution (Hu and Burdige, 2008). Bacteria and fungi have also been documented to biocorrode or produce clustered holes on the surface of forams, urchin spines, and biogenic carbonate grains. The clustered pattern is described as the result of a bacterium moving from one location to the next. A similar clustered pattern of small holes is seen in our experiments, but it only seen occasionally. Also our features are larger than the size of bacterial holes shown in Friedwald (1995), leaving the source of the holes up for debate.

Explorers Cove is an area dominated by multi-year sea-ice coverage and very low current velocities (Cummings et al., 2006; Norkko, et al. 2002). Anderson (1975) describes how the sea-ice can eliminate the gas exchange between sea and atmosphere. When gas exchange is limited, biological respiration and organic decay can lead to increased levels of CO₂ concentrations. Increased levels of CO₂ usually coincide with an increase in an under-saturation of CaCO₃. This is a phenomenon documented to occur in the Arctic (Steinsund and Hald, 1994) and results in calcareous foram dissolution at the SWI. Steinsund and Hald (1994) also mentioned that the polar night amplifies the build-up of CO₂, because there is no uptake by the photosynthetic process, which could also affect the porewater chemistry in Explorers Cove. Similar to Osterman and Kellogg (1979) we believe reduced atmospheric exchange is a possible explanation for alterations in the pore water chemistry, but do not know the rate at which equilibrium is reached or how long a system must be uncovered, before the bottom water and it is altered to the point where it enhances calcite dissolution.

Sedimentation

For ossicles to completely dissolve before they can be incorporated deep into the sediment cores, they must be exposed in the TAZ before the sediment can bury them out of the TAZ. This could be due to low sedimentation rates, which is what we have observed to be true (observation by Molly Miller).

Bioturbation: TAZ

Bioturbators such as the scallops, *O. victoriae*, and the starfish are documented to rearrange large amounts of sediment and potentially oxygenate the pore water fueling microbial activity (Broach et al, 2011, McClintock et al., 2010). They are potentially suspending the

ossicles with the sediment when they flapping their valves. Re-suspension of the ossicles would extend their residence time in the TAZ, because it will prevent the ossicles from being buried and removed from the TAZ.

Degradation by predation

The dissections revealed the assumed early stages of soft tissue removal/digestion. The ossicles removed from the stomach were not statistically different from the pristine ossicles; therefore, we assume they are both relatively unaltered. This ruled out the hypothesis that recycling of material through predation has an effect on the rate of chemical dissolution which corroborates with the work completed by Kellogg (et al., 1982) showing that digestion by ophiuroids does not alter hard parts. However, the dissections did show an acceleration of the soft tissue removal and ossicle freeing process. A more extensive study is needed to determine residence times within the stomachs and extent of damage incurred during the later stages of digestion.

Degradation and the Sediment Record

Physical breakage and chemical dissolution manifest destruction microstructurally, macrostructurally and through a variety of dissolution patterns on the microstructural scale. All three *in situ* experiments (Pole, Aquarium, and Hanging Bag) show the effects of dissolution in comparison to the pristine ossicles. It is apparent that dissolution is occurring and at a relatively rapid rate.

Similar to the results seen from the DVDP core and the ANDRILL 1B core, ossicles are not found deeper than 6cm below the SWI. It is apparent that few if any ophiuroids ossicles will be seen in the records of these cold-water, multi-year sea-ice environments. The Cenozoic fossil

record from Explorers Cove is severely misrepresentative of the benthic ophiuroid community. Studies such as those conducted by Kidwell (2001) show that the fossil record can be a fairly representative proxy for the past communities. We show the fossil record in Explorers Cove, Antarctica is not a representative proxy for its most recent communities. The sediment cores would suggest there are no ophiuroids and there haven't been any ophiuroids, but we know that is not the case.

CHAPTER V

CONCLUSIONS

Both macrostructural and microstructural dissolution features form on the trabeculae of ossicles of the ophiuroid *Ophionotus victoriae* within two years of deployment at less than 30m water depth in Explorers Cove (EC). Ossicles from the experiments closest to the sediment-water interface (SWI) experienced the greatest amount of damage. The SWI is in the taphonomically active zone which is well oxygenated by means of bioturbation by scallops and ophiuroids, which probably increases microbial activity, and thus may enhance dissolution thru pore water chemistry alteration. Ingestion of *O. victoriae* by *O. gigas*, on the other hand does not appear to increase dissolution of the ossicles, but does accelerate soft tissue removal. In spite of the fact that *O. victoriae* is abundant in EC, ossicles are rare to absent in the subfossil record of near shore sediment cores of EC and there is only a single report of ossicles in the Cenozoic sediments from numerous cores in McMurdo Sound. The rapid dissolution on the EC seafloor demonstrated in this study may explain the rarity of ossicles in the cores.

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APPENDIX A

TABLE 1: Percentage data for all ossicles analyzed.

| Location | Exp Type | ID | S.A. Loss | Porosity | wt% loss |
|-------------------|------------|---------------------------|-----------|----------|----------|
| Antarctica | Pristine | Natural_Decay_Ov | 12.34% | - | - |
| Antarctica | Pristine | Natural_Decay_Ov | 3.04% | - | - |
| Antarctica | Pristine | Natural_Decay_Ov | 6.83% | - | - |
| Jamesway | Puke Pile | P.Pile_from_JW | 9.16% | - | - |
| Jamesway | Puke Pile | P.Pile_from_JW | 2.34% | - | - |
| Jamesway | Puke Pile | P.Pile_from_JW | 1.49% | - | - |
| Jamesway | Puke Pile | P.Pile_from_JW | 4.49% | - | - |
| Jamesway | Pole | JW_Top_A_80_no treatment | 17.37% | 77.97% | - |
| Jamesway | Pole | JW_Top_A_80_no treatment | - | 80.56% | - |
| Jamesway | Pole | JW_Top_A_80_no treatment | 22.27% | 78.77% | - |
| Jamesway | Pole | JW_Top_A_80_no treatment | 22.36% | 77.92% | - |
| Antarctica | Aquarium | Aquar#42(whole,Frozen) | 6.89% | 75.18% | - |
| Antarctica | Aquarium | Aquar#42(whole,Frozen) | 5.03% | 78.76% | - |
| Antarctica | Aquarium | Aquar#42(whole,Frozen) | 20.23% | 74.16% | - |
| Antarctica | Aquarium | Aquar#42(whole,Frozen) | 34.70% | 76.24% | - |
| Delta | Dissection | Og_stomach_con_(Ov legs) | 18.32% | - | - |
| Delta | Dissection | Og_stomach_con_(Ov legs) | 18.08% | - | - |
| Delta | Dissection | Og_stomach_con_(Ov legs) | 4.29% | - | - |
| Delta | Dissection | Og_stomach_con_(Ov legs) | - | - | - |
| Herberston | Dissection | Og_stomach_con(Disc&legs) | 22.37% | - | - |
| Herberston | Dissection | Og_stomach_con(Disc&legs) | 19.36% | - | - |
| Herberston | Dissection | Og_stomach_con(Disc&legs) | 5.80% | - | - |
| Herberston | Dissection | Og_stomach_con(Disc&legs) | 14.84% | - | - |
| Double Curtain | Dissection | Og_stomach_con(Leg_bits) | 15.06% | - | - |
| Double Curtain | Dissection | Og_stomach_con(Leg_bits) | 17.44% | - | - |
| Double Curtain | Dissection | Og_stomach_con(Leg_bits) | 18.83% | - | - |
| Ice Cliff | Pole | Ice_Cliff#3_no-Treatment | - | - | - |
| Ice Cliff | Pole | Ice_Cliff#3_no-Treatment | 11.13% | - | - |
| Ice Cliff | Pole | Ice_Cliff#3_no-Treatment | 8.18% | - | - |
| Ice Cliff | Pole | Ice_Cliff#3_no-Treatment | 22.38% | - | - |
| Berg | Pole | Berg_#1_no_Treatment | 24.01% | 76.38% | - |
| Berg | Pole | Berg_#1_no_Treatment | 14.70% | 77.31% | - |
| Berg | Pole | Berg_#1_no_Treatment | 19.55% | 75.48% | - |
| Berg | Pole | Berg_#1_no_Treatment | - | 77.12% | - |
| Herberston | Pole | Herb_#4_Top_no_treatment | 1.90% | - | - |
| Herberston | Pole | Herb_#4_Top_no_treatment | 10.45% | - | - |
| Herberston | Pole | Herb_#4_Top_no_treatment | 10.18% | - | - |
| Herberston | Pole | Herb_#4_Top_no_treatment | -0.20% | - | - |
| Antarctica | Aquaria | Aquar#43_JW_no_treatment | - | - | - |
| Antarctica | Aquaria | Aquar#43_JW_no_treatment | 16.03% | - | - |

| Location | Exp Type | ID | S.A. Loss | Porosity | wt% loss |
|---------------|-------------|--------------------------|-----------|----------|----------|
| Antarctica | Aquaria | Aquar#43_JW_no_treatment | 19.51% | - | - |
| Antarctica | Aquaria | Aquar#43_JW_no_treatment | 9.88% | - | - |
| Antarctica | Aquaria | Aquar#29_JW_no_treatment | 42.35% | 73.75% | - |
| Antarctica | Aquaria | Aquar#29_JW_no_treatment | 20.64% | 72.09% | - |
| Antarctica | Aquaria | Aquar#29_JW_no_treatment | 22.11% | 72.54% | - |
| Antarctica | Aquaria | Aquar#29_JW_no_treatment | 47.82% | 72.08% | - |
| Antarctica | Aquaria | Aquar#29_JW_no_treatment | - | - | - |
| Jamesway | Hanging Bag | Hanging_bag-#41 | -13.00% | - | - |
| Jamesway | Hanging Bag | Hanging_bag-#41 | -2.90% | - | - |
| Jamesway | Hanging Bag | Hanging_bag-#41 | 0.09% | - | - |
| Jamesway | Hanging Bag | Hanging_bag-#41 | 15.18% | - | - |
| Jamesway | Hanging Bag | Hanging_36_38_40_41 | 14.49% | 70.66% | 0.27% |
| Jamesway | Hanging Bag | Hanging_36_38_40_42 | 16.03% | 71.44% | 0.55% |
| Jamesway | Hanging Bag | Hanging_36_38_40_43 | 24.18% | 70.47% | 0.80% |
| Jamesway | Hanging Bag | Hanging_36_38_40_44 | - | 69.97% | 0.86% |
| Antarctica | Fridge | Untreated #37 | 4.44% | 75.15% | - |
| Antarctica | Fridge | Untreated #37 | 4.36% | 74.43% | - |
| Antarctica | Fridge | Untreated #37 | 0.41% | 76.48% | - |
| Antarctica | Fridge | Untreated #37 | 11.02% | - | - |
| Ant/Untreated | Waterbath | #38 | - | - | 0.55% |
| Ant/Untreated | Waterbath | #38 | - | - | 0.95% |
| Ant/Untreated | Waterbath | #38 | - | - | 0.54% |
| Ant/Untreated | Waterbath | #38 | - | - | 0.56% |
| Ant/Untreated | Waterbath | #38 | - | - | 0.82% |
| Ant/Untreated | Waterbath | #38 | - | - | 1.23% |
| Ant/Untreated | Waterbath | #36 | - | - | 0.35% |
| Ant/Untreated | Waterbath | #36 | - | - | 0.22% |
| Ant/Untreated | Waterbath | #36 | - | - | 0.22% |
| Ant/Untreated | Waterbath | #36 | - | - | -0.17% |
| Ant/Untreated | Waterbath | #36 | - | - | 0.27% |
| Ant/Untreated | Waterbath | #36 | - | - | 0.79% |
| Ant/Untreated | Waterbath | #36 | - | - | 0.28% |
| Ant/Untreated | Waterbath | #41 | - | - | 0.07% |
| Ant/Untreated | Waterbath | #41 | - | - | 0.41% |
| Ant/Untreated | Waterbath | #41 | - | - | 0.69% |
| Ant/Untreated | Waterbath | #41 | - | - | 0.86% |

| Location | Exp Type | ID | S.A. Loss | Porosity | wt% loss |
|---------------|-----------|----------------------------|-----------|----------|----------|
| Ant/Untreated | Waterbath | #41 | - | - | 0.66% |
| Ant/Untreated | Waterbath | #41 | - | - | 0.55% |
| Ant/Untreated | Waterbath | #40 | - | - | 0.38% |
| Ant/Untreated | Waterbath | #40 | - | - | 0.22% |
| Ant/Untreated | Waterbath | #40 | - | - | 6.47% |
| Ant/Untreated | Waterbath | #40 | - | - | 0.80% |
| Ant/Untreated | Waterbath | #40 | - | - | 0.24% |
| Ant/Untreated | Waterbath | #40 | - | - | 0.88% |
| Jamesway | Pole | JW_80'_BottomB(5050B:W) | 36.16% | - | - |
| Jamesway | Pole | JW_80'_BottomB(5050B:W) | 23.55% | - | - |
| Jamesway | Pole | JW_80'_BottomB(5050B:W) | 20.88% | - | - |
| Jamesway | Pole | JW_80'_BottomB(5050B:W) | 4.75% | - | - |
| Delta | Pole | Delta_60'_BottomA(5050P:W) | - | - | - |
| Delta | Pole | Delta_60'_BottomA(5050P:W) | 24.89% | - | - |
| Delta | Pole | Delta_60'_BottomA(5050P:W) | 22.07% | - | - |
| Delta | Pole | Delta_60'_BottomA(5050P:W) | 33.38% | - | - |

Appendix B

TABLE 2: All SEM damage recorded. P = physical damage; C = chemical damage, C-E = Etched the lowest level of chemical damage seen, C-1H = Shallow Holes, C-1P= Shallow Peel, C-2H = Deep Holes, C-2P = Deep Peel, C-J = Jagged Edges, and C-T = Tunneling the highest level of damage seen; M = there is More organic material present than visible damage; L = damage is Localized; S = damage is Spotty or has multiple occurrences; W = damage is Widespread. 3,000x usually determined the type of damage and the lower magnifications (1,500x and 800x) determined how extensive the damage was.

| Dive | Location | Exp Type | ID | ID2 | Location | 3000x | 1500x | 800x |
|------------|-----------|------------------|----|-----|----------|---------|------------|----------|
| Antarctica | Pristine | Natural_Decay_Ov | A | A | A | more | - | P-L |
| Antarctica | Pristine | Natural_Decay_Ov | A | B | B | more | widespread | W |
| Antarctica | Pristine | Natural_Decay_Ov | A | C | C | P, C | P-S, C-L | P-S |
| Antarctica | Pristine | Natural_Decay_Ov | A | D | D | more | localized | L |
| Antarctica | Pristine | Natural_Decay_Ov | A | E | E | more | C-L | more |
| Antarctica | Pristine | Natural_Decay_Ov | B | A | A | C-J | C-W | C-W, P-L |
| Antarctica | Pristine | Natural_Decay_Ov | B | B | B | C-E | C-W | - |
| Antarctica | Pristine | Natural_Decay_Ov | B | C | C | C-E | C-W | - |
| Antarctica | Pristine | Natural_Decay_Ov | B | D | D | P | P-W | P-W |
| Antarctica | Pristine | Natural_Decay_Ov | B | E | E | - | - | - |
| Antarctica | Pristine | Natural_Decay_Ov | C | A | A | C-E, P | C-W. P-S | C-W. P-S |
| Antarctica | Pristine | Natural_Decay_Ov | C | B | B | C-E | C-W | - |
| Antarctica | Pristine | Natural_Decay_Ov | C | C | C | C-E | C-W | - |
| Antarctica | Pristine | Natural_Decay_Ov | C | D | D | more, P | m-S, P-S | - |
| Antarctica | Pristine | Natural_Decay_Ov | C | E | E | MORE | M-W | - |
| Antarctica | Pristine | Natural_Decay_Ov | D | A | A | C-E | C-W | C-W |
| Antarctica | Pristine | Natural_Decay_Ov | D | B | B | C-E | C-W | - |
| Antarctica | Pristine | Natural_Decay_Ov | D | C | C | C-E | C-W | - |
| Antarctica | Pristine | Natural_Decay_Ov | D | D | D | more, P | m-S, P-S | - |
| Antarctica | Pristine | Natural_Decay_Ov | D | E | E | more | etching? | - |
| Jamesway | Puke Pile | P.Pile_from_JW | A | A | A | P | P-S | - |
| Jamesway | Puke Pile | P.Pile_from_JW | A | B | B | none | none | M |
| Jamesway | Puke Pile | P.Pile_from_JW | A | C | C | M, C-1H | C-S, M-S | C-S, M-S |
| Jamesway | Puke Pile | P.Pile_from_JW | A | D | D | P | P-S | P-S |

| Dive Location | Exp Type | ID | ID2 | Location | 3000x | 1500x | 800x |
|---------------|-----------|--------------------------|-----|----------|--------------|----------------|---------------|
| Jamesway | Puke Pile | P.Pile_from_JW | A | E | C-1H, M | M-S, C-L | M-S, C-L |
| Jamesway | Puke Pile | P.Pile_from_JW | B | A | P | P-S | M, P-S |
| Jamesway | Puke Pile | P.Pile_from_JW | B | B | M | M-W | M-W |
| Jamesway | Puke Pile | P.Pile_from_JW | N/A | C | - | - | - |
| Jamesway | Puke Pile | P.Pile_from_JW | N/A | D | - | - | - |
| Jamesway | Pole | JW_Top_A_80_no treatment | A | A | C-1P, P | C-S, P-L | - |
| Jamesway | Pole | JW_Top_A_80_no treatment | A | B | C-1P, C-1H | C-1P-L, C-1H-S | - |
| Jamesway | Pole | JW_Top_A_80_no treatment | A | C | C-E, C-1H | C-S | - |
| Jamesway | Pole | JW_Top_A_80_no treatment | A | D | C-1P | C-1P-L, P-S | - |
| Jamesway | Pole | JW_Top_A_80_no treatment | A | E | C-1H, C-E | C-S, C-E-W | C-HS, C-E-W |
| Jamesway | Pole | JW_Top_A_80_no treatment | B | A | C-E, C-1P, P | C-W, P-L | C-W, P-W |
| Jamesway | Pole | JW_Top_A_80_no treatment | B | B | C-1P | C-W | - |
| Jamesway | Pole | JW_Top_A_80_no treatment | B | C | - | - | - |
| Jamesway | Pole | JW_Top_A_80_no treatment | B | D | C-1P | C-W | C-W |
| Jamesway | Pole | JW_Top_A_80_no treatment | B | E | C-E | C-W | C-W |
| Jamesway | Pole | JW_Top_A_80_no treatment | C | A | P, | C-1H-S, P-W | C-1H-S, P-W |
| Jamesway | Pole | JW_Top_A_80_no treatment | C | B | C-1P | C-W | C-W |
| Jamesway | Pole | JW_Top_A_80_no treatment | C | C | - | - | - |
| Jamesway | Pole | JW_Top_A_80_no treatment | C | D | C-1H, C-1P | C-W | C-W |
| Jamesway | Pole | JW_Top_A_80_no treatment | C | E | C-E-, C-1H | C-E-W, C-1H-S | C-E-W, C-1H-S |

| Dive Location | Exp Type | ID | ID2 | Location | 3000x | 1500x | 800x |
|---------------|------------|--------------------------|-----|----------|----------------|--------------------|----------------|
| Jamesway | Pole | JW_Top_A_80_no treatment | D | A | C-1H | C-2P-L, C-1H-S | C-2P-L, C-1H-S |
| Jamesway | Pole | JW_Top_A_80_no treatment | D | B | C-1H | C-W | C-S |
| Jamesway | Pole | JW_Top_A_80_no treatment | D | C | - | - | - |
| Jamesway | Pole | JW_Top_A_80_no treatment | D | D | C2H | C-L | C-S |
| Jamesway | Pole | JW_Top_A_80_no treatment | D | E | - | - | C-1H-W |
| Antarctica | Aquaria | Aquar#42(whole,Frozen) | A | A | C-J | C-J-W, C-2P-L | C-J-W, C-2P-S |
| Antarctica | Aquaria | Aquar#42(whole,Frozen) | A | B | C-J, C-1P | C-J-W, C-1P-W | C-J-W, C-1P-W |
| Antarctica | Aquaria | Aquar#42(whole,Frozen) | A | C | C-E | C-W | - |
| Antarctica | Aquaria | Aquar#42(whole,Frozen) | A | D | P, C-J | P-W, C-J-W, C-1H-L | P-W, C-J-W |
| Antarctica | Aquaria | Aquar#42(whole,Frozen) | A | E | C-J,E,2P, 1H | C-W | C-W, C-T |
| Antarctica | Aquaria | Aquar#42(whole,Frozen) | B | A | C-E, J, 1P,D | C-W | C-W |
| Antarctica | Aquaria | Aquar#42(whole,Frozen) | B | B | M | M-W, C-2H-S | M-W, C-2H-S |
| Antarctica | Aquaria | Aquar#42(whole,Frozen) | B | C | C-2H,D | C-D-W, C-2H-W | C-D-W, C-2H-W |
| Antarctica | Aquaria | Aquar#42(whole,Frozen) | B | D | - | - | - |
| Antarctica | Aquaria | Aquar#42(whole,Frozen) | B | E | C-2P, J, E, 1H | C-W | C-W |
| Antarctica | Aquaria | Aquar#42(whole,Frozen) | C | A | M | P-S | P-S |
| Antarctica | Aquaria | Aquar#42(whole,Frozen) | C | B | M | P-S | P-S |
| Antarctica | Aquaria | Aquar#42(whole,Frozen) | C | C | - | - | - |
| Antarctica | Aquaria | Aquar#42(whole,Frozen) | C | D | P-J, | - | - |
| Antarctica | Aquaria | Aquar#42(whole,Frozen) | C | E | (M or C-J) | - | - |
| Antarctica | Aquaria | Aquar#42(whole,Frozen) | D | A | - | - | - |
| Antarctica | Aquaria | Aquar#42(whole,Frozen) | D | B | M | - | M-W |
| Antarctica | Aquaria | Aquar#42(whole,Frozen) | D | C | C-1P,1H | C-1H-S, C-1P-S | - |
| Antarctica | Aquaria | Aquar#42(whole,Frozen) | D | D | C-2P,J | C-W | C-W |
| Antarctica | Aquaria | Aquar#42(whole,Frozen) | D | E | C-2P,T,1H,2H | C-W | C-W |
| Delta | Dissection | Og_stomach_con_(Ov legs) | A | A | P | P-L | P-S |
| Delta | Dissection | Og_stomach_con_(Ov legs) | A | B | M | - | - |

| Dive Location | Exp Type | ID | ID2 | Location | 3000x | 1500x | 800x |
|---------------|------------|--------------------------|-----|----------|-------|-------|----------|
| Delta | Dissection | Og_stomach_con_(Ov legs) | A | C | P | P-L | P-L |
| Delta | Dissection | Og_stomach_con_(Ov legs) | A | D | M | - | - |
| Delta | Dissection | Og_stomach_con_(Ov legs) | A | E | C-1H | C-S | - |
| Delta | Dissection | Og_stomach_con_(Ov legs) | B | A | P, M | - | - |
| Delta | Dissection | Og_stomach_con_(Ov legs) | B | B | M | M-S | M-S |
| Delta | Dissection | Og_stomach_con_(Ov legs) | B | C | none | - | - |
| Delta | Dissection | Og_stomach_con_(Ov legs) | B | D | - | - | - |
| Delta | Dissection | Og_stomach_con_(Ov legs) | B | E | M | - | - |
| Delta | Dissection | Og_stomach_con_(Ov legs) | C | A | M, P | M-L | M-L, P-L |
| Delta | Dissection | Og_stomach_con_(Ov legs) | C | B | none | - | - |
| Delta | Dissection | Og_stomach_con_(Ov legs) | C | C | none | - | - |
| Delta | Dissection | Og_stomach_con_(Ov legs) | C | D | P-W | P-W | P-W |
| Delta | Dissection | Og_stomach_con_(Ov legs) | C | E | none | - | - |
| Delta | Dissection | Og_stomach_con_(Ov legs) | D | A | - | - | - |
| Delta | Dissection | Og_stomach_con_(Ov legs) | D | B | M | - | - |
| Delta | Dissection | Og_stomach_con_(Ov legs) | D | C | - | - | - |
| Delta | Dissection | Og_stomach_con_(Ov legs) | D | D | M | - | - |
| Delta | Dissection | Og_stomach_con_(Ov legs) | D | E | - | - | - |

| Dive Location | Exp Type | ID | ID2 | Location | 3000x | 1500x | 800x |
|----------------------|-----------------|---------------------------|------------|-----------------|--------------|--------------|-------------|
| Herberston | Dissection | Og_stomach_con(Disc&legs) | A | A | M | M-W | M-W |
| Herberston | Dissection | Og_stomach_con(Disc&legs) | A | B | M | M-W | M-W |
| Herberston | Dissection | Og_stomach_con(Disc&legs) | A | C | M | M-W | M-W |
| Herberston | Dissection | Og_stomach_con(Disc&legs) | A | D | M | M-W | M-W |
| Herberston | Dissection | Og_stomach_con(Disc&legs) | A | E | - | C-T-S | - |
| Herberston | Dissection | Og_stomach_con(Disc&legs) | B | A | M | M-W | M-W |
| Herberston | Dissection | Og_stomach_con(Disc&legs) | B | B | M | - | - |
| Herberston | Dissection | Og_stomach_con(Disc&legs) | B | C | M | - | - |
| Herberston | Dissection | Og_stomach_con(Disc&legs) | B | D | P | P-W | - |
| Herberston | Dissection | Og_stomach_con(Disc&legs) | B | E | C-1P,E, 1H | M-W, C-L | M-W, C-L |
| Herberston | Dissection | Og_stomach_con(Disc&legs) | C | A | M, P | - | - |
| Herberston | Dissection | Og_stomach_con(Disc&legs) | C | B | M | - | - |
| Herberston | Dissection | Og_stomach_con(Disc&legs) | C | C | M | - | - |
| Herberston | Dissection | Og_stomach_con(Disc&legs) | C | D | M | - | - |
| Herberston | Dissection | Og_stomach_con(Disc&legs) | C | E | C-1P,E, 1H | - | - |
| Herberston | Dissection | Og_stomach_con(Disc&legs) | D | A | - | - | - |
| Herberston | Dissection | Og_stomach_con(Disc&legs) | D | B | - | - | - |
| Herberston | Dissection | Og_stomach_con(Disc&legs) | D | C | - | - | - |

| Dive Location | Exp Type | ID | ID2 | Location | 3000x | 1500x | 800x |
|----------------|------------|---------------------------|-----|----------|----------|--------|------|
| Herberston | Dissection | Og_stomach_con(Disc&legs) | D | D | - | - | - |
| Herberston | Dissection | Og_stomach_con(Disc&legs) | D | E | M, | - | - |
| Double Curtain | Dissection | Og_stomach_con(Leg_bits) | A | A | M | - | - |
| Double Curtain | Dissection | Og_stomach_con(Leg_bits) | A | B | M | - | - |
| Double Curtain | Dissection | Og_stomach_con(Leg_bits) | A | C | M | - | - |
| Double Curtain | Dissection | Og_stomach_con(Leg_bits) | A | D | M | P-S | - |
| Double Curtain | Dissection | Og_stomach_con(Leg_bits) | A | E | M | - | - |
| Double Curtain | Dissection | Og_stomach_con(Leg_bits) | B | A | P-, C-1H | - | - |
| Double Curtain | Dissection | Og_stomach_con(Leg_bits) | B | B | M | - | - |
| Double Curtain | Dissection | Og_stomach_con(Leg_bits) | B | C | M | - | - |
| Double Curtain | Dissection | Og_stomach_con(Leg_bits) | B | D | M | - | M-W |
| Double Curtain | Dissection | Og_stomach_con(Leg_bits) | B | E | M | - | - |
| Double Curtain | Dissection | Og_stomach_con(Leg_bits) | C | A | C-1H | - | - |
| Double Curtain | Dissection | Og_stomach_con(Leg_bits) | C | B | C-1H | C-W | - |
| Double Curtain | Dissection | Og_stomach_con(Leg_bits) | C | C | none | - | - |
| Double Curtain | Dissection | Og_stomach_con(Leg_bits) | C | D | M | M-W | - |
| Double Curtain | Dissection | Og_stomach_con(Leg_bits) | C | E | C-1H | C-W, M | M-S |
| Double Curtain | Dissection | Og_stomach_con(Leg_bits) | D | A | - | - | - |

| Dive Location | Exp Type | ID | ID2 | Location | 3000x | 1500x | 800x |
|----------------|------------|--------------------------|-----|----------|---------------|---------------------|---------------|
| Double Curtain | Dissection | Og_stomach_con(Leg_bits) | D | B | none | - | M |
| Double Curtain | Dissection | Og_stomach_con(Leg_bits) | D | C | M | - | - |
| Double Curtain | Dissection | Og_stomach_con(Leg_bits) | D | D | M | - | - |
| Double Curtain | Dissection | Og_stomach_con(Leg_bits) | D | E | C-1H, 1P | C-W | M, C-1H-S |
| Ice Cliff | Pole | Ice_Cliff#3_no-Treatment | A | A | C-1P, D | C-1P-S, C-D-W | C-1P-S, C-D-W |
| Ice Cliff | Pole | Ice_Cliff#3_no-Treatment | A | B | C-E | - | - |
| Ice Cliff | Pole | Ice_Cliff#3_no-Treatment | A | C | C-2H, | C-W | C-W |
| Ice Cliff | Pole | Ice_Cliff#3_no-Treatment | A | D | C-1H, D | C-L | C-L |
| Ice Cliff | Pole | Ice_Cliff#3_no-Treatment | A | E | C-1H,1P, D | C-W | C-W |
| Ice Cliff | Pole | Ice_Cliff#3_no-Treatment | B | A | M | M-W | C-L |
| Ice Cliff | Pole | Ice_Cliff#3_no-Treatment | B | B | C-E | C-W | - |
| Ice Cliff | Pole | Ice_Cliff#3_no-Treatment | B | C | C-1H | C-W | - |
| Ice Cliff | Pole | Ice_Cliff#3_no-Treatment | B | D | C-D, 1P | C-W | C-L |
| Ice Cliff | Pole | Ice_Cliff#3_no-Treatment | B | E | C-1P, E, 1H | C-W | C-W |
| Ice Cliff | Pole | Ice_Cliff#3_no-Treatment | C | A | C-2H, D | C-2H-S, C-D-L | C-2H-S, C-D-L |
| Ice Cliff | Pole | Ice_Cliff#3_no-Treatment | C | B | C-E, C-1H | C-S | C-S |
| Ice Cliff | Pole | Ice_Cliff#3_no-Treatment | C | C | C-E, 1H | C-1H-S, C-E-W | C-1H-S |
| Ice Cliff | Pole | Ice_Cliff#3_no-Treatment | C | D | C-1H, D | C-1H-W, C-D-W, C-1P | C-1H-S, C-D-W |
| Ice Cliff | Pole | Ice_Cliff#3_no-Treatment | C | E | C-1H,2H,1P,2P | C-W | C-W |
| Ice Cliff | Pole | Ice_Cliff#3_no-Treatment | D | A | P, C-1H,2H,D | P-S, C-W | P-S, C-W |
| Ice Cliff | Pole | Ice_Cliff#3_no-Treatment | D | B | C-E,1H | C-W | C-S |
| Ice Cliff | Pole | Ice_Cliff#3_no-Treatment | D | C | C-2H,1H | C-W | C-S |
| Ice Cliff | Pole | Ice_Cliff#3_no-Treatment | D | D | C-2P-, 1H, D | C-W | C-W |
| Ice Cliff | Pole | Ice_Cliff#3_no-Treatment | D | E | C-1P, 1H, 2P | C-W | C-W |
| Berg | Pole | Berg_#1_no_Treatment | A | A | C-E | C-1H-S, C-E-L | - |
| Berg | Pole | Berg_#1_no_Treatment | A | B | C-1H | C-1H-S | C-1H-S |
| Berg | Pole | Berg_#1_no_Treatment | A | C | C-E | - | - |
| Berg | Pole | Berg_#1_no_Treatment | A | D | - | P-S, M-L | - |
| Berg | Pole | Berg_#1_no_Treatment | A | E | C-E, C-1H | C-W | C-W |
| Berg | Pole | Berg_#1_no_Treatment | B | A | P, C-1H | P-W, C-1H-W | - |
| Berg | Pole | Berg_#1_no_Treatment | B | B | C-1H | C-S | C-S |

| Dive Location | Exp Type | ID | ID2 | Location | 3000x | 1500x | 800x |
|---------------|----------|--------------------------|-----|----------|------------------|----------------|------------------|
| Berg | Pole | Berg_#1_no_Treatment | B | C | - | C-1H-S | - |
| Berg | Pole | Berg_#1_no_Treatment | B | D | - | C-1P-S, C-1H-W | C-1P-S, C-1H-S |
| Berg | Pole | Berg_#1_no_Treatment | B | E | C-E, C-1H | C-E-W, C-1H-S | C-E-W, C-1H-W |
| Berg | Pole | Berg_#1_no_Treatment | C | A | - | - | - |
| Berg | Pole | Berg_#1_no_Treatment | C | B | M | - | - |
| Berg | Pole | Berg_#1_no_Treatment | C | C | - | - | - |
| Berg | Pole | Berg_#1_no_Treatment | C | D | - | - | - |
| Berg | Pole | Berg_#1_no_Treatment | C | E | C-1H,2H, C-E | C-W | - |
| Berg | Pole | Berg_#1_no_Treatment | D | A | C-1H | C-S | C-S |
| Berg | Pole | Berg_#1_no_Treatment | D | B | - | - | - |
| Berg | Pole | Berg_#1_no_Treatment | D | C | - | - | - |
| Berg | Pole | Berg_#1_no_Treatment | D | D | - | - | - |
| Berg | Pole | Berg_#1_no_Treatment | D | E | C-1H, C-2H | C-S | C-S |
| Herberston | Pole | Herb_#4_Top_no_treatment | A | A | C-D | M | M |
| Herberston | Pole | Herb_#4_Top_no_treatment | A | B | C-1P | C-L | M |
| Herberston | Pole | Herb_#4_Top_no_treatment | A | C | thinning | W | W |
| Herberston | Pole | Herb_#4_Top_no_treatment | A | D | C-1H,2H | C-W | C-L |
| Herberston | Pole | Herb_#4_Top_no_treatment | A | E | M | C-2P | - |
| Herberston | Pole | Herb_#4_Top_no_treatment | B | A | C-E, 1P, 2H | C-W | C-W, P |
| Herberston | Pole | Herb_#4_Top_no_treatment | B | B | C-2C, M | C-S, M-W | M-W |
| Herberston | Pole | Herb_#4_Top_no_treatment | B | C | - | - | - |
| Herberston | Pole | Herb_#4_Top_no_treatment | B | D | P, C-D | C-W | C-W, P-W, C-2H-L |
| Herberston | Pole | Herb_#4_Top_no_treatment | B | E | C-1H, 2H, 1P, 2P | C-W | C-W |

| Dive Location | Exp Type | ID | ID2 | Location | 3000x | 1500x | 800x |
|---------------|----------|--------------------------|-----|----------|------------------------------|----------------------------|---------------------------|
| Herberston | Pole | Herb_#4_Top_no_treatment | C | A | - | - | - |
| Herberston | Pole | Herb_#4_Top_no_treatment | C | B | C-E | C-E-W, C-1H-S | C-E-W, C-1H-S |
| Herberston | Pole | Herb_#4_Top_no_treatment | C | C | M | M | - |
| Herberston | Pole | Herb_#4_Top_no_treatment | C | D | C-J, 1H, 2H, | C-W | C-W |
| Herberston | Pole | Herb_#4_Top_no_treatment | C | E | C-T, E, J, 1H, 2H, 1P, 2P | C-W | C-W |
| Herberston | Pole | Herb_#4_Top_no_treatment | D | A | - | C-J-W | C-W |
| Herberston | Pole | Herb_#4_Top_no_treatment | D | B | C-1P, E | C-1P-S, C-E-W | C-1P-S, C-E-W |
| Herberston | Pole | Herb_#4_Top_no_treatment | D | C | - | C-2P-S, M | M |
| Herberston | Pole | Herb_#4_Top_no_treatment | D | D | C-1P, E, 1H | C-E-W, C-1H-- S, C-1P-S | C-E-W, C-1H--S, C-1P-S |
| Herberston | Pole | Herb_#4_Top_no_treatment | D | E | C-2P, 1P, 1H, 2H | C-S | C-S |
| Antarctica | Aquaria | Aquar#43_JW_no_treatment | A | A | P, C-E, 1P, J, 2H | P&C-1P,2H,J-S, C-E-W | P&C-1P,2H,J-S, C-E-W |
| Antarctica | Aquaria | Aquar#43_JW_no_treatment | A | B | C-1P | C-S | C-S |
| Antarctica | Aquaria | Aquar#43_JW_no_treatment | A | C | C-1P, 1H | C-S, D-S | C-1H-S, C-D-S |
| Antarctica | Aquaria | Aquar#43_JW_no_treatment | A | D | C-E, J, 1P,D | C-W | C-W |
| Antarctica | Aquaria | Aquar#43_JW_no_treatment | A | E | C-1H, 1P, J, D | C-T-W, C-W | C-W |
| Antarctica | Aquaria | Aquar#43_JW_no_treatment | B | A | C-E, 1H, 2H, 1P | C-W | C-W |
| Antarctica | Aquaria | Aquar#43_JW_no_treatment | B | B | M | - | - |
| Antarctica | Aquaria | Aquar#43_JW_no_treatment | B | C | - | - | M |

| Dive Location | Exp Type | ID | ID2 | Location | 3000x | 1500x | 800x |
|---------------|----------|--------------------------|-----|----------|---------------------|--------------------|--------------------|
| Antarctica | Aquaria | Aquar#43_JW_no_treatment | B | D | C-J, 1P | C-W | C-L |
| Antarctica | Aquaria | Aquar#43_JW_no_treatment | B | E | C-1H, 2H, 2P, 1P, E | C-W | C-W |
| Antarctica | Aquaria | Aquar#43_JW_no_treatment | C | A | C-1H, 1P, E | C-W | C-W |
| Antarctica | Aquaria | Aquar#43_JW_no_treatment | C | B | - | - | M |
| Antarctica | Aquaria | Aquar#43_JW_no_treatment | C | C | C-1H, E, M | C-S | M-W |
| Antarctica | Aquaria | Aquar#43_JW_no_treatment | C | D | C-2P, 1P, 1H | C-W | C-L |
| Antarctica | Aquaria | Aquar#43_JW_no_treatment | C | E | C-2P, 1P, 2H, 1H, E | C-W | C-W |
| Antarctica | Aquaria | Aquar#43_JW_no_treatment | D | A | C-E, J | C-W | - |
| Antarctica | Aquaria | Aquar#43_JW_no_treatment | D | B | C-1H, 2H, | C-S, M | C-S, M-S |
| Antarctica | Aquaria | Aquar#43_JW_no_treatment | D | C | C-D, 2H | C-D-W | C-D-W |
| Antarctica | Aquaria | Aquar#43_JW_no_treatment | D | D | C-E, 2P, 1H | C-W | C-L |
| Antarctica | Aquaria | Aquar#43_JW_no_treatment | D | E | - | - | C-2P, 1P, 1H, 2H-W |
| Antarctica | Aquaria | Aquar#29_JW_no_treatment | A | A | P | P-W | P-W |
| Antarctica | Aquaria | Aquar#29_JW_no_treatment | A | B | - | - | - |
| Antarctica | Aquaria | Aquar#29_JW_no_treatment | A | C | C-1P | - | - |
| Antarctica | Aquaria | Aquar#29_JW_no_treatment | A | D | P, C-1P, E | P-W, C-E-W, C-1P-S | P-W, C-E-W, C-1P-S |
| Antarctica | Aquaria | Aquar#29_JW_no_treatment | A | E | C-1&2P | C-W | C-W |
| Antarctica | Aquaria | Aquar#29_JW_no_treatment | B | A | C-E, C-1P | C-W | C-W |

| Dive Location | Exp Type | ID | ID2 | Location | 3000x | 1500x | 800x |
|---------------|-------------|--------------------------|-----------|----------|-------------|--------------------------------------|---------------------|
| Antarctica | Aquaria | Aquar#29_JW_no_treatment | B | B | - | M | - |
| Antarctica | Aquaria | Aquar#29_JW_no_treatment | B | C | M | - | - |
| Antarctica | Aquaria | Aquar#29_JW_no_treatment | B | D | C-2H, 1P, E | - | C-W |
| Antarctica | Aquaria | Aquar#29_JW_no_treatment | B | E | C-2P,E | C-W | C-W |
| Antarctica | Aquaria | Aquar#29_JW_no_treatment | C | A | - | C-T-L, C-1P-S, P-S, C-E&1-W | - |
| Antarctica | Aquaria | Aquar#29_JW_no_treatment | C | B | C-1P, P | P-S/W, C-1P-W | P-S/W, C-1P-W |
| Antarctica | Aquaria | Aquar#29_JW_no_treatment | C | C | | | |
| Antarctica | Aquaria | Aquar#29_JW_no_treatment | C | D | C-2H &1P | C-W | C-W |
| Antarctica | Aquaria | Aquar#29_JW_no_treatment | C | E | C-2P & 1H | C-2P-W, C-T- W, C-1H-W, C- E-W | - |
| Antarctica | Aquaria | Aquar#29_JW_no_treatment | D | A | - | - | - |
| Antarctica | Aquaria | Aquar#29_JW_no_treatment | D | B | - | P | P-W |
| Antarctica | Aquaria | Aquar#29_JW_no_treatment | D | C | - | - | - |
| Antarctica | Aquaria | Aquar#29_JW_no_treatment | D | D | - | - | - |
| Antarctica | Aquaria | Aquar#29_JW_no_treatment | D | E | C-2P, T | C-W | C-W |
| Jamesway | Hanging Bag | Hanging_bag-#41 | Slanty | A | P | - | - |
| Jamesway | Hanging Bag | Hanging_bag-#41 | Slanty | B | none | - | - |
| Jamesway | Hanging Bag | Hanging_bag-#41 | Slanty | C | - | - | - |
| Jamesway | Hanging Bag | Hanging_bag-#41 | Slanty | D | - | - | - |
| Jamesway | Hanging Bag | Hanging_bag-#41 | Slanty | E | C-E, | C-L | - |
| Jamesway | Hanging Bag | Hanging_bag-#41 | Round Top | A | P, C-D | P-S, C-L, C-E- W | P-S, C-L, C-E- W |
| Jamesway | Hanging Bag | Hanging_bag-#41 | Round Top | B | none | none | P-L |

| Dive Location | Exp Type | ID | ID2 | Location | 3000x | 1500x | 800x |
|---------------|-------------|---------------------|-----------|----------|--------|---------|---------|
| Jamesway | Hanging Bag | Hanging_bag-#41 | Round Top | C | none | - | - |
| Jamesway | Hanging Bag | Hanging_bag-#41 | Round Top | D | P | P-S | P-S |
| Jamesway | Hanging Bag | Hanging_bag-#41 | Round Top | E | - | - | - |
| Jamesway | Hanging Bag | Hanging_bag-#41 | large | A | P, C-E | P-W,C-W | P-W,C-W |
| Jamesway | Hanging Bag | Hanging_bag-#41 | large | B | none | - | - |
| Jamesway | Hanging Bag | Hanging_bag-#41 | large | C | C-E | C-W | C-W |
| Jamesway | Hanging Bag | Hanging_bag-#41 | large | D | C-E | C-W | C-W |
| Jamesway | Hanging Bag | Hanging_bag-#41 | large | E | none | - | - |
| Jamesway | Hanging Bag | Hanging_bag-#41 | Medium | A | P | P-S | P-S |
| Jamesway | Hanging Bag | Hanging_bag-#41 | Medium | B | none | none | none |
| Jamesway | Hanging Bag | Hanging_bag-#41 | Medium | C | none | none | none |
| Jamesway | Hanging Bag | Hanging_bag-#41 | Medium | D | P | P-W | P-L |
| Jamesway | Hanging Bag | Hanging_bag-#41 | Medium | E | C-1H | C-S | C-S |
| Jamesway | Hanging Bag | Hanging_36_38_40_41 | 36 | A | P | P-W | P-W |
| Jamesway | Hanging Bag | Hanging_36_38_40_41 | 36 | B | none | - | - |
| Jamesway | Hanging Bag | Hanging_36_38_40_41 | 36 | C | C-E | C-W | C-W |
| Jamesway | Hanging Bag | Hanging_36_38_40_41 | 36 | D | P | P-W | P-W |
| Jamesway | Hanging Bag | Hanging_36_38_40_41 | 36 | E | M | - | - |
| Jamesway | Hanging Bag | Hanging_36_38_40_41 | 38 | A | M | - | - |
| Jamesway | Hanging Bag | Hanging_36_38_40_41 | 38 | B | none | - | - |

| Dive Location | Exp Type | ID | ID2 | Location | 3000x | 1500x | 800x |
|---------------|-------------|---------------------|-----|----------|-------|-------|------|
| Jamesway | Hanging Bag | Hanging_36_38_40_41 | 38 | C | C-E | C-W | - |
| Jamesway | Hanging Bag | Hanging_36_38_40_41 | 38 | D | M | - | - |
| Jamesway | Hanging Bag | Hanging_36_38_40_41 | 38 | E | M | - | - |
| Jamesway | Hanging Bag | Hanging_36_38_40_41 | 40 | A | M | - | P-S |
| Jamesway | Hanging Bag | Hanging_36_38_40_41 | 40 | B | - | - | - |
| Jamesway | Hanging Bag | Hanging_36_38_40_41 | 40 | C | C-E | C-W | C-W |
| Jamesway | Hanging Bag | Hanging_36_38_40_41 | 40 | D | M | - | - |
| Jamesway | Hanging Bag | Hanging_36_38_40_41 | 40 | E | M | - | - |
| Antarctica | Fridge | Untreated #37 | A | A | P, | P-S | - |
| Antarctica | Fridge | Untreated #37 | A | B | none | - | - |
| Antarctica | Fridge | Untreated #37 | A | C | - | - | - |
| Antarctica | Fridge | Untreated #37 | A | D | - | - | - |
| Antarctica | Fridge | Untreated #37 | A | E | - | - | - |
| Antarctica | Fridge | Untreated #37 | B | A | M | - | M-W |
| Antarctica | Fridge | Untreated #37 | B | B | M | - | M-W |
| Antarctica | Fridge | Untreated #37 | B | C | M | - | - |
| Antarctica | Fridge | Untreated #37 | B | D | P | - | P-S |