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Ichthyoliths Across the K-Pg Boundary: Response of Pelagic Consumers to a Mass Extinction

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Project Report

94 large limestone samples (>500g where possible) were collected from across the famous Cretaceous-Paleogene Boundary outcrop located just North of Gubbio, Italy. Samples will be dissolved in weak acid for the extraction of ichthyoliths, the microfossil group that includes fish and shark teeth, scales, and occasionally bone fragments, to assess the ecological response of fish across the boundary, and better understand how the upper trophic levels of the marine ecosystem recovered after the mass extinction. This well-studied outcrop was selected for this project both for its paleogeographic location in the Tethys Sea, and due to the extensive body of prior work, which has given it a well-defined timescale, and includes records of trace elements, stable isotopes, and the traditional microfossil groups, thus providing a more complete ecological backdrop for the study.

Background

The Cretaceous-Paleogene Boundary (KPg or K-T) 65 million years ago is associated with a large impact event, widely linked to a mass extinction on land and in the ocean. open ocean ecosystems suffered profound extinctions, with >90% species losses in calcareous primary producers (nannoplankton) and consumers (foraminifera) and a nearly complete extinction of large pelagic predators such as ammonites and ichthyosaurs (D'Hondt 2005; Coxall et al. 2006; Schulte et al. 2010). Friedman (2009) conducted a study on well-preserved body fossils of large fish, and found that among the predatory fish, there was a selective extinction, with large and fast-jawed fishes faring worse than their smaller-jawed counterparts. However this study was conducted on only a handful of known full-body fossils of larger predatory fish, the upper trophic level, while most fish diversity and biomass resides in the smaller, more abundant species of lower trophic level. These small, open-ocean fish do not often fossilize under similar well-preserved conditions leaving a missing link in the understanding of past open ocean ecosystems, between the zooplankton and large predatory fish. It has generally been assumed that this middle trophic level collapsed at the KPg Extinction as well, due to the major upheaval and changes in the lower trophic levels, which are thought to have caused a bottom-up trophic cascade.

Despite lacking in well-preserved body fossils, small pelagic fish have an excellent, but almost entirely unexploited fossil record in the form of ichthyoliths: fish teeth, shark dermal denticles, and other bone fragments preserved in pelagic sediments (Doyle et al. 1974). The ichthyoliths in pelagic sediments are typically <150 μm, and likely representatives of precisely the small, open ocean taxa that are underrepresented as rare body fossils (Friedman 2009). Ichthyolith morphotypes are highly diverse and have been used for stage-level biostratigraphy in otherwise fossil-poor sediments such as red clays (Doyle et al. 1974, Johns et al 2004). Despite this, virtually no work has been done to actually identify the ichthyoliths taxonomically. I am currently in the beginning stages of a project to help better define modern taxonomic groups of

fish and their tooth morphotypes, which will hopefully shed some light on the ecological aftermath of the extinction.

A previous study I conducted on ichthyoliths across the KPg boundary, used deep-sea sediment samples from Shatsky Rise in the Central Pacific, from Site 1209, an Ocean Drilling Program site with a well-developed and well-studied KPg Boundary section. Using methods pioneered by Doyle et al. (1974, 1977, 1983) we generated a high-resolution (20-60 kyr resolution) record of ichthyoliths across the boundary, from 66 Ma to 61 Ma, spanning the boundary at 65.28 Ma. Prior work on the core suggests a local change in the primary producers and zooplankton communities, similar to other sites from around the world, but surprisingly no major drop in export production. The hypothesis was that the small pelagic fish would likely crash as well, due to the extinctions and changes in the lower trophic levels. However, the work revealed that in the Pacific, the ichthyolith accumulation was constant across the boundary and then increased three-fold within 200 thousand years after the extinction – a significantly shorter timescale than the foraminifera or nannofossils recovered at the same site. These data suggest that at least a few groups of fish must have become abundant in the post-extinction central Pacific, and were not negatively affected by the changes in the lower trophic levels.

There have been two other studies that looked at ichthyoliths across the KPg boundary. Shackleton (1984) conducted a study at DSDP site 527, located on Walvis Ridge in the South Atlantic, and calculated accumulation of fish teeth from the Maastrichtian to the middle Eocene, at 1 million year intervals. He found that there was likely a drop in accumulation of ichthyoliths across the boundary, the low temporal resolution (1 million year intervals, as opposed to 20-60 kyr intervals) suggests that more work is necessary to resolve the fish response to the extinction in the South Atlantic. Winfrey et al. (1987) identified and counted ichthyoliths for biostratigraphy in red clays at DSDP site 596 in the South Pacific. Using sedimentation rate data and the associated age model for site 596 developed by Zhou and Kyte (1992), we were able to calculate ichthyolith accumulation across the boundary. While these samples were also 1-2 million years apart, the data do show an increase in ichthyolith accumulation across the boundary. Data for foraminiferas and nannofossils from several different geographic regions suggest that there was considerable geographic heterogeneity in the extinction pattern and subsequent recovery at lower trophic levels (Hull et al, 2011), and we expect that the response of fish will be similarly heterogeneous. This project is designed to test geographic differences in marine ecosystems following the KPg boundary by studying the fossil record of fish productivity in the Tethyan basin.

Field Work and Collection (APS Funded portion of research)

The field work took place August 1-7, 2012, at the famous KPg Boundary site located just North of Gubbio, Italy, along Highway SS298. (43.36561°N, 012.58261°E). The boundary is exposed along a roadcut, and its geological and historical significance is commemorated by a plaque and small tourist-destination sign, somewhat rusted, but still legible. The outcrop is part of the Scalia Rosa section of the Umbria-Marche Formation, a succession of pink to red-colored chalk and limestone stretching from the end of OAE2 (approximately 93 Ma) through the end-Cretaceous and into the Cenozoic. The outcrop was chosen for this project precisely due to its fame and incredible body of prior work on which to build. It has a well-developed paleomagnetic and biostratagraphic chronology as well as extensive paleontological and geochemical data. In

addition to many trace element and isotope studies, numerous studies on microfossil groups, including foraminifera, radiolarians, and nannofossils have been done at Gubbio, providing an important environmental and lower trophic level backdrop to compare with the ichthyolith record. In fact, the boundary itself is so recessed due to sampling and weathering of the clay layer, that it is instantly recognizable as a deep gap along the outcrop.

Over the course of a week, 94 samples were collected across the boundary at 20 cm resolution from 5 meters below through 11 meters above the base of the boundary layer. Based on prior ichthyolith studies, we estimate that the 500g samples collected (where possible) will contain 400-1000 identifiable ichthyoliths, slightly more than the 300 that is the ballpark for gaining a good diversity estimate of microfossils. In addition to the 20 cm background resolution, samples were collected every 10 cm from 60 cm below the boundary through 2 meters above the boundary, to better resolve the response of the ecosystem in the earliest Paleocene to the mass extinction, in addition to a longer timescale Cretaceous and later Paleocene records. The samples span approximately 750 kyr before the boundary to about 2 million years after, which will establish a baseline Cretaceous ecosystem and its variability for comparison with the Paleocene post-disaster ecosystem.

Samples were packed and shipped using the courier services of Mailboxes, Etc. and FedEx Ground Shipping, which was the most cost-effective and reliable way to get the samples to Scripps Institution of Oceanography for processing.

Sample Processing and future work

While bulk limestone sample collection was relatively fast, processing of ichthyoliths is a complex, multi-step process. The samples will be split, to save a small (20-40 gram) fraction for any additional desired geochemical or micropaleontological studies that the ichthyolith results may inspire. The remaining limestone will be dissolved in weak (5-10%) acetic acid. Because ichthyoliths are calcium phosphate (apatite), while the majority of the rock is limestone (calcium carbonate), the carbonates can be removed by dissolution in relatively weak acid, without causing damage to the teeth. Once dissolved, the remaining non-carbonate material is retained over a 38μm sieve, and the remaining fraction is then massed. If only ichthyoliths remain, they are identified, sorted, and counted. However if there is other insoluble material remaining, the teeth must be removed and re-massed, to get accurate accumulation rates and numbers of ichthyoliths present. Depending on the amount and type of other material, this may be done chemically, using heavy liquid separation (specific gravity 2.7) or immersion in hydrogen peroxide or bleach. Alternatively, if there are few teeth, the material may simply be picked out of the sample, or the teeth may be removed directly. Picking is done using a dissection microscope, using established micropaleontology techniques. The final product will be a record of mass accumulation of ichthyoliths across the boundary at Gubbio, and a biostratagraphic range chart documenting the groups of fish present before and after the extinction. I expect to find that the Italian sections record a major drop in fish productivity (accumulation) as is suggested by Shackleton's 1984 study of the South Atlantic. The similarity between Atlantic/Tethyan basins is hypothesized based on the perceived similarity between the Central and South Pacific records.

Note: Once the ichthyolith data has been obtained for these samples, an amendment to this report will be filed to include the scientific results.