Using the Manicouagan Impact Ejecta to Calibrate the Cyclostratigraphy of the Newark Basin

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Introduction

The Newark Basin, which contains the Triassic-Early Jurassic Newark Supergroup, is one of the best-studied early Mesozoic stratigraphic successions. A high-resolution cyclostratigraphic and magnetostratigraphic framework has been developed for the Newark Basin that encompasses approximately 30 my. When combined with biostratigraphy, this high-resolution record allows for global correlation of the Newark Basin succession with other Mesozoic basins, as well as the marine record. However, the high-resolution framework and the resulting correlations are based upon the assumption that the cyclostratigraphy is periodic and that the periods are known. There are only a few radiometric ages to constrain this cyclostratigraphy, most of which are from sills and basalt flows of the Central Atlantic Magmatic Province (CAMP) that on the basis of biostratigraphy are near the very base of the Jurassic. All other ages are based on extrapolation using the well-developed McLaughlin cycles that are considered to be 404 ky in duration. Our unpublished U-Pb results from stromatolite calcite and phosphate coprolites yield precise ages that support the assumed periodicity of the cycles. However, the occurrence of radiometrically datable syndepositional material in the Newark Basin is barely exploited. The Manicouagan Impact event would have produced a syndepositional horizon that potentially provides an additional test of the age and thus the cycle periods. Large-scale meteorite impacts can generate globally distributed ejecta layers. Modeling of the Manicouagan event, which is one of the 5 largest impact events recorded in the rock record, indicates at least 5 cm of ejecta would have been deposited within the Newark Basin. Ramezani et. al. recently obtained a high precision U-Pb age of 215.5 Ma for the Manicouagan melt sheet, which along with magnetic polarity data that require it occurred during a normal polarity interval, are being used in conjunction with the cyclostratigraphic and magnetostratigraphic framework developed in the Newark Basin to identify the Manicouagan ejecta layer.

Background

Newark Basin

The Newark Super Group is found in a collection of 30 rift basins located along the eastern margin of North America that formed as a result of the break-up of Pangea and the formation of the Atlantic Ocean (Weems and Olsen 1997). One of the largest of these rift basins, the Newark Basin, is located in the northeastern United States and straddles parts of New York, New Jersey, and Pennsylvania, as illustrated in figure 1(Kent, Olsen et al. 1995). The Newark Basin is a half graben that contains several kilometers of sediment that

Figure 1. Location of the Newark Basin. Modified from (USGS: Geology of the New York Region, 2005).

represent a continuous 30 my. record spanning the middle Triassic to early Jurassic periods (Kent, Olsen et al. 1995; Olsen and Kent 1996).

The sediments contained within the Newark basin have been studied in great detail and have been extensively characterized as a result of the Newark Basin Coring Project, a National Science Foundation funded study that produced over 6 km of core providing not only a continuous section but overlapping cores to better constrain the stratigraphic positions (Cornet 1985; Olsen 1986; Fowell and Olsen 1993; Fowell, Cornet et al. 1994; Olsen, Kent et al. 1996; Olsen, Kent et al. 2002) (Newark Basin Coring Project, 2005). These cores reveal repeating cycles of facies changes contained within primarily lacustrine sediments, which correlate with observations made of outcrops throughout the Newark Basin. The cyclicity of these facies changes has been determined to be the result of Milankovitch based orbitally induced climate change, which is primarily expressed in the form of four types of cycles as described in Olsen et al 1996: (1) The Van Houten cycle, (2) the short modulating cycle, (3) the McLaughlin cycle, and (4) the long modulating cycle. Figure 2 illustrates graphically how these 4 cycles nest within one another and correlate with orbital precession and eccentricity models (Olsen, Kent et al. 1996).

In addition to the cyclostratigraphic framework that has been developed for the Newark Basin, a magnetostratigraphic framework has also been assembled from the cores collected through the Newark Basin Coring Project (Kent and Olsen 1999). This magnetostratigraphic framework, when combined with the cyclostratigraphy, provides a high-resolution stratigraphic framework that can be correlated globally (Muttoni, Kent et al. 2001; Muttoni, Kent et al. 2004).

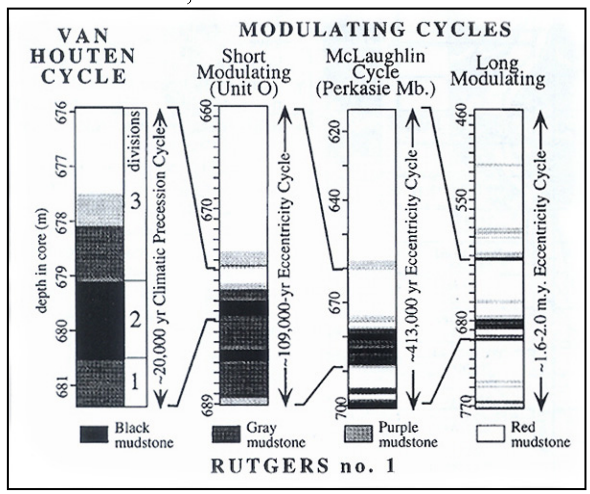


Figure 2. Milankovitch based modulating cycles (Modified from Olsen et. al. 1996).

Manicouagan Crater, Quebec, Canada

At 100 km in diameter, the Manicouagan impact structure, located approximately 200 km north of the St. Lawrence River in east-central Quebec province, is one of the largest known impact craters on Earth (Fig. 3)(Earth Impact Database, 2005). It is located near the Grenville front in the Canadian Shield and straddles the Archean parautochthon and allochthonous material with Paleoproterozoic heritage (Dickin 2000).

Figure 3. Space Shuttle image of the Manicouagan Impact Crater, Quebec Canada (Earth Impact Database, 2005).

The target rock consists of amphibolite facies metagabbros, anorthosite, charnockite, and remnants of Paleozoic limestone (Floran, Grieve et al. 1978; Grieve and Floran 1978). Paleomagnetic analyses of the Manicouagan melt sheet indicated it is of normal polarity and yields poles that are consistent with a Triassic age for the melt (Larochel.A and Currie 1967; Robertson 1967). Unpublished geochemical analyses of the melt sheet yielded a εNd value of –18.

Impact Cratering Process

A review of the meteorite impact process is presented here to illustrate how impact ejecta is formed and distributed. The impact process can be broken down into three stages: contact and compression; excavation; and modification (Melosh 1989). When a meteorite strikes the Earth's surface, the kinetic energy of the meteorite is transmitted to the target rock, generating shock waves on the order of 100's of gigapascals (Melosh 1989). Figure 4 is a schematic depiction of the contact and compression stage of a meteorite impact. The left side of the figure depicts the passage of the shock wave resulting from an impact, while the right side depicts the effect on the target material as the shock pressure is released upon passage of the rarefaction, or release wave. As can be seen on the left side of figure 4, the shock front moves through the target rock, decaying exponentially as it moves out and away from the point of contact. This results in a "shock gradient" that produces a range of shock pressures in the target rock. An "acceleration gradient", which correlates with the shock gradient, occurs as the rarefaction, or release wave follows the shock wave and the target material "unloads" as the excavation stage begins (Simonds, Floran et al. 1978; Melosh 1989). The material closest to the point of impact is vaporized along with most of the projectile. A "melt zone" followed in turn by zones of "shock metamorphism", and

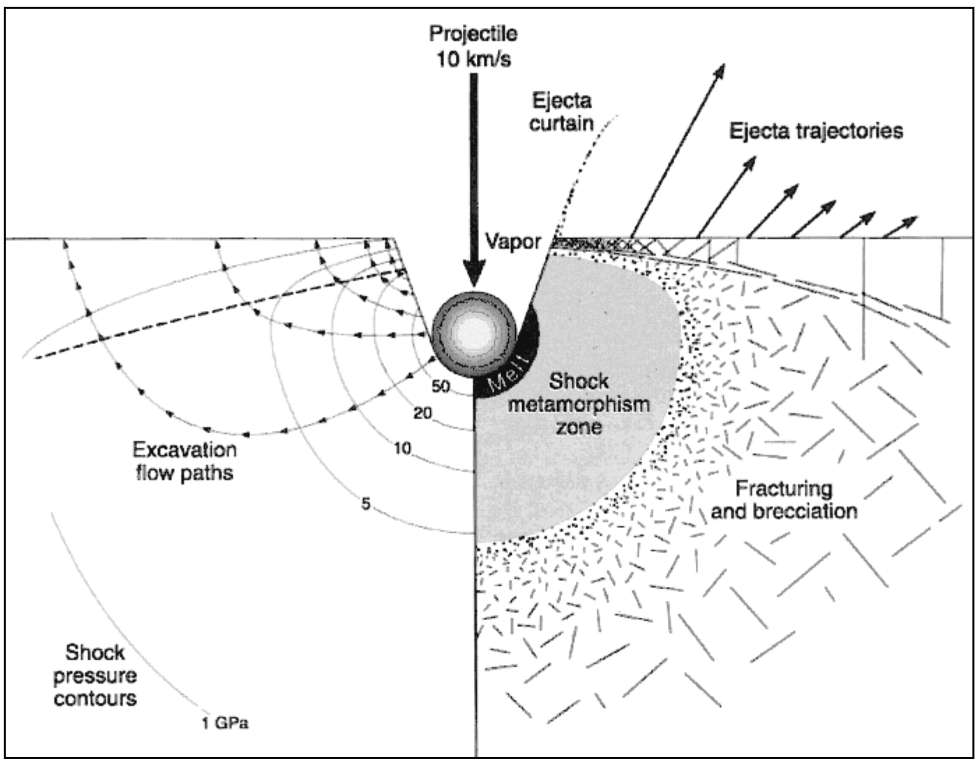
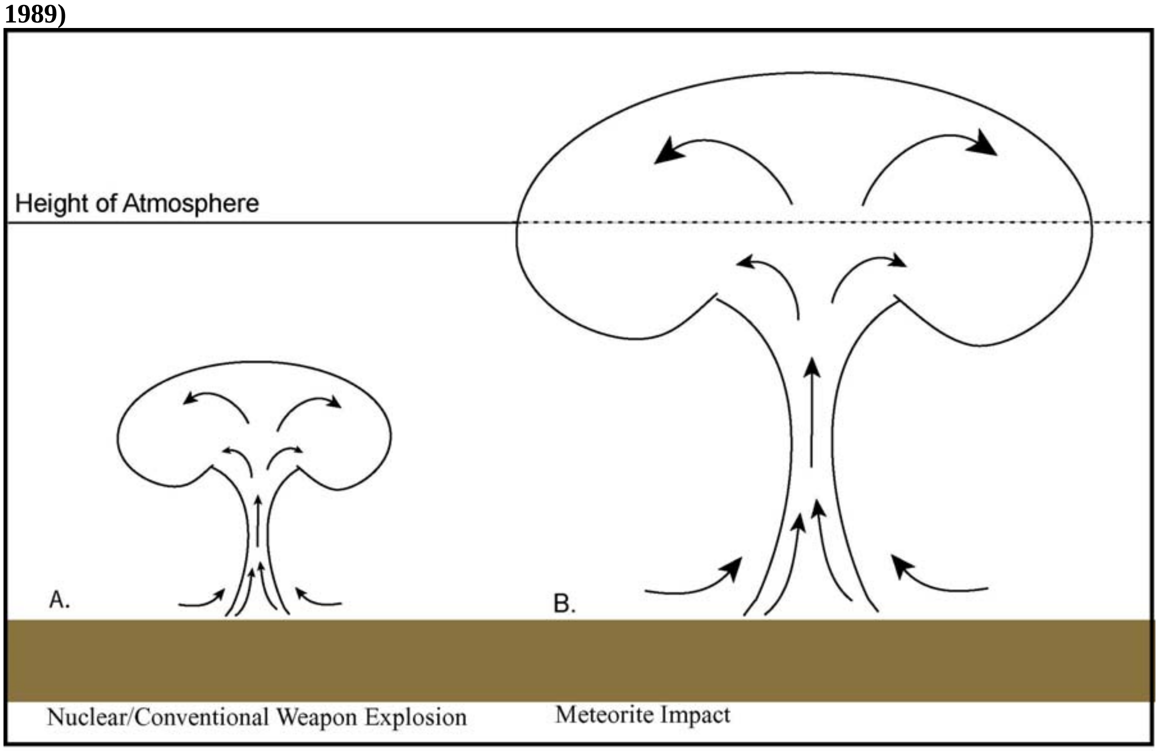


Figure 4. Contact and Compression Stage of a meteorite impact. Adapted from French, 1998.

"fracturing and brecciation" forms around the "vapor" zone. This acceleration gradient produces a process whereby melted material flows down into the transient crater faster than the less shocked material, causing a turbulent flow that thoroughly mixes melted; shock metamorphosed, and unmetamorphosed target material (Simonds, Floran et al. 1978).

For impact events that form craters of ≥ 10 -12 km in diameter, material that is ejected at angles of ≥ 45º is propelled out of the atmosphere and distributed globally (Alvarez, Claeys et al. 1995). Melosh (1989) describes this process as 'atmospheric blowout', which results from the size of the vapor cloud that is generated during a large-scale meteorite impact. In the case of a nuclear, or conventional weapon detonation, a vapor cloud is created that expands and rises up into the atmosphere. As the vapor cloud cools and equilibrates with the surrounding air, it forms into a classical mushroom shape and disperses through the atmosphere. A large meteorite impact, on the other hand, generates a vapor cloud that exceeds the height of the atmosphere, which allows for material entrained in the vapor cloud to be transported above the atmosphere and dispersed around the Earth as the vapor cloud equilibrates with its surroundings. This process is illustrated schematically in figure 5 below.

Figure 5. Vapor Cloud Comparison. Large-scale meteorite impacts create vapor clouds with heights larger than the Earth's atmosphere, allowing for 'atmospheric blowout'. (Modified from Melosh, 1989)



The resulting ejecta layer consists of a range of material due to the grading of shock pressure referred to in figure 4. This "mixed-bag" of material can contain traces of the impactor precipitated from the vapor; high pressure polymorphs of quartz, such as coesite and stishovite; shocked quartz grains with PDFs (Planar Deformation Features); diaplectic glasses, and melt spherules. The distribution of the material entrained by the vapor cloud is affected by several factors, including the Earth's rotation and atmosphere (Alvarez, Claeys et al. 1995; Kring and Durda 2002; Wrobel 2003). Wrobel and Schultz (2003) modeled the Manicouagan impact event taking these various factors into account and have predicted a layer at least 5 cm thick would have been deposited throughout North America.

Searching for the Manicouagan Ejecta Layer

Search Constraints

The key to constraining the search for the Manicouagan ejecta layer within the Newark Basin cores is the high precision $^{206}Pb/^{238}U$ age of 215.5 Ma obtained by Ramezani et. al. (2005). As can be seen in figure 6, this constrains the search for the ejecta layer to the top of the Titusville core and the lower half of the Rutgers core. When combined with the paleomagnetic data (Larochel.A and Currie 1967; Robertson 1967; Kent and Olsen 1999)**, which requires the ejecta to be located in a normal polarity sequence, the search is further constrained to the very top of the Titusville core and the lower quarter of the Rutgers core. This is approximately 900 feet of core to be examined for evidence of an impact ejecta layer.

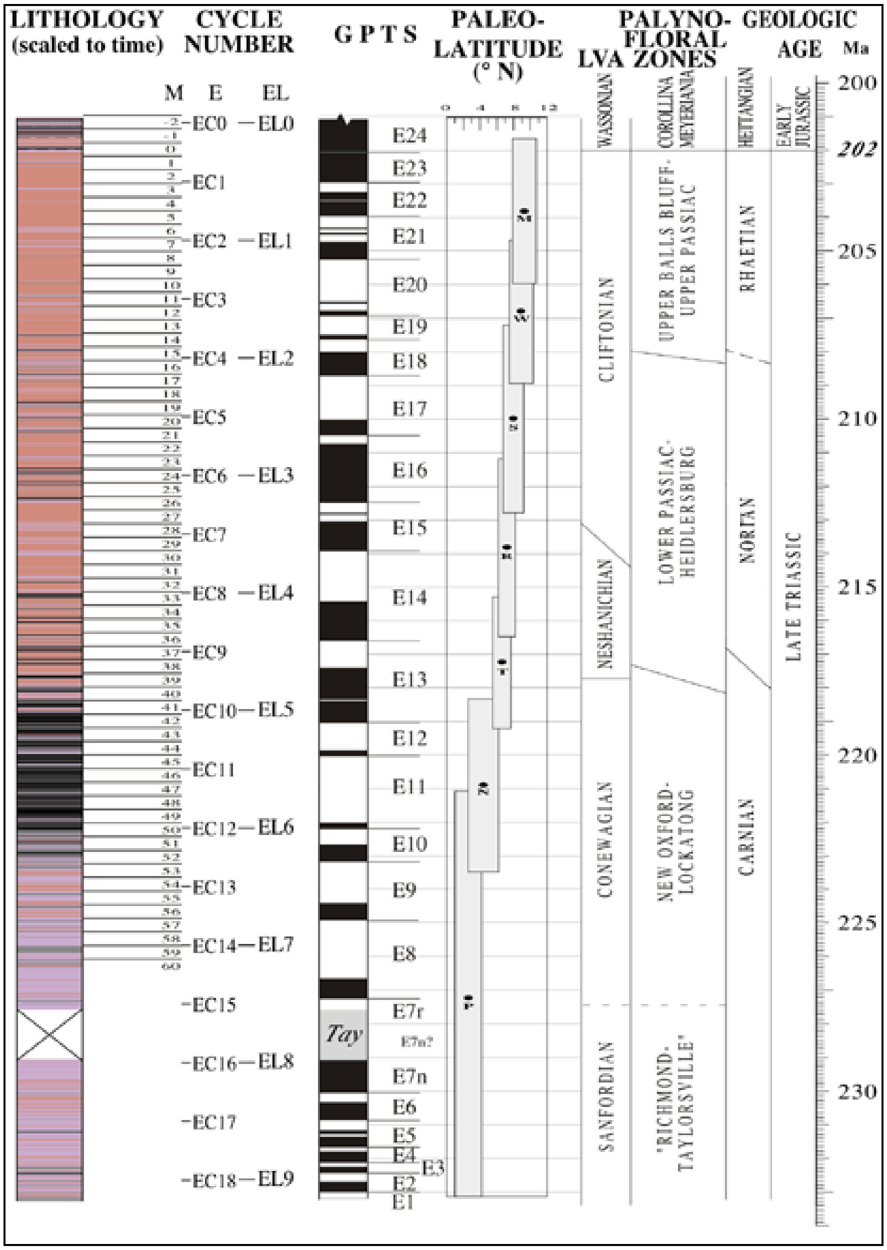


Figure 6. Abridged Triassic-Early Jurassic Timescale. Modified from (Newark Basin Coring Project, 2005).

Identifying Ejecta

The primary criterion for identifying the layer in the core is some type of physical expression that stands out from the background sediments. Although Wrobel and Schultz (2003) predict a minimum of 5 cm of ejecta to occur in the region of the Newark Basin, there currently is no way to predict what the layer will look like. However, the ejecta distribution pattern developed by Wrobel and Schultz (2003) indicates the ejecta layer would be comprised of material that had been subjected to a range of shock pressures, and therefore a range in accelerations. This should produce a layer in the Newark Basin that is comprised of material of varying sizes and shock metamorphic grades that would arrive at different times, similar to distal ejecta from the Chicxulub crater (Alvarez, Claeys et al. 1995). This would likely result in a graded layer, with some material that is readily discernible from the background sediment. Once a section of core has been identified as a possible ejecta layer, thin sections are prepared and examined for petrographic evidence of shock effects, i.e. melt spherules, planar deformation features, shock isotropization, etc. If a layer is identified as being an impact ejecta layer, geochemical analyses will be conducted to determine if the layer can be linked with the Manicouagan crater. The primary method for identifying the source of the ejecta layer would be to determine the εNd value of the layer and compare that with the εNd value for the Manicouagan crater. Unpublished results of Nd analyses of sediments from the Hartford Basin, which is a Newark Supergroup rift basin located in Connecticut with a provenance similar to that of the Newark Basin, yielded εNd values in the range of –10 to –8. Since the Manicouagan melt sheet yields an εNd value of –18, there should be an easily discernible signal within the Newark Basin cores.

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