PETROGRAPHY, TRACE ELEMENT MAPPING AND U-Pb SYSTEMATICS IN TRIASSIC TUFA CALCITE OF THE NEWARK BASIN

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Introduction

One of the greatest problems in geology is time resolution. There is a growing list of authigenic sedimentary minerals that have favorable U/Pb ratios and robust U-Pb systematics, which show great potential for dating the sedimentary rock record. Research in the Isotope Lab of the Department of Geosciences at Stony Brook shows that it is possible to date some sedimentary carbonates with a precision of one percent or better (Rasbury et al., 1997; Rasbury et al., 1998; Wang et al., 1998; Becker et al., 2002). When the authigenic minerals can be placed in a relative time framework, the ages may also accurately date the geologic event they represent. We have focused on carbonates that form during deposition or very shortly following deposition whose ages should reflect the time of sedimentation. Here we present results from tufa calcite from the Passaic Formation of the Newark Basin. These tufas are stromatolitic coatings of carbonate on branches and are interpreted to reflect the transgression of the lake as the vegetation was drowned (DeWet et al., 2002). The tufa sample gives an age of 208.5 ± 2.1 Ma (2 sigma), quite consistent with the estimate that this interval is approximately 212 Ma based on extrapolation from a dated horizon using cycles and magnetostratigraphy (Kent et al., 1995). Although the tufa shows clear evidence for alteration of the original fabric, U appears to have been immobile during this alteration. Tufas are relatively common at the shorelines of large lakes and our results suggest that calcite formed in these settings has great potential for providing the sorely needed time constraints for terrestrial settings.

Geologic Setting

The Newark Basin of New Jersey and Pennsylvania is one of numerous Triassic-Jurassic rift basins that formed along the eastern margin of North America during the breakup of Pangea. This series of basins records a high-resolution lake record that spans 40 million years and is collectively known as the Newark Supergroup (Olsen, 1986). Ages of zircons

and baddeleyite from the Palisades sill of the Newark Basin and Gettysburg sill of the Gettysburg Basin give ages of 201 ± 1 Ma (Dunning and Hodych, 1990). Where constrained stratigraphically, the basalt flows of the Triassic Basins postdate the Triassic-Jurassic boundary (Olsen, 1986). Although stratigraphic constraints suggest the Orange Mountain Basalt, which lies directly above the Triassic-Jurassic boundary, predates the Palisades sill (Ratcliffe, 1988), the age of the Orange Mountain Basalt is 201 ± 2.1 Ma based on ^{40}Ar-^{39}Ar ages of plagioclase (Hames et al., 2000). There are some problems with lab standardization and some researchers suggest there is as much as a 1-3% discrepancy between U-Pb ages and ^{40}Ar-^{39}Ar ages, with the ^{40}Ar-^{39}Ar ages being too young (e. g. Schmidt and Bowring, 2001). Based on U-Pb zircon ages from ashes in a marine section in British Columbia, Palfy et al. (2000) estimates the age of the Triassic-Jurassic boundary at 199 ± 0.3 Ma. This leads to speculation on the apparent discrepancy between the boundary as it is recognized in the terrestrial sections versus the marine section (Palfy et al., 2000). In the Newark Basin, the Triassic part of the sequence is divided into three formations, from oldest to youngest these are the Stockton, Lockatong and Passaic Formations. Our sample comes from the Metlars Member of the Passaic Formation, which is Norian age (Kent et al., 1995). The tufas are stromatolites that encrusted branches and roots as the lake expanded and drowned the vegetation. These stromatolites were then buried by mud that accumulated in the lake. This was followed by a shallowing (regression) of the lake, representing the end of a lake cycle.
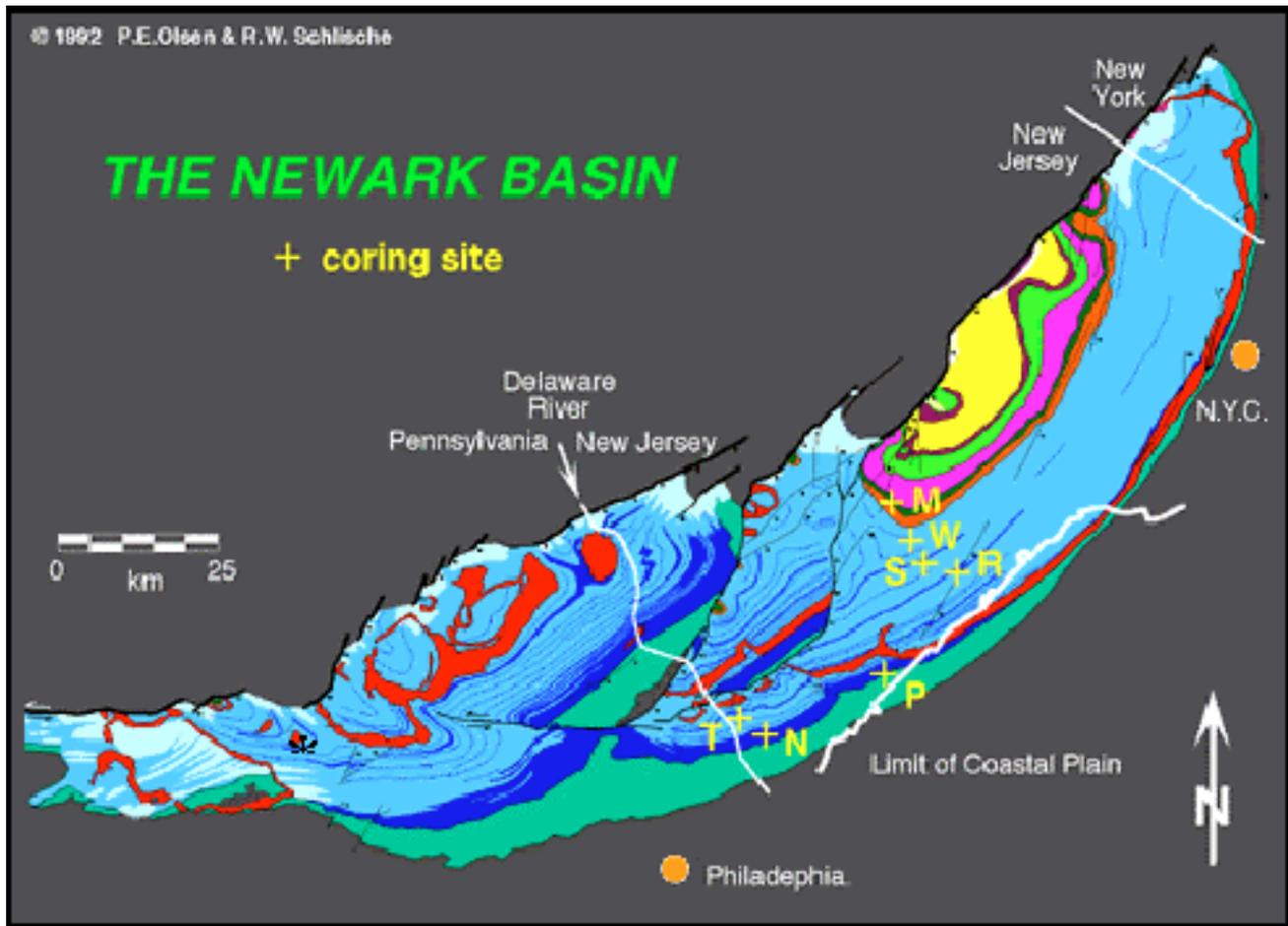
Figure 1: Map of the Newark Basin from the Newark Basin Coring Project headed by Paul Olsen and Dennis Kent (http://www.ldeo.columbia.edu/~polsen/nbcp/nbcp.html). The asterisk marks the approximate location from which the tufa sample was collected.

Petrography

Although elevated uranium is not a requirement for elevated U/Pb ratios, phosphor imaging is an easy test of hand specimens and is fast and inexpensive (Cole et al., 2003). The tufa sample was chosen for this study because of its elevated uranium concentrations based on phosphor imaging (Figure 2). Examination of thin sections shows that the tufa calcite has been recrystallized, however we were optimistic that this alteration did not dramatically move the uranium around because this element shows a clear layering that coincident with growth layers (Figure 2). The core of the tufa sample is composed of sparry calcite with bright luminescence (Figure 3a, 3b). There is a lot of pyrite in this zone. Layer 1 is a non-luminescent micritic layer and pyrite in places separates the core from layer 1 (Figure 4a, 4b). In other areas of layer 1 the micritic calcite is broken by brightly luminescent sparry calcite (Figure 4c, 4d). Layers 2 and 3 have bands of very dark (organic rich?) non-luminescing micritic calcite which is sandwiched between layers of heterogeneously bright-dull luminescent sparry calcite. Taken together, the petrography suggests that the original

layers may have alternated between micritic and something more coarsely crystalline. The micritic layers appear to not have been significantly changed by the fluid that formed the sparry calcite in the core. However, the sparry calcite layers between the micritic layers have been altered because the mosaic calcite is not a typical texture for these types of deposits. Based on similarities in the luminescence between the sparry calcite in the core and within the layered portion of the tufa sample, it appears that the same fluid may have been responsible for both. There is somewhat of a correspondence between the sparry calcite and pyrite. Both the luminescence of the calcite and presence of pyrite suggest reducing conditions during their formation. This observation is consistent with fluids associated with anoxic conditions in the lake being responsible for this alteration. If this is true, the alteration event was less than 20 ky after the formation of the stromatolitic coatings. However, reducing conditions do not rule out a fluid associated with emplacement of the basaltic flows and intrusions at about 201 Ma.
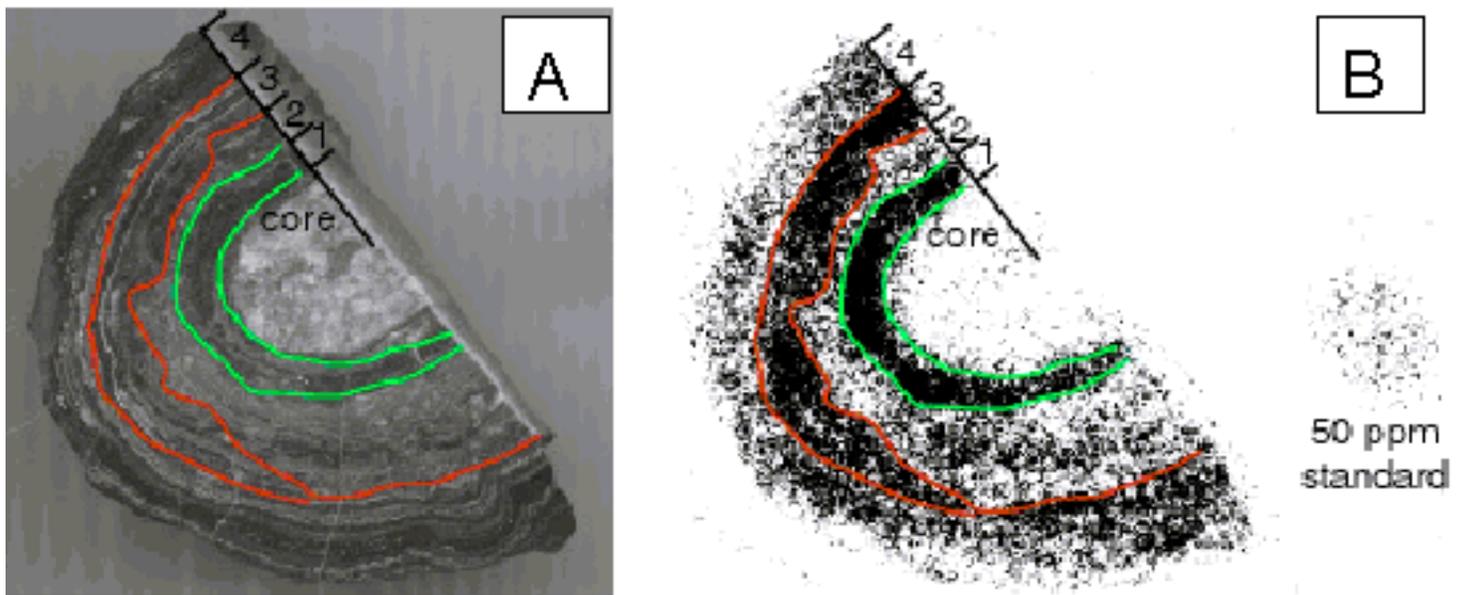
Figure 2: A. Polished slab of tufa calcite. The area with light colored calcite marked "core" was likely originally where a branch provided a nucleous for tufa growth. Layers were added from the core to the outside (1 to 4). B. Phosphor imagine of the polished slab left on the imaging plate for 3 days. Clearly most areas on this sample have more U than the 50 ppm standard.
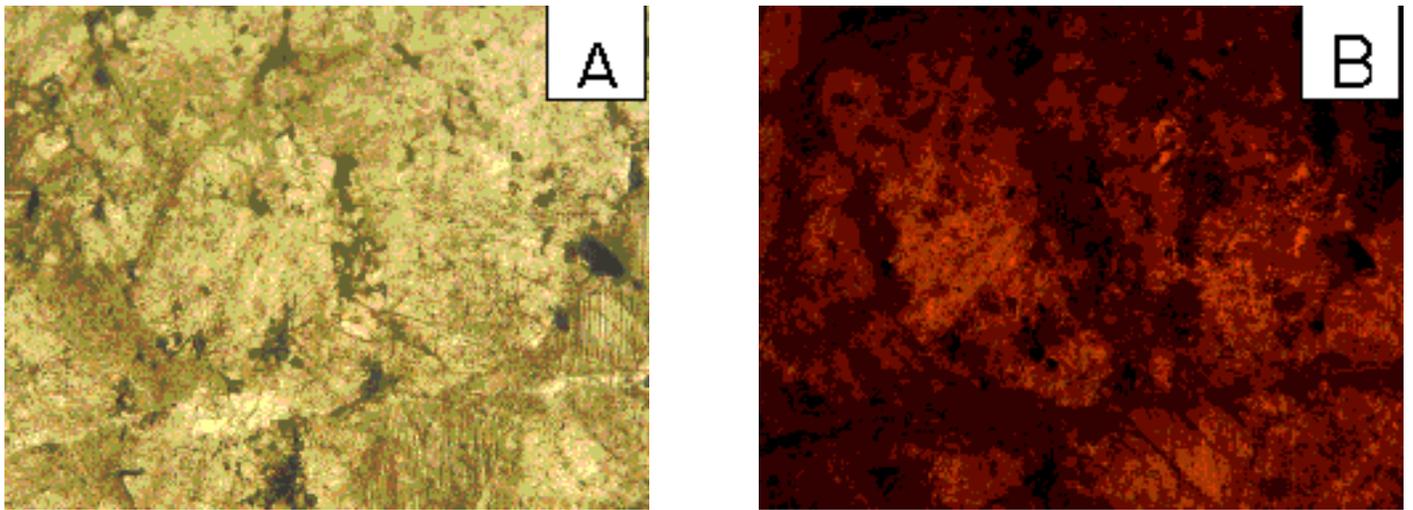
Figure 3: A. Plane light photomicrograph of sparry calcite with associated pyrite (dark areas) that forms the core of the tufa sample of this study (see figure 2). B. CL photomicrograph of the same area as A. The luminescence is somewhat blotchy but generally bright.
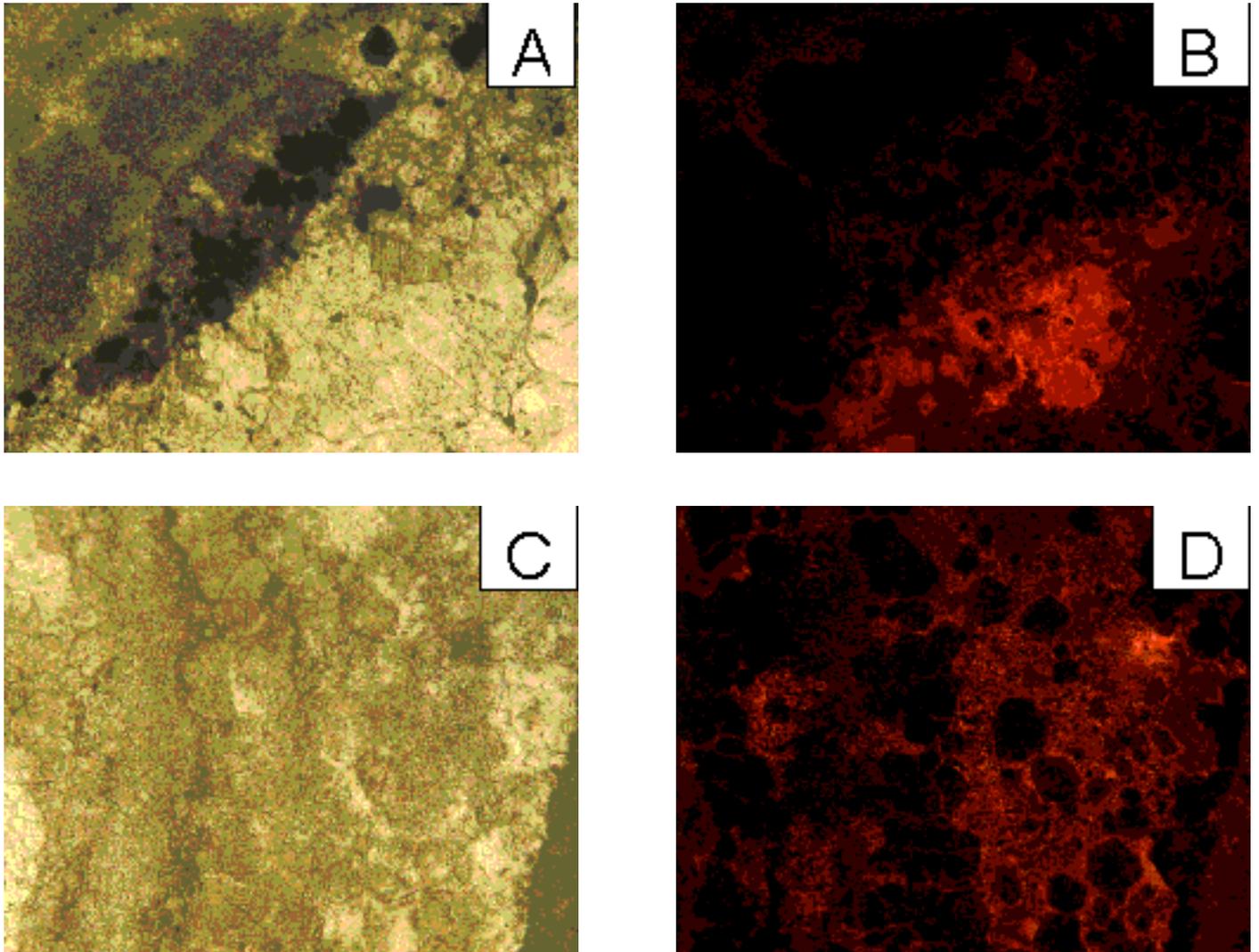
Figure 4: A. Plane light photomicrograph of the boundary between the core (to the right) and layer 1. The dark mineral at the boundary is pyrite. B. CL photomicrograph of the same

area as A. Here you can see the sparry calcite is mostly brightly luminescent while the micrite calcite of layer 1 is non-luminescent. C. Plane light photomicrograph of layer 1 with sparry calcite intergrowths. D. CL photomicrograph of the same area as C. Here the micritic calcite appears to have luminescence but this is likely because the CL is a surface interaction while the plane light photomicrograph represents the entire depth of the thin section. Therefore this is interpreted as non-luminescent micritic calcite intergrown with sparry luminescent calcite that looks very much like the calcite that forms the core of the tufa sample.

U-Pb data

Samples were taken from layers 1, 2, and 3 (Figure 2) for U-Pb analyses. Layer 4 was excluded because it forms the outside of the tufa and might have seen a recent weathering history. Layer 2 was sampled even though the uranium concentrations were not as elevated as the other layers because what is necessary for a precise age is to have enough of a spread in the U/Pb to define the isochron line. Five aliquots give Pb concentrations that range from 15-681 ppm and U concentrations that ranged from 25-42 ppm. Two aliquots from layer 1 had the highest U concentrations, 41.9 and 42.4 ppm, and also had the most favorable $^{238}U/^{204}Pb$ ratios, 94.6 and 204.01. Two aliquots from layer 2 had lower U concentrations, 25.9 and 27.6 and had dramatically different Pb concentrations, 269.7 and 681 ppm, giving a range of $^{238}U/^{204}Pb$, 2.42-6.53. Only one aliquot from layer 3 was a successful run, and it gave a U concentration of 45.7 ppm, a Pb concentration of 266.4 ppm and a $^{238}U/^{204}Pb$ of 11.02. The five aliquots give a Total U-Pb isochron age (Ludwig, 2001) of 208.5 ± 2.1 Ma (2 sigma uncertainty) with a MSWD (Mean Standard Weighted Deviates) of 13 (Figure 5).
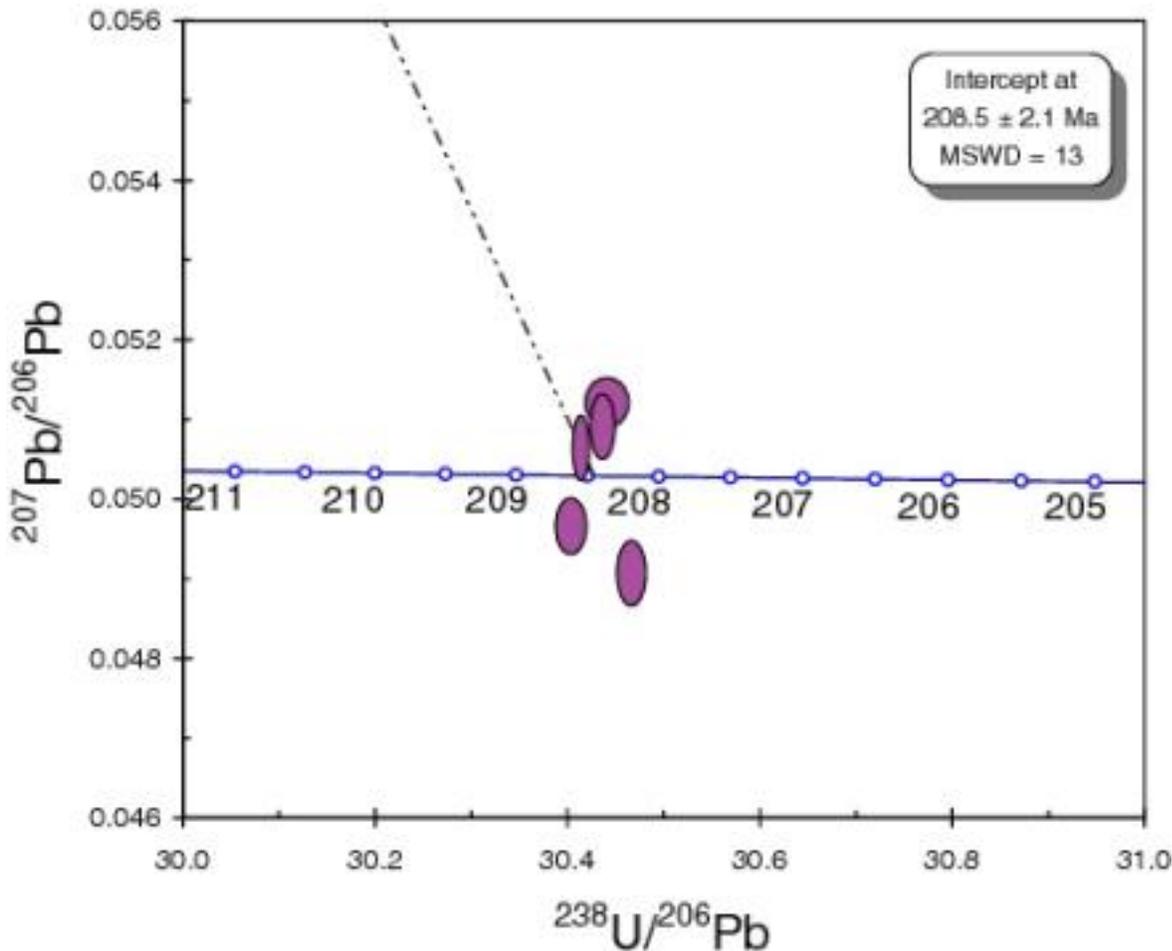
Figure 5: Total U-Pb isochron plot of five aliquots from Triassic tufa. Data were reduced using PbDat (Ludwig, 1993) and Isoplot (Ludwig, 1999).

Discussion

The Newark Supergroup is one of the best-studied sections that includes the Triassic-Jurassic boundary. This terrestrial section represents a high-resolution 40-million-year lake history (Olsen, 1986). The best age constraints for the basins are from sills and basalt flows that are constrained on the basis of biostratigraphy to the lower Jurassic. Based on Ar geochronology (Hames et al., 2000) and on U-Pb zircon and baddelyite analyses (Dunning and Hoydch, 1990;) these flows and sills have been dated at about 201 ± 1 Ma. The age of the boundary should be slightly older than this age. However, Palfy et al. (2000) estimates the Triassic-Jurassic boundary at 199 ± 0.3 Ma on the basis of U-Pb zircon ages from ashes that occur in a marine section in British Columbia. Based on the position of the Metlars Member of the Passaic Formation, Kent et al. (1995) estimate that this section should be about 10 million years older than the boundary. If we consider the ages of the basalts a reasonable estimate of the boundary age this would suggest the Metlars Member should be 211 ± 1 Ma. This result is within uncertainty of the age of the 208.5 ± 2.1 Ma age of the tufa. If the Palfy et al. (2000) age of 199 for the boundary is used, the Metlars Member should be 209 Ma, precisely the age we obtain from the tufa. Pb concentrations in the tufa are appreciably higher than might be expected from lake water. There are two times in the

history of these deposits that Pb addition might have occurred: 1) right after deposition from waters associated the overlying black shale, black shales are commonly metal enriched; 2) in association with the emplacement of the basalts and sills of the lower Jurassic at about 201 Ma. The precision of the age and the fact that it is very similar to the age that would be predicted based on extrapolation leads us to believe that Pb addition was quite early, likely during the same lake cycle.

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