Age and Origin of the Merrimack Terrane, Southeastern New England: A Detrital Zircon U-Pb Geochronology Study

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AGE AND ORIGIN OF THE MERRIMACK TERRANE, SOUTHEASTERN NEW ENGLAND: A DETRITAL ZIRCON U-PB GEOCHRONOLOGY STUDY

by

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ABSTRACT

Metasedimentary rocks of the Merrimack terrane (MT) originated as a thick cover sequence on Ganderia consisting of sandstones, calcareous sandstones, pelitic rocks and turbidites. In order to investigate the age, provenance and stratigraphic order of these rocks and correlations with adjoining terranes, detrital zircon suites from 7 formations across the MT along a NNE-trending transect from east-central Massachusetts to SE New Hampshire were analyzed by U-Pb LA-ICP-MS methods on 90-140 grains per sample. The youngest detrital zircons in the western units, the Worcester, Oakdale and Paxton Formations, are ca. 438 Ma while those in the Kittery, Eliot and Berwick Formations in the northeast are ca. 426 Ma. The Tower Hill Formation previously interpreted to form the easternmost unit of the MT in MA, has a distinctly different zircon distribution with its youngest zircon population in the Cambrian.

All samples except for the Tower Hill Formation have detrital zircon age distributions with significant peaks in the mid-to late Ordovician, similar abundances of early Paleozoic and late Neoproterozoic zircons, significant input from ~1.0 to ~1.8 Ga sources and limited Archean grains.

The similarities in zircon provenance suggest that all units across the terrane, except for the Tower Hill Formation, belong to a single sequence of rocks, with similar sources and with the units in the NE possibly being somewhat younger than those in east-central Massachusetts. The continuous zircon age distributions observed throughout the Mesoproterozoic and late Paleoproterozoic are consistent with an Amazonian source. All samples, except the Tower Hill Formation, show sedimentary input from both Ganderian and Laurentian sources and suggest that Laurentian input increases as the maximum depositional age decreases.

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Chapter 1. Introduction

Definition and Purpose of Problem

The New England Appalachians were formed by several tectonic terranes colliding and accreting to the North American continent throughout the early and middle Paleozoic. The tectonic significance of some of these terranes, such as the largely metasedimentary Merrimack terrane (MT), is poorly understood. The MT is the westernmost of the three terranes that comprise the eastern margin of the Appalachian orogenic belt in southeastern New England (Figure 1.1). It has been called the Merrimack belt (Zen et al., 1983) and the Merrimack synclinorium (Williams, 1978) and has been considered to be the New England portion of the Gander zone (Williams, 1978) or Gander terrane (Williams and Hatcher, 1983).

To better understand the role of the MT in the Appalachian orogeny, four main questions were addressed:

- What is the maximum depositional age of its sediments?
- What are the correlations among units within the MT?
- What are the correlations with adjacent terranes?
- What is the provenance of the MT?

To answer these questions U-Pb LA-ICP-MS age determinations were made on detrital zircons from seven samples across the MT in Massachusetts and southeastern New Hampshire. The seven formations analyzed from NE to SW are the Kittery, Eliot, Berwick, Oakdale, Tower Hill, Worcester, and the Paxton Formation. (Figure 1.1). A majority of these formations had not been previously dated and their ages were based on stratigraphic arguments and cross-cutting relationships with intrusive rocks (Robinson and Goldsmith, 1991) because there is no direct fossil evidence. Only portions of the Berwick and Kittery Formations in Maine have been previously dated (Wintsch et al., 2007). Furthermore, improved dating techniques and re-dating of several cross-cutting plutons have shown that some of the original ages may not be accurate. The current research provides new evidence for ages, correlations and provenance of these seven units and leads to the clarification of the tectonic history of a significant part of the southeastern New England Appalachians.

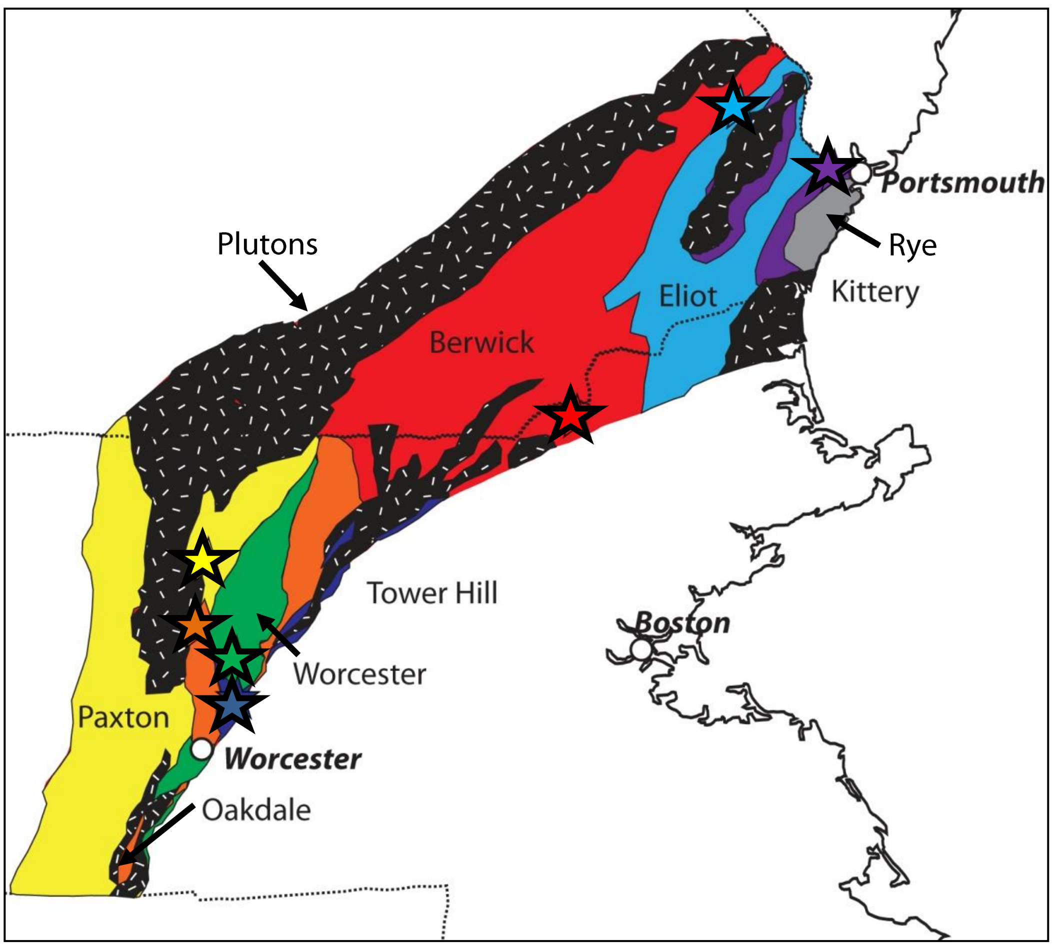

Figure 1.1 General location map of the seven main formations in the MT in New Hampshire and Massachusetts. Sample locations are shown by stars. Modified from Robinson and Goldsmith (1991) and Lyons et al. (1997).

Terranes of New England

Avalon terrane

Avalon is the easternmost terrane in the New England Appalachian belt (Figure 1.2). It is bounded on the west side by the Bloody Bluff fault in eastern Massachusetts and is comprised of Late Proterozoic and Early Paleozoic sedimentary units and Late Proterozoic to Devonian intrusions of granite, gabbro, and diorite. The western portion of the Avalon terrane in Massachusetts is dominated by mid-Paleozoic mafic plutonic rocks (Kohut and Hepburn, 2004) that are weakly metamorphosed and largely unaffected by the Acadian orogeny (Hepburn et al., 1995).

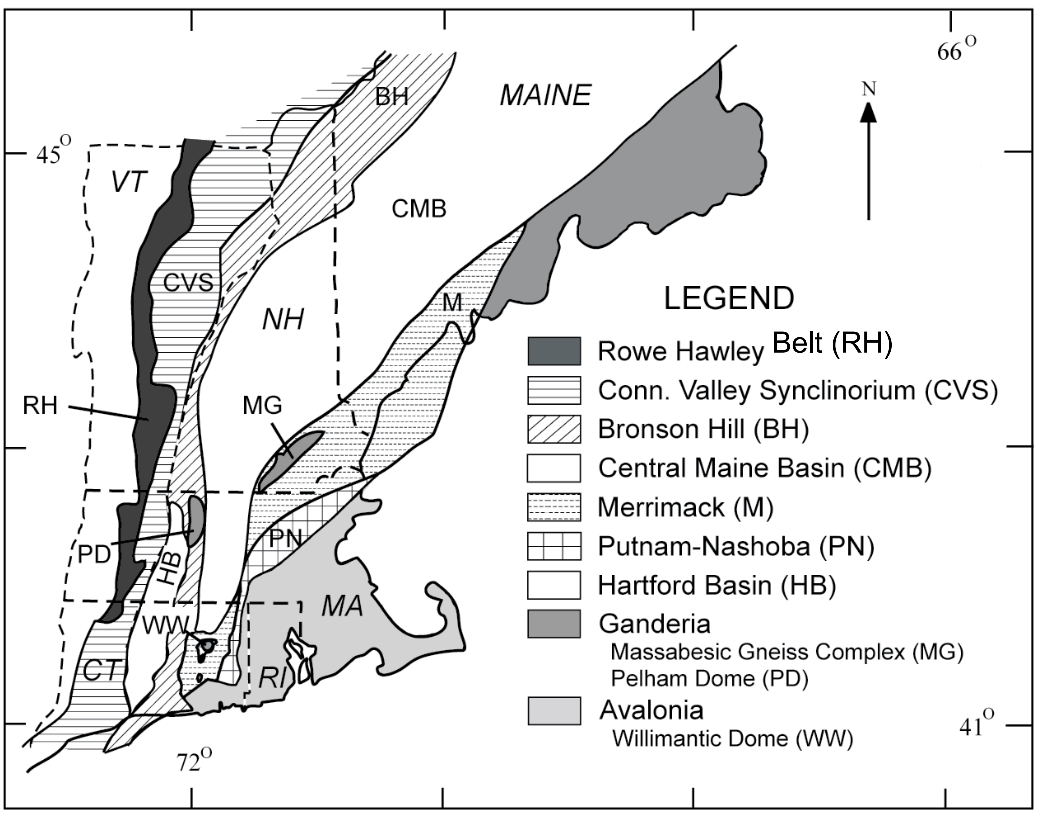

Figure 1.2 Generalized tectonic map of geologic terranes in New England (after Wintsch et al., 1992; Dorais et al., 2009).

The Avalon terrane in New England is correlative with the type area of Avalon in Newfoundland (Skehan and Rast, 1983; Williams and Hatcher, 1983; Rast and Skehan, 1993; Hepburn et al., 1995). It is a peri-Gondwanan terrane that likely formed on juvenile crust around ~1.0-1.3 Ga and accreted to the northern Gondwana margin by ~650 Ma (Nance et al., 2008). Following a long history of magmatism and rifting, the Avalon terrane broke away from Gondwana, traversed the Iapetus Ocean and accreted to the Laurentian margin during the Acadian orogeny (Nance et al., 2009).

Nashoba terrane

The Nashoba terrane is the northern part of the Putnam-Nashoba terrane, and is separated from the Avalon terrane to the east by the Bloody-Bluff fault (Zen et al., 1983; Goldsmith, 1991) (Figure 1.2). It consists of highly metamorphosed and multiply deformed Late Proterozoic to Early Paleozoic volcanic and volcanogenic sedimentary rocks that are cut by abundant younger intermediate composition and granitic plutons (Hepburn et al., 1995). The stratified units typically dip steeply northwest with a majority of the metasedimentary rocks in the western portion of the terrane (Bell and Alvord, 1976; Zen et al., 1983; Hepburn et al., 1995). Recent U-Pb LA-ICP-MS detrital zircon data show that the youngest grains from the metasedimentary units are ca. 450-470 Ma (Loan et al., 2011). These results also showed there was no correlation with the Avalon terrane. The detrital populations resembled those of Ganderia, suggesting a similar source as Ganderia, or that the detritus was derived from Ganderia (Loan et al., 2011).

Merrimack terrane

The MT trends NNE from south-central Connecticut through central and northeast Massachusetts and continues along the New Hampshire and Maine coastlines (Figures 1.1 and 1.2). The boundary between the MT and the Nashoba terrane to its east is the Clinton-Newbury fault. The boundary between the MT and the Central Maine terrane to the west is less well-defined, possibly by a ductile shear boundary (Watts et al., 2000; Wintsch et al., 2007; Hussey et al., 2010). In general, the eastern portion of the MT consists of stratified rocks that include a thick sequence of metamorphosed calcareous turbidites, metasandstones and metapelites (Zen et al., 1983; Robinson and Goldsmith, 1991; Hussey and Bothner, 1995). The general consensus among workers in the region is that the MT is largely composed of Ordovician and Silurian rocks (Lyons et al., 1997; Hussey et al., 2010) and has a metamorphic grade that increases from greenschist facies in the east to amphibolite facies in the west (Lyons et al., 1997; Watts et al., 2000). In the eastern portion of the MT, just west of the Clinton-Newbury fault, there is a series of granitic and dioritic Silurian to Early Devonian plutons (Zen et al., 1983; Robinson and Goldsmith, 1991; Zartman and Marvin, 1991; Lyons et al., 1997; Watts el al., 2000; Hon et al., 2007).

Central Maine terrane

The Central Maine terrane extends northerly from Connecticut to New Brunswick (Figure 1.2) and is composed of Silurian and Devonian metasedimentary cover rocks (Lyons et al., 1997; Bradley et al., 1998; Robinson et al., 1998). The Silurian cover rocks are considered to be an eastward thickening sequence of deep water turbidites that were deposited in either: (1) a passive margin basin (Moench and Pankiwskyj, 1988; Robinson et al., 1998), or (2) a forearc basin associated with a northwest dipping subduction complex (Hanson and Bradley, 1989; Eusden et al., 1996a; Bradley et al., 1998). The Devonian components are dominated by westerly thickening metaturbidites that reflect the advancing Acadian orogenic front (Hanson and Bradley, 1989; Bradley et al., 1998).

Bronson Hill Arc

The Bronson Hill Arc (Figure 1.2) consists of a belt of gneiss domes containing a wide range of metamorphosed plutonic, volcanic, and sedimentary rocks of Precambrian to Devonian in age (Robinson et al., 1998; Hollocher et al., 2002). Tucker and Robinson (1990) dated the Bronson Hill Arc in Massachusetts and New Hampshire using U-Pb zircon and report ages ranging 442-454 Ma. Originally this arc was thought to be the cause of the Taconic Orogeny, but the ages of Tucker and Robinson (1990) indicate that the Bronson Hill Arc is too young for this since the Taconic orogeny begun by 470 Ma (Karabinos et al., 1998, van Staal et al., 2009).

Connecticut Valley Synclinorium or trough

The Connecticut Valley Synclinorium (or trough) is located between the Bronson Hill Arc and the Shelburne Falls Arc in New England and is thought to converge with the Central Maine terrane in northern New England and New Brunswick (Hueber et al., 1990; Karabinos et al., 1998; Rankin et al., 2007; McWilliams et al., 2010). It is composed of mainly Silurian to early Devonian metasedimentary and metavolcanic rocks with many metasediments being turbiditic or calcareous turbidites (Karabinos et al., 1998; Rankin et al., 2007). McWilliams et al. (2010) dated detrital zircons from formations within the Connecticut Valley Synclinorium in Vermont using U-Pb SHRIMP analysis and found youngest ages of ~409-415 Ma.

Shelburne Falls Arc

The Shelburne Falls Arc is separated from the Bronson Hill Arc in the north by the Connecticut Valley Gaspé Synclinorium or trough and in the south by a Mesozoic rift basin, which makes the boundary between the two difficult to interpret (Karabinos et al., 1998; Rankin et al., 2007). It is composed of schist, granofels, serpentinite, amphibolite, quartzite, and gneiss (Zen at al., 1983). Karabinos et al. (1998) used U-Pb dates on zircons and geochemistry to determine that the Shelburne Falls Arc formed between 470 and 485 Ma, thus making its accretion to the Laurentian margin the most likely cause of the Taconic orogeny (Karabinos et al., 1998; Karabinos and Hepburn, 2001).

Summary of orogenic events in Northern Appalachians

Regional Geology

The orogenic events that formed the Appalachian mountain chain represent a complete Wilson cycle that began with the break-up of Rodinia in the Neoproterozoic (Cawood and Nemchin, 2001). This occurred with the separation of Laurentia, Baltica, and Gondwana (Murphy et al., 2010) and led to the formation of the Iapetus Ocean. During the Late Cambrian-Early Ordovician the Iapetus Ocean began to close and the Rheic Ocean started to develop. This resulted when several peri-Gondwanan terranes that had formed on the edges of Amazonia and West Africa drifted northward away from the Gondwanan margin and towards Laurentia (van Staal et al., 2009; Murphy et al., 2010). A succession of orogenic events occurred as several peri-Laurentian and peri-Gondwanan terranes collided with the Laurentian margin. In order of occurrence the orogenic events are: the Taconic orogeny, Salinic orogeny and Acadian orogeny (van Staal et al., 2009).

Taconic orogeny

The Taconic orogeny is defined by van Staal et al.(2007) as all orogenic events that occurred in the peri-Laurentian realm between the Late Cambrian and the Late Ordovician (450-495 Ma) and involved the accretion of peri-Laurentian terranes and the leading edge of Ganderia, largely volcanic arcs, to the Laurentian margin (e.g., Shelburne Falls Arc).

During the Cambrian to Early Ordovician, a spreading center developed within the micro-continent Ganderia splitting it into an active leading edge, the Penobscot Arc (495-515 Ma) and a passive trailing margin (van Staal et al., 2011). By ~480-485 Ma, the two halves of Ganderia came back together resulting in local orogenesis, uplift and erosion known as the Penobscot orogeny (Zagorevski et al., 2010; van Staal et al., 2011). Following this a new arc, the Popelogan-Victoria Arc developed on the remnants of the older and now extinct Penobscot Arc along the leading edge of Ganderia (van Staal et al., 2011). The end of the Taconic orogeny was marked by the collision of the leading edge of Ganderia (Popelogan-Victoria Arc) and the Laurentian margin at ~450-460 Ma (van Staal et al., 2009).

Prior to accretion, the Popelogan-Victoria Arc was extensional in nature and rifting within it during the early Ordovician (~475 Ma) led to multiple pulses of sea-floor spreading. Spreading lasted ~10-15 Ma and was responsible for the formation of the Tetagouche-Exploits back-arc basin, an oceanic basin on the order of 1000-1500 km wide (Figure 1.3) (van Staal et al., 2009).

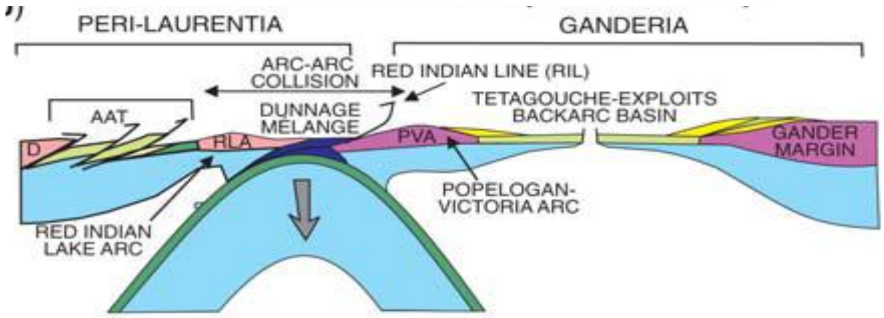

Figure 1.3 Late Ordovician Taconic arc–arc collision in Newfoundland and New Brunswick, the accretion of the Popelogan–Victoria Arc and the formation of the Tetagouche-Exploits backarc basin. Figure from van Staal et al. (2009).

Salinic Orogeny

The Salinic orogeny occurred at ~420-440 Ma (van Staal et al., 2009). It resulted from the collision of the passive Gander trailing margin and the now expanded Laurentian margin with the Popelogan-Victoria Arc on Ganderian basement on its leading edge (van Staal et al., 2011). This closed the Tetagouche-Exploits back-arc basin, (Figure 1.4) (van Staal et al., 2009; 2011) and led to arc-like mafic and felsic plutonism. Chemical signatures of the plutonism suggests magmatism in a subduction environment (Whalen et al., 2006; van Staal et al., 2009). The Dog Bay Line in Newfoundland represents the suture between Ganderia and Laurentia. On the east side of the Dog Bay line, Lower Silurian marine foreland sedimentary rocks were deposited (on Ganderia) and rocks typical of being deposited in an arc-trench gap lay to the west of this line (on Laurentia) (van Staal et al., 2009). Although this line is clear in Newfoundland it is less obvious to the south with no known correlatives in southern New England (van Staal et al., 2009).

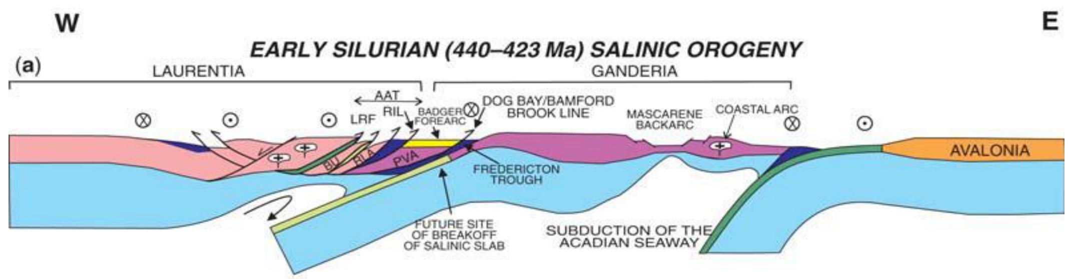

Figure 1.4 Reconstruction of the Salinic Orogeny showing the closure of the Tetagouche-Exploits backarc basin and the collision of the Laurentian margin with the passive trailing edge of Ganderia. Figure from van Staal et al., 2009.

Acadian Orogeny

The Acadian orogeny occurred during the Late Silurian to Early/Middle Devonian (~421-400 Ma) as a result of the micro-continent Avalonia colliding with and being subducted beneath Ganderia's trailing edge (now the Laurentian margin) (van Staal et al., 2011). Silurian arc and backarc magmatism occurred on the Ganderian margin at ~443-423 Ma from the subduction of the Acadian seaway located between Avalonia and the trailing edge of Ganderia. Evidence of this arc magmatism can be seen from Newfoundland to New England as the Coastal Volcanic belt in Maine and Massachusetts (Cumming, 1967; Hay, 1967; Ruitenberg, 1968; van Wagoner et al., 2002; van Staal et al., 2009).

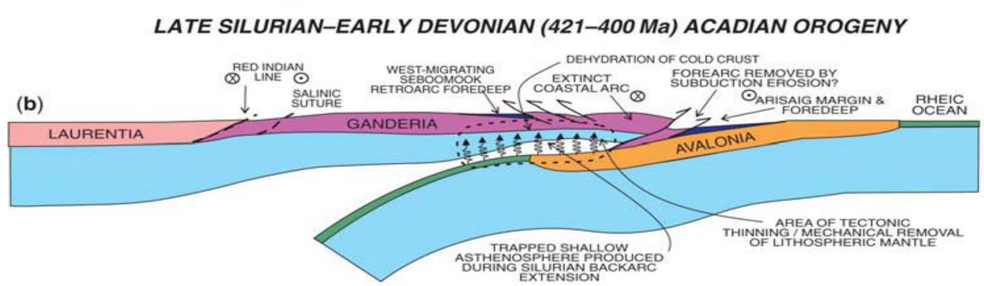

Figure 1.5 Reconstruction of the Acadian Orogeny and the closure of the Acadian seaway between Ganderia and Avalonia. Figure from van Staal et al. (2009).

Chapter 2. Geology of the Merrimack terrane

With no direct fossil evidence, ages, correlations and stratigraphic order of metasedimentary units in the MT are uncertain. Robinson and Goldsmith (1991) defined it as "the belt of Upper Ordovician, Silurian, Lower Devonian, and local Pennsylvanian strata east of the easternmost exposures of Lower Silurian Clough Quartzite and west of the Clinton-Newbury fault." This definition highlights the wide range of ages the MT has been assigned in the literature (e.g. Carboniferous to Late Proterozoic). The MT consists of both high grade (sillimanite or higher in the west) and low grade (garnet grade or lower in the east) metamorphosed and multiply deformed sedimentary rocks that are cut by abundant plutons of intermediate to felsic composition. It is believed the MT has experienced four folding and faulting events and one faulting event after metamorphism (Robinson and Goldsmith, 1991) making correlations and stratigraphic order difficult to interpret.

The stratigraphic order in the northeastern portion of the MT has especially been debated. In New Hampshire and Maine the Kittery, Eliot, and Berwick Formations comprise a thick sequence of calcareous turbidites known as the Merrimack group (Hitchcock, 1877; Billings, 1956; Fargo and Bothner, 1995). Recent work suggests only the Kittery and Eliot Formations compose the Merrimack group with the Kittery Formation lying conformably above the Eliot Formation (Hussey et al., 2010). Freedman (1950) and Billings (1956) included the Berwick Formation within the Merrimack group as the youngest member, which was also suggested by Zen et al. (1983) and Robinson and Goldsmith (1991) for the Massachusetts portion. Lyons et al. (1997) reversed this order making the Kittery Formation the youngest unit and the Berwick Formation the oldest based on map-scale fold patterns and plunge direction within these formations (Hussey et al., 2010).

Rock descriptions and mineralogies from the literature and past mapping will be used to help describe the formations in detail in this section. Descriptions and mineralogies of the specific outcrops used for each sample analyzed are given in Chapter 5.

Formations within the Merrimack terrane

Kittery Formation

The Kittery Formation is located in southeast Maine and New Hampshire and a small portion is located in northeastern Massachusetts (Figure 2.1). The type locality of the Kittery Formation, named by Katz (1917), is in Kittery, ME, along the Piscataqua River (Fargo and Bothner, 1995). It is a thin to thick bedded sequence of feldspathic and calcareous, ankeritic metaturbidites (Bothner and Hussey, 1999). More specifically the Kittery Formation contains gray to greenish-gray feldspathic, calcareous, biotitic metasiltstone, biotite phyllite and schist, calc-silicate gneiss, and minor fine-grained quartzite and feldspathic quartzite. The quartzites are commonly fine-grained, thinly bedded to laminated rocks with thicker beds with cross lamination (Robinson and Goldsmith, 1991). Several paleocurrent indicators in the Kittery Formation suggest a source to the southeast (Rickerich, 1983; 1984; Hussey et al., 1984). Robinson (1979) and Zen et al. (1983) considered the Worcester Formation to be the southern equivalent of the Kittery Formation based on similar lithologies and structural position. The Kittery Formation is assigned an Early Silurian age (Hussey et al., 2010; this study), but it has been called Ordovician or older in the past based on U-Pb ages of cross-cutting plutons

(Zartman and Naylor, 1984). As mentioned above, the stratigraphic position of the Kittery Formation has been contested. The most recent literature suggests it lies conformably above the Eliot Formation (Hussey et al., 2010).

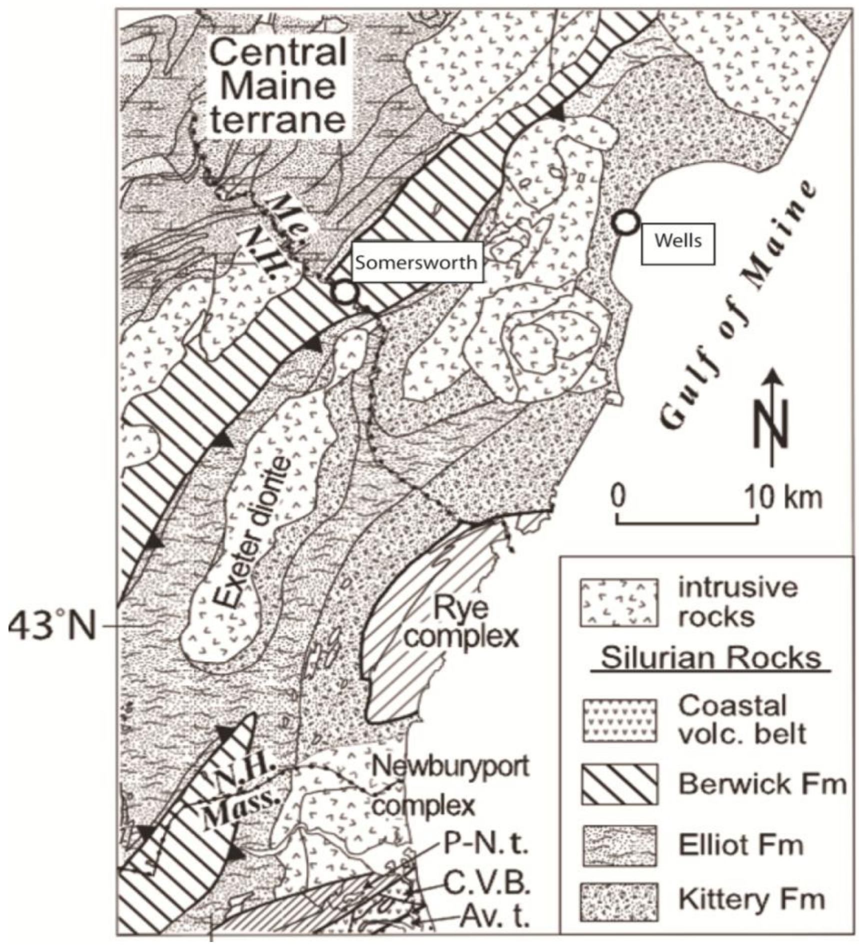

Figure 2.1 Geologic map of coastal northern Massachusetts, New Hampshire and Maine (P-N.t.-Putnam-Nashoba terrane, C.V.B–Coastal volcanic belt, Av.t.–Avalon terrane) (From Wintsch et al., 2007 adapted after Lyons et al., 1997; Bothner et al., 2004).

Eliot Formation

The Eliot Formation is located in southeast Maine and New Hampshire and extends into northeastern Massachusetts (Figures 1.1 and 2.1). The “type-section” of the

Eliot Formation is located at Lee Five Corners (Hussey, 1985), Lee, NH at the intersections of Route 155 and Route 4 (Fargo and Bothner, 1995). The Eliot Formation is composed of gray to green phyllite, calcareous feldspathic quartzite, quartz-mica schist, and well-bedded calc-silicate (Lyons et al., 1997) and contains metasiltstone sequences (Robinson and Goldsmith, 1991). The Eliot Formation has been correlated with the Macworth Formation (now abandoned) of the Casco Bay Group in ME, and, if correct, the age of the Eliot Formation falls along the Silurian/Ordovician boundary (Hussey et al., 2010). Much like the Kittery Formation, it has been assigned an Ordovician or older age in the past based on U-Pb ages of cross-cutting plutons (Zartman and Naylor, 1984).

Berwick Formation

The Berwick Formation lies west of the Clinton-Newbury fault and is located in northern Massachusetts and southern New Hampshire (Figures 1.1 and 2.1). It was originally named the "Berwick Gneiss" by Katz (1917) and its type locality is in Berwick, ME (Fargo and Bothner, 1995; Hussey et al., 2010). It is composed primarily of thin to thick tabular and lenticular beds of calcareous metasiltstone, biotitic metasiltstone, purplish biotite-quartz- feldspar granofels, and fine-grained metasandstone (Robinson and Goldsmith, 1991; Fargo and Bothner, 1995). Some layers contain quartz, biotite, and actinolite where it has been metamorphosed to the greenschist facies. At higher metamorphic grade diopside, hornblende, and plagioclase are common (Robinson and Goldsmith, 1991). Most of the Berwick Formation is in the garnet zone, although areas in the sillimanite zone are present (Robinson and Goldsmith, 1991). The Berwick Formation has been correlated with the Eliot Formation, but due to an increase in the grade of metamorphism in the Berwick Formation, they have been considered to be two separate formations (Billings, 1956). The Berwick Formation has been correlated with the Oakdale and Paxton Formations in Massachusetts (Smith and Barosh, 1981) and also with the Vassalboro Formation of the Central Maine terrane based on stratigraphic correlations and recent detrital zircon age work (Wintsch et al., 2007). Based on the age of the youngest detrital zircon as analyzed by Wintsch et al. (2007), the Berwick Formation is considered to be Late Silurian in age, which is similar to the age assignment by Zen et al. (1983).

Oakdale Formation

The Oakdale Formation trends north-south in central Massachusetts and lies west of the Clinton-Newbury fault. It extends from Pepperell, MA to the border of Massachusetts and Connecticut (Figure 1.2). It was originally named by Emerson (1917) the Oakdale Quartzite for the village of Oakdale, in West Boylston, MA (Robinson and Goldsmith, 1991). The Oakdale Formation is composed of interlayered brownish gray to light-gray ankeritic metasiltstone, green-gray to purplish-gray impure quartzite, muscovite schist, and greenish-gray, gray, and dark-brown calcareous phyllite (Hepburn, 1976; Zen et al., 1983; and Robinson and Goldsmith, 1991). The Oakdale Formation has been correlated with higher grade portions of the Berwick Formation in New Hampshire and has been considered to be the low grade equivalent of the Paxton Formation (Zen et al., 1983; Pease, 1989). Based on mapping and cross-cutting dated intrusions, it has a Silurian age (Robinson and Goldsmith, 1991). The Worcester Formation is interpreted as overlying the Oakdale Formation, which in turn overlies the Tower Hill and Vaughn Hill Formations (Zen et al., 1983).

Tower Hill Formation

The Tower Hill Formation is located in east-central Massachusetts along the Clinton-Newbury fault from Worcester through Harvard, MA in small outcrops in fault contact with the Oakdale Formation and the Ayer granite (Zen et al., 1983). Its type locality is located on Main Street in Boylston, MA (Figure 2.2). Grew (1970) first named the "Tower Hill Quartzite" as a member of the Boylston Formation. The Tower Hill Formation is light gray to buff in color and consists of a massive orthoquartzite with beds of dark gray phyllite or mica-schist with the presence of biotite and garnet porphyroblasts (Hepburn, 1976). The overall thickness of the Tower Hill Formation ranges from 0 to 91 meters (Peck, 1976) and has sequences of the phyllite reaching 65 meters in thickness (Robinson and Goldsmith, 1991). The Tower Hill Formation has been correlated with the Vaughn Hill Quartzite based on lithological similarities. However, these two formations never meet and extensive faulting within the outcrop areas makes this correlation unclear (Robinson and Goldsmith, 1991). The Tower Hill Formation is interpreted as Silurian in age and has been mapped as overlying the Boylston Schist and underlying the Oakdale Formation (Robinson and Goldsmith, 1991).

Worcester Formation

The Worcester Formation is located in east-central Massachusetts, west of the Clinton-Newbury fault and Oakdale Formation and extends from Pepperell, MA to slightly south of Auburn, MA (Figures 1.1, 2.2). It is named after Emerson's (1889) Worcester Phyllite from the type locality in Worcester, MA. Portions originally mapped as the Worcester Phyllite (Perry and Emerson, 1903; Emerson, 1917) were later determined to be Pennsylvanian in age and were reassigned to the Coal Mine Brook Formation (Goldsmith et al., 1982; Robinson and Goldsmith, 1991). The Worcester Formation (Worcester phyllite) is composed of gray and dark-gray carbonaceous slate, well-foliated micaceous phyllite or schist containing andalusite and chiastolite with interbeds of impure quartzite, calc-silicate or meta-siltstone a few centimeters to one meter thick (Hepburn, 1976; Robinson and Goldsmith, 1991). Peck (1975) interpreted the Worcester Formation as the youngest formation in the sequence and therefore correlated it with the Devonian Littleton Formation. However, interpretations by Robinson (1981) and Hepburn (1976) place the Worcester Formation stratigraphically lower and equivalent to the Tower Hill Formation (Robinson and Goldsmith, 1991). The Worcester Formation is listed as Silurian and Early Devonian in age on the Massachusetts state bedrock map based on correlations with the Littleton Formation, placing it conformably above the Oakdale and Tower Hill Formations (Zen et al., 1983; Robinson and Goldsmith, 1991).

Paxton Formation

The Paxton Formation is located in central Massachusetts and is named for the town of Paxton from the “Paxton Quartz Schist” of Emerson (1917). In general, the Paxton Formation is composed of stratified rocks that are predominantly gray-weathering, slabby, quartz-plagioclase-biotite granofels (Robinson and Goldsmith, 1991). The sample collected for this research was a part of the Granofels Member (Sp) that makes up the majority of the Paxton Formation (Robinson and Goldsmith, 1991). The Granofels member consists of 2-3 centimeter thick slabby and well-layered purplish biotite granofels with calcic plagioclase (Robinson and Field, 1982). The granofels member is similar in lithology to the less metamorphosed Oakdale Formation and the Hebron Formation of central CT (Robinson and Goldsmith, 1991). It has also been considered to be similar in lithology to the Vassalboro Formation in ME (Osberg, 1980) and the Eliot and Berwick Formations in southern NH (Robinson and Goldsmith, 1991). The Paxton Formation is assigned a Silurian age on the state bedrock map (Zen et al., 1983) but a late Proterozoic age has been suggested based on detrital zircons (Barosh and Moore, 1988). Regionally the granofels member lies conformably above the sulfidic schist and quartzite unit (Spsq) and the quartzite and rusty schist unit (Spqr) of the Paxton Formation and unconformably on the Patridge Formation. It may be gradational into the overlying Littleton Formation (Robinson and Goldsmith, 1991).

Intrusive Units in the Merrimack terrane

The MT in Massachusetts and New Hampshire is cross-cut by a range of granitic and dioritic plutons that have contact metamorphosed several of the formations. The ages of these plutons provide minimum ages of deposition for the sediments within the MT.

The Newburyport Complex is located in southeastern New Hampshire and northeastern Massachusetts from Newburyport, MA to Seabrook, NH and intrudes the Kittery and Eliot Formations (Robinson and Goldsmith, 1991). The plutons range in composition from granite through granodiorite to tonalite. They were dated using U/Pb zircon techniques and were determined to have an age of 418 ± 1 Ma (Bothner et al., 1993) constraining the age of the Kittery and Eliot Formations to be no younger than the Late Silurian.

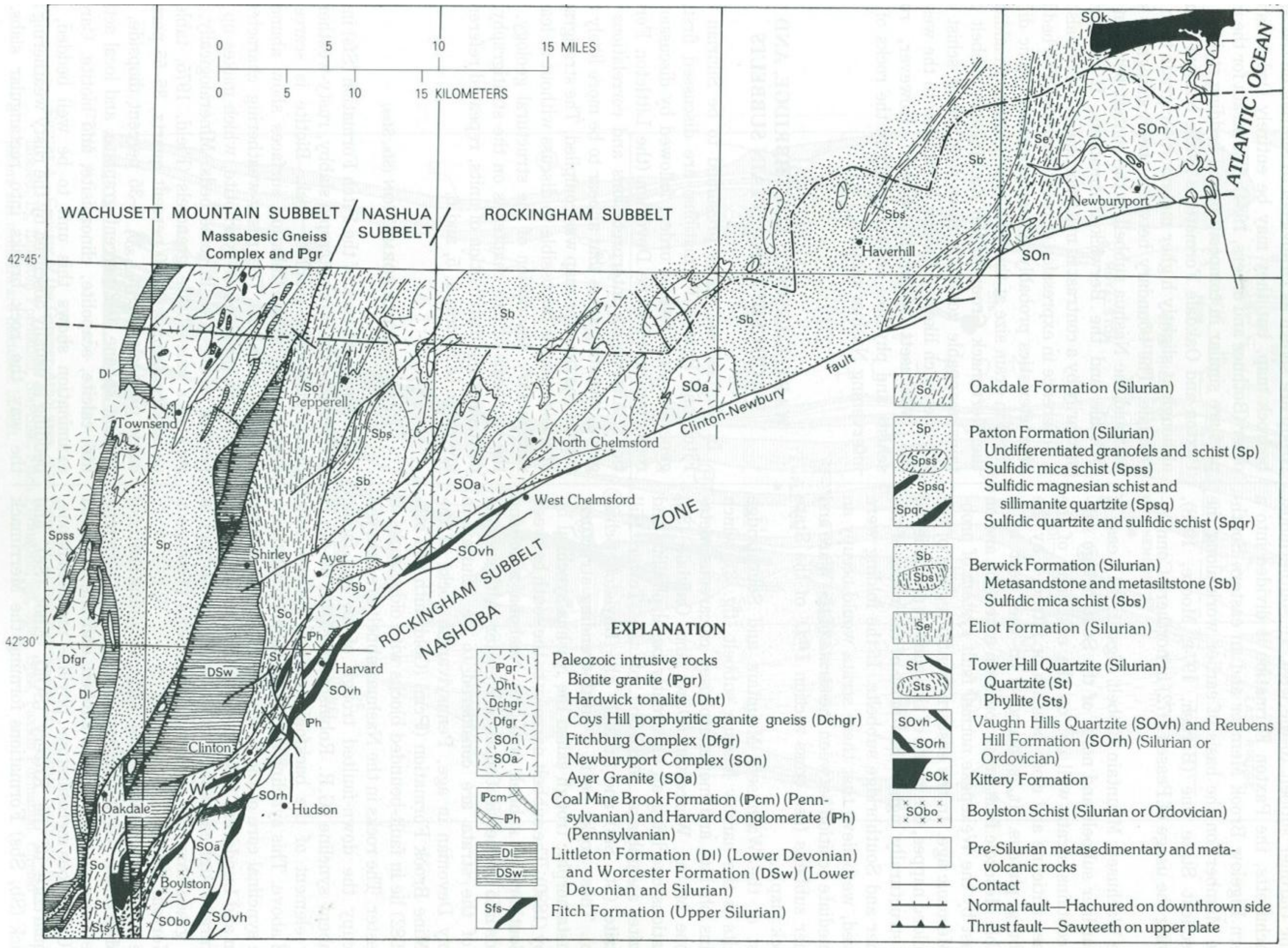

Figure 2.2 Locations of the Kittery, Eliot, Berwick, Oakdale, Tower Hill, Worcester and Paxton Formations within eastern MA from Robinson and Goldsmith (1991).

The Exeter Pluton, located in southern New Hampshire from Exeter, NH north to Rollinsford, NH, intrudes the Kittery and Eliot Formations. It is dominated by biotite quartz diorite and pyroxene or pyroxene-amphibole diorite and minor gabbro, but also contains granodiorite and minor granite (Lyons et al., 1997). The Exeter pluton was dated at 407 ± 0.3 Ma using U-Pb CA-TIMS analysis constraining the depositional age of the Kittery and Eliot Formations to be Early Devonian or older (Bothner et al., 2009).

The Oakdale and Berwick Formations are intruded by the Ayer Granite in north-central Massachusetts along the Clinton-Newbury fault. The Ayer Granite is extensively sheared and foliated and is a light gray, moderately coarse-grained, two-mica granodiorite to granite (Gore, 1976). U-Pb zircon SHRIMP analysis indicates the age of the Ayer Granite is 407 Ma (Walsh et al., 2008). This suggests that much like the Kittery and Eliot Formations, the Berwick and Oakdale Formations are Early Devonian or older (Bothner et al., 2009).

Chapter 3. Previous detrital zircon studies in the northern Appalachians

Detrital zircon studies have been conducted on various tectonic terranes in the Appalachian mountain belt. For the ease of comparisons with the current study, details of several of these studies are discussed below.

Previous detrital zircon studies performed in New England

Nashoba terrane

Using U-Pb LA-ICP-MS, Loan (2011) and Loan et al. (2011) dated detrital zircons from various formations within the Nashoba terrane. The youngest detrital zircon populations from these were: the Tadmuck Brook Schist ~463 Ma, the Nashoba Formation ~465 Ma, the Shawsheen Gneiss ~470 Ma, and the Marlboro Formation ~470 Ma. The largest population of detritus was found to be ~540 Ma (Figure 3.1),

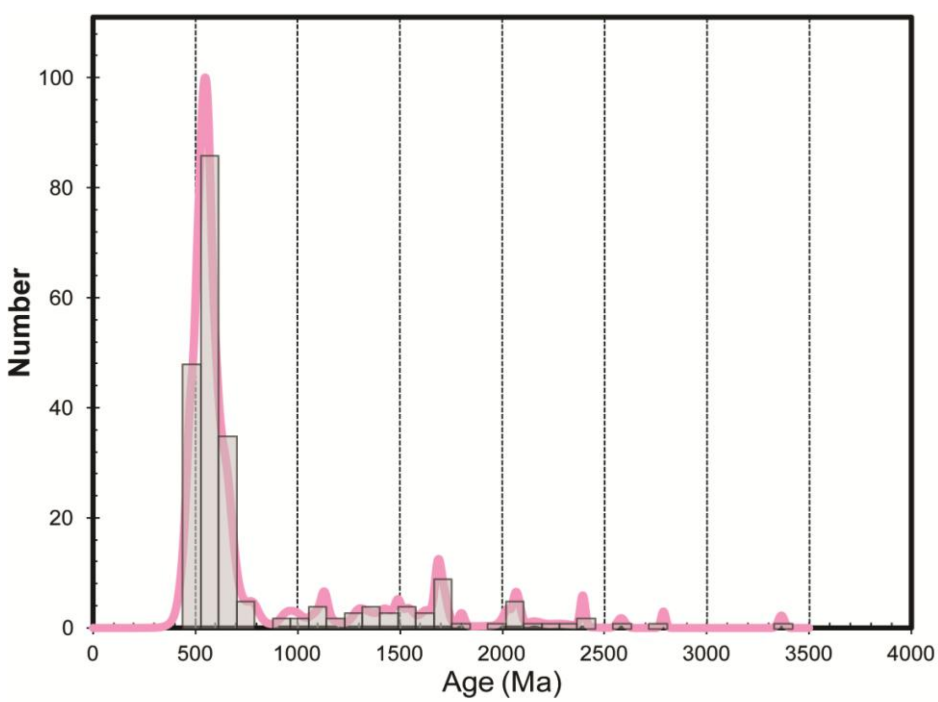

Figure 3.1 Probability density plot of the combined U-Pb detrital zircon data from the four Nashoba terrane formations analyzed by Loan (2011).

comparable to the signature of Ganderia. Loan (2011) interpreted the Nashoba terrane as a piece of the passive trailing margin of Ganderia based on similarities in detrital zircon populations of the Nashoba terrane and Ganderia. Both have major peaks at ~540 Ma. Also, Loan (2011) determined the maximum age of deposition of the Nashoba terrane coincides with when the Popelogan-Victoria Arc accreted to the Laurentian margin.

Central Maine terrane

Dorais et al. (2009) analyzed detrital zircons from the youngest formation (Carrabassett Formation) of the Central Maine terrane using U-Pb LA-ICP-MS. The youngest detrital zircon was found to be 412 ± 23 Ma. The 49 zircon grains analyzed showed sediment in the Carrabassett Formation was largely derived from Ganderia. Dominant populations found were ~600 Ma, 900-1440 Ma, and 2000-2400 Ma. Zircon populations at ~600 Ma and 2000-2400 Ma such as in the Carrabassett Formation, are

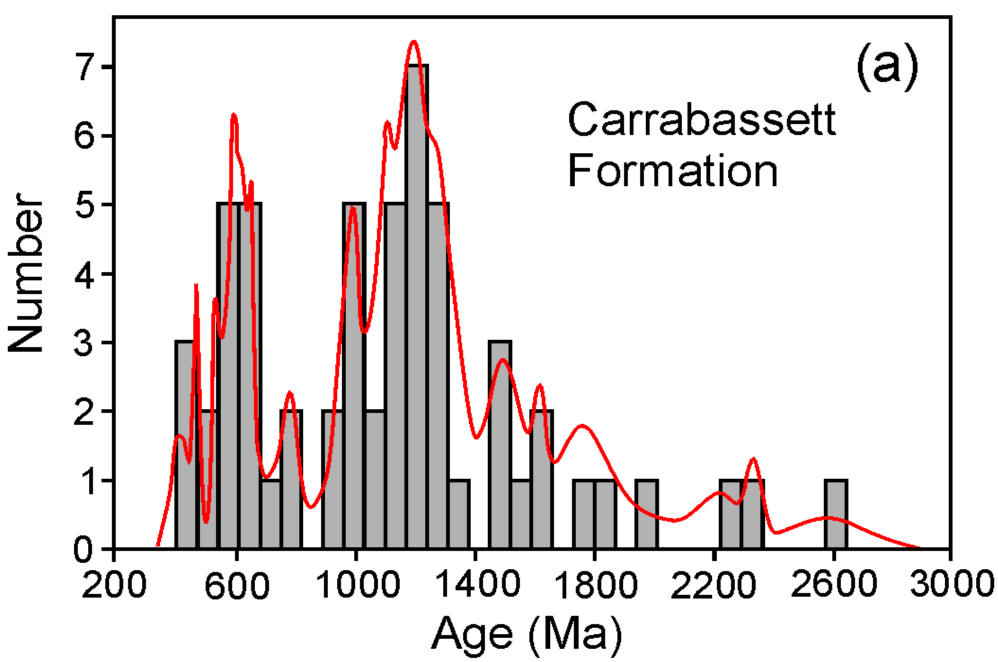

Figure 3.2 Probability density plot of the Carrabassett Formation from U-Pb LA-ICP-MS detrital zircon analysis by Dorais et al. (2009).

typically not observed in sediment from Laurentia. From the results of the study it was interpreted that the sediments in the Carrabassett Formation were deposited during the Acadian orogeny (Dorais et al., 2009).

Merrimack terrane

SHRIMP U-Pb analysis was done on detrital zircons from the Kittery and Berwick Formations in Maine, and the Hebron Formation in Connecticut (Wintsch et al., 2007). The Hebron Formation has been correlated with the Oakdale and Paxton Formations in Massachusetts (Robinson and Goldsmith, 1991). All three Hebron Formation samples in Connecticut (north, central, and south) by Wintsch et al. (2007) had age populations of ~420-490, 800-1200 Ma, a small population 1300-1750 Ma and a gap 550-800 Ma. The youngest detrital zircons in the Hebron Formation were determined to be 423, 425, and 434 Ma (all ±9 Ma, 2σ uncertainty) (Wintsch et al., 2007)

The 50 zircon grains analyzed from the Kittery Formation in southern Maine had an age population of 925-1900 Ma with a gap from ~1200-1400 Ma (Wintsch et al., 2007). Two younger grains were found with ages of 485 and 650 Ma and three older grains around 2.7 Ga (Wintsch et al., 2007). Wintsch et al. (2007) interpreted that the Eliot Formation has a similar provenance to the Kittery Formation based on lithological similarities and stratigraphic order.

Fifty zircon grains analyzed from the Berwick Formation from southern Maine yielded three distinct age populations: ~425-475 Ma, ~900-1435 Ma, and ~2600-2850 Ma. The youngest zircon age was found to be 426 Ma (Wintsch et al., 2007).

From these data Wintsch et al. (2007) concluded that the Hebron and Berwick Formations are correlative and members of the same terrane with a depositional age of Late Silurian. They also suggested that the age populations showed a net transport to the east for its detrital sediments. This is in direct contrast to the Kittery Formation, found by Wintsch et al. (2007) to have an older depositional age between Early Ordovician and Late Silurian and a westerly paleocurrent direction for its sediments. Wintsch et al. (2007) concluded that the Berwick and Hebron Formations and the Kittery Formation do not correlate and assigned the Kittery and Eliot Formations to the Fredericton trough and not to the MT.

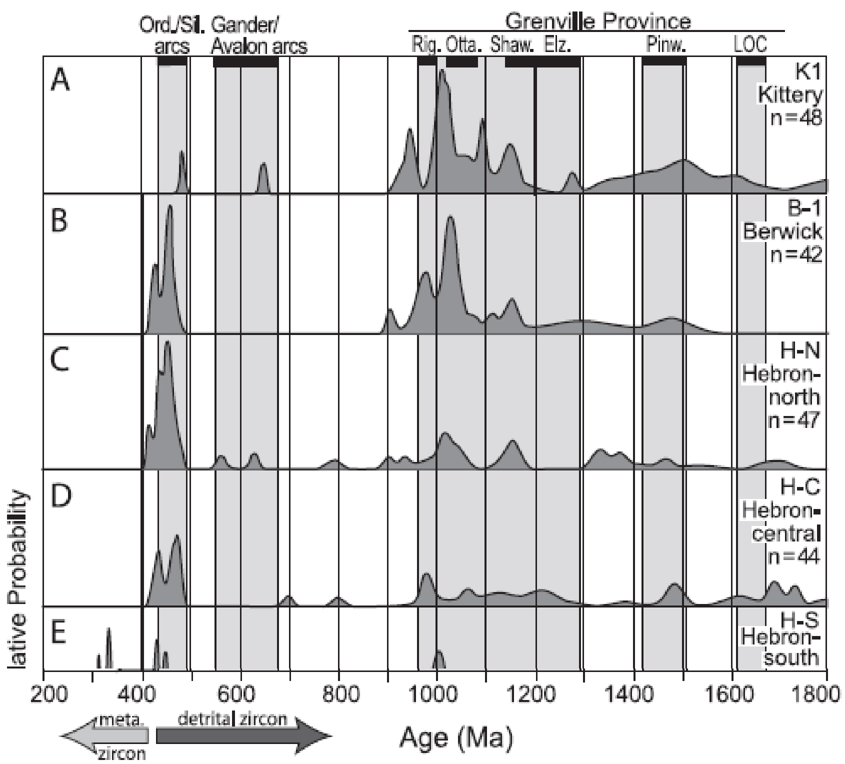

Figure 3.3 Probability density plots of the Kittery, Berwick, and Hebron Formations as analyzed by U-Pb SHRIMP analysis by Wintsch et al. (2007). From Wintsch et al. (2007).

Previous detrital zircon studies performed in Atlantic Canada

Much of the geologic history of eastern New England is similar to that in Atlantic Canada (Nova Scotia, New Brunswick, Newfoundland). A significant amount of detrital zircon work has been performed there providing a clearer picture of the geological history than further south in New England.

Ganderia

Pollock et al. (2007) report U-Pb results of detrital zircons analysis from formations on either side of the Dog Bay Line in Newfoundland (see section 1.3). The formations sampled southeast of the Dog Bay Line (Davidsville and Indian Islands groups) showed a Ganderian source with age ranges of: 440-520 Ma, 580-713 Ma, 890-1160 Ma, 1350-1800 Ma and 2650-2850 Ma.

Fyffe et al. (2009) analyzed zircons using U-Pb SHRIMP from six samples within Ganderia in New Brunswick and coastal Maine to understand how Ganderia evolved through time. All samples were found to have dominant zircon populations of Neoproterozoic age with smaller groupings of grains of Mesoproterozoic, Paleoproterozoic, and Archean ages (Fyffe et al., 2009). Major population peaks were found to be: 539-556 Ma, 585 Ma, 611 Ma, and 674 Ma. Some of these older peaks are accounted for by local igneous units, basement gneisses, and intruding plutonic rocks (Fyffe et al., 2009). Youngest detrital zircon ages ranged from ~507-602 Ma. Detrital zircon analyses from Fyffe et al. (2009) and Pollock et al. (2007) are combined in Figure 3.4 to show a typical Ganderian signature.

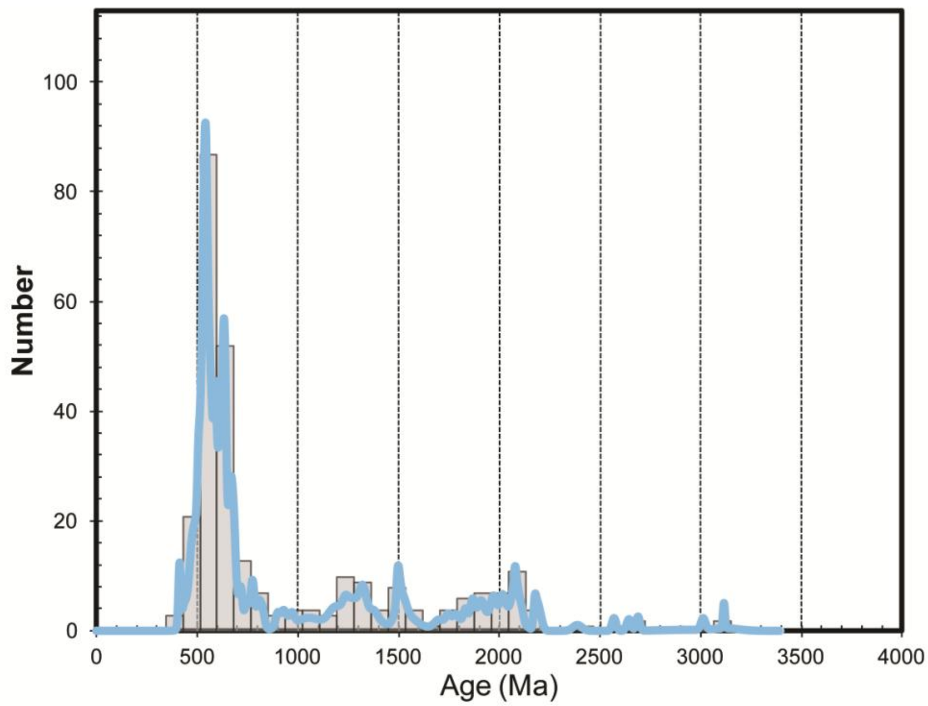

Figure 3.4 Probability density plot of Ganderia from combined U-Pb detrital zircon analysis by Pollock et al. (2007) (Newfoundland) and Fyffe et al. (2009) (New Brunswick and coastal Maine).

Laurentia

Cawood and Nemchin (2001) dated detrital zircons from rift-related, drift-related, and foreland basins from the Humber zone in Newfoundland, a portion of the eastern Laurentian margin. Four main age groups were found: 570-760 Ma, 950-1450 Ma, 1750-1950 Ma, and 2600-2850 Ma. Of these grains, those deposited during the late Neoproterozoic to early Paleozoic were sourced from the Grenville orogen.

Formations dated by Pollock et al. (2007) northwest of the Dog Bay line (Botwood and Badger groups) showed a Laurentian source with age ranges from Archean to Early Paleozoic with gaps 510-550 Ma and 1520-1600 Ma. These data have been combined with the work of Cawood and Nemchin (2001) to provide an overall Laurentian signature as shown in Figure 3.5.

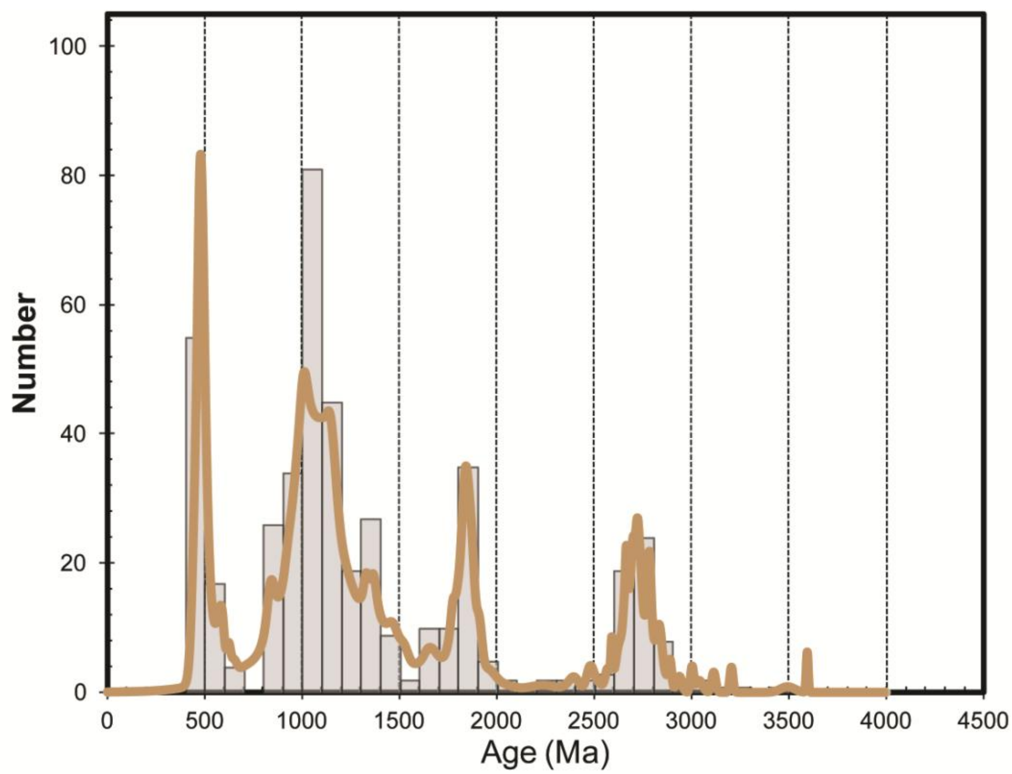

Figure 3.5 Probability density plot of Laurentia from combined U-Pb detrital zircon analysis by Pollock et al. (2007) (Newfoundland) and Cawood and Nemchin (2001) (Newfoundland).

Chapter 4. Methods

Summary of Methods

Zircon grains or cores can remain intact and unaltered through metamorphism and maintain their original ages of crystallization. The ages of these unaltered zircon grains can then be used to determine the maximum depositional age of clastic sedimentary rocks and provide information on the provenance of the sediments. In order to perform analysis, zircon grains had to be extracted from bulk samples collected from the Kittery, Eliot, Berwick, Oakdale, Tower Hill, Worcester, and Paxton Formations.

All samples were processed in the mineral separation laboratory in the Department of Earth and Environmental Sciences at Boston College. All mineral separation techniques were "clean processes" and all equipment and tools were cleaned thoroughly prior and after use, using compressed air, a shop vacuum, ethyl alcohol, paper towels, water, and wire brushes.

Mineral Separation

Cleaned bulk samples were first crushed from fist-sized to gravel sized pieces through the use of the Bico International Inc "Chipmunk" WD Jaw Crusher. The gravel sized pieces were further processed into fine sand size particles using the Bico International Inc. Disc Mill Pulverizer. This uses one stagnant and one rotating metal round plate placed approximately a papers width apart (less than 1/2 millimeter).The samples were then sieved using a ro-tap, with two different sieve sizes: 500 µm, and 250 µm. Material was separated into > 500 µm, 250-500 µm and < 250 µm size fractions. For this research the size of less than 250 µm was used as it was anticipated that zircon grains would be no larger than this size fraction.

The <250 µm grains were further processed on the Outotec Wilfley™ table to separate out the heavy minerals. As the Wilfley™ table shakes and water moves over it, it divides the grains fed over the table by weight. Zircon grains with a density of 4.6 g/cm^3 come out with the heaviest mineral separates and are further separated using a Frantz™ magnetic separator. The separation was first run at 0.25A with a forward slope of 20° and a side slope of 10°. Zircon grains are non-magnetic at 0.25A unless they are extremely metamict, so zircon grains analyzed went into the non-magnetic collection bucket.

Once the initial voltage level of 0.25A was complete and the more magnetic material at 0.25A was removed from the sample, the less-magnetic material was further separated by heavy liquid separations using Methylene Iodide. Methylene Iodide has a specific gravity of 3.3 g/cm^3, so all material with a specific gravity lighter than this (ex. feldspars and micas) will float, and all of the material with a specific gravity heavier than this (ex. zircon and titanite) will sink to the bottom of the separation funnel. The denser material extracted from heavy liquids was further separated using the Frantz™ magnetic separator at 0.4A, 0.8A, 1.2A, and 1.5A. The remaining less-magnetic material after 1.5A was applied was then placed into a Petri dish with ethyl alcohol and single zircon grains were handpicked with tweezers using a stereomicroscope.

Mineral Selection

Approximately 150 to 200 zircon grains were picked per sample from the mineral separates as shown in Figure 4.1. Zircon grains were randomly selected from all samples so that no sample bias would occur and all sizes, shapes, and colors of zircon were included. Morphologies included faceted zircons, rounded naturally abraded zircons and metamict zircons with the occurrence of each varying per sample. Once ~150-200 zircons grains were picked and separated into a new Petri dish, they were further divided visually into three class sizes: small (40-80 μm), medium (80-120 μm), and large (120-200 μm) in separate Petri dishes. The sizes were based on approximations amongst grains within the individual sample and not compared with zircon sizes of other samples.

Once separated into three dishes, each size fraction per sample was mounted using tweezers on a glass slide covered with double sided tape in rows of approximately 10 to 20 grains. Grains were then mounted in an epoxy resin to produce three one inch diameter mounts (small, medium, large grain size) for each sample. All mounts were then polished with a Struers Labo-Pol 5 in order to expose the inner cores of the zircon grains.

SEM

Once three mounts were made and polished for each sample, they were carbon coated and imaged using back-scattered electron (BSE) and cathodoluminescence (CL) image analysis at either the Massachusetts Institute of Technology in Cambridge, MA or at the INCO Innovation Centre of Memorial University in St. John's, Newfoundland, Canada. Imaging was done to show zonation within individual grains due to the occurrence of overgrowths. Using analysis that measured both a rim and a core of a grain would likely result in discordant data (e.g. Bennett et al., 2009). It is important to know the locations of the cores and rims of each zircon grains so the spot chosen for analysis does not hit multiple domains if at all possible.

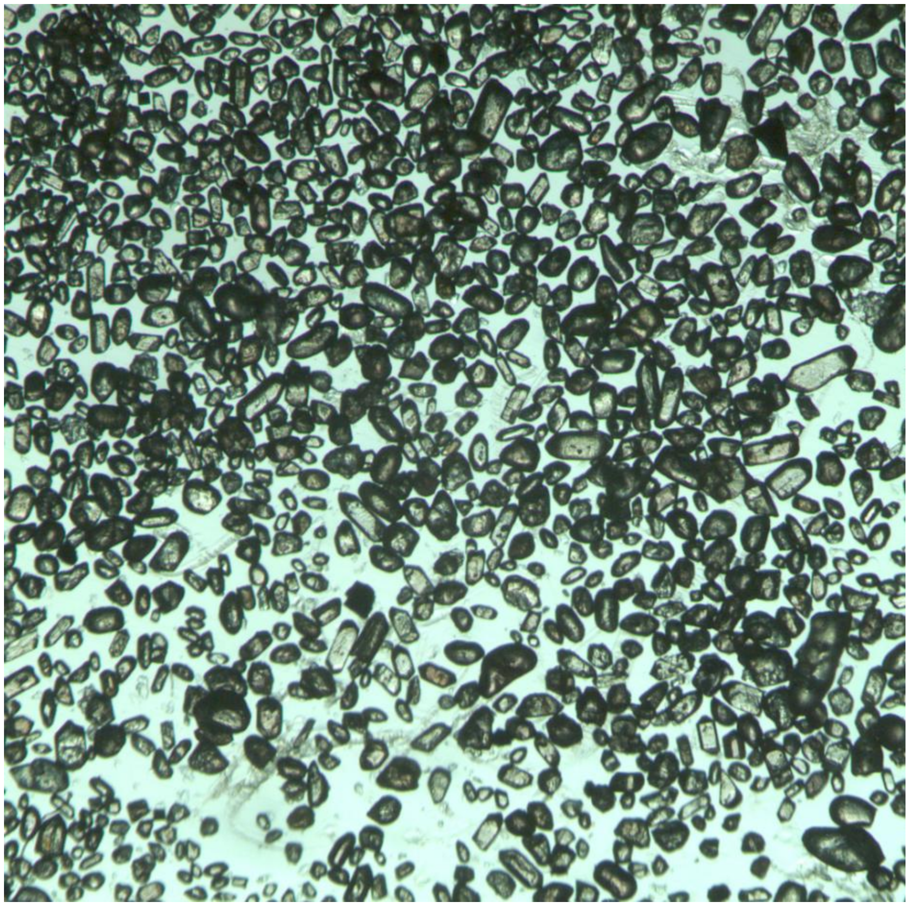

Figure 4.1 Example of a mineral separate from the Eliot Formation under a stereomicroscope at 5x magnification.

LA-ICP-MS

Once imaged, mounts were analyzed on a Laser Ablation Inductively Coupled Plasma Mass Spectrometer (LA-ICP-MS) at the INCO Innovation Centre at Memorial University in St. John's, Newfoundland. Mounts were first cut to approximately ¼ inch in height with a saw at Memorial University to fit the sample holder and washed with HNO_3 solution to remove any surface debris.

Mounts were placed in the sample chamber along with three standards: PL, 91500, and 02123 for reference and quality control purposes (Bennett and Tubrett, 2010). The three standards and all sample grains were measured using a Finnigan ELEMENT

XR double focusing magnetic-sector field ICP-MS connected to a Geolas 193 nm excimer laser (Bennett and Tubrett, 2010). A 10 µm laser beam was rastered over each grain analyzed to provide a 40x40 µm or 30x30 µm (dependent on grain size) square spot. Laser energy was set at 6 J/cm^3, the velocity was 10 $\mu m/s^{-1}$, and the laser repetition was set at 8 Hz.

Once material was ablated from each grain it was nebulized and introduced into the ELEMENT XR using a mixed Ar-He carrier gas (Bennett and Tubrett, 2010). A standard tracer solution was also nebulized with the sample material and included a mixture of natural TI, ^{209}Bi, and enriched ^{233}U and was used to correct for instrumental mass bias (Bennett and Tubrett, 2010).

Measurements were taken for each grain using time-resolved data acquisitions that were roughly 120-205 seconds long. Prior to measurements taken of ablated material, data was acquired for the Ar-He gas and tracer solution for approximately 20-30 seconds (Bennett and Tubrett, 2010). Elemental masses measured during the time-resolved measurements included: ^{204}(Hg), ^{203}(Tl), ^{205}(Tl), ^{206}(Pb), ^{207}(Pb), ^{209}(Bi), ^{232}(Th), ^{233}(U), ^{237}(Np), ^{238}(U), ^{249}($^{233}U^{16}O$), ^{253}($^{237}Np^{16}O$) and ^{254}($^{238}U^{16}O$) (Bennett and Tubrett, 2010). Raw data was corrected for and reduced by staff members at the INCO Innovation Lab of Memorial University in St. John’s, Newfoundland according to methods based upon by Sylvester and Ghaderi (1997), Horn et al. (2000), and Kosler et al. (2002). Ages of individual zircon grains were calculated using LAMdate (Kosler et al., 2002) with Isoplot v. 2.06 of Ludwig (1999).

Number of grains Used

Approximately 150-200 randomly selected (includes random sizes and morphologies) grains were analyzed per sample to provide a strong statistical representation and to ensure that no age populations were missed. According to Vermeesch (2004), 117 grains must be analyzed to be sure that no fraction comprising more than .05 of the population is missed at the 95% confidence level.

Data Analysis

A concordia diagram is a graphical representation of how concordant the ages of zircon grains are, based on their $^{207}Pb/^{235}U$ and $^{206}Pb/^{238}U$ ratios (Figure 4.2) (Dickin, 2005; Faure and Mensing, 2005). If both ratios yield the same age the zircon analysis will fall along the concordia curve. If grains suffer from lead loss or two age domains are analyzed, the data will not plot along the concordia curve and are considered to be discordant (Faure and Mensing, 2005). Discordance is represented by the probability of concordance. This shows how much of the error ellipse overlaps with concordia. If this value is <0.05, grains are considered to be discordant (Pollock et al., 2009) and were excluded from this study.

Although a concordia plot is an excellent way to show data, it can become difficult to read when there are large quantities of data such as this study. A probability density plot is easier to read and shows how ages are distributed using bins and a histogram. All probability density plots in this study (ex. Figure 4.3) were made using Isoplot v. 4.11 (Ludwig, 2008).

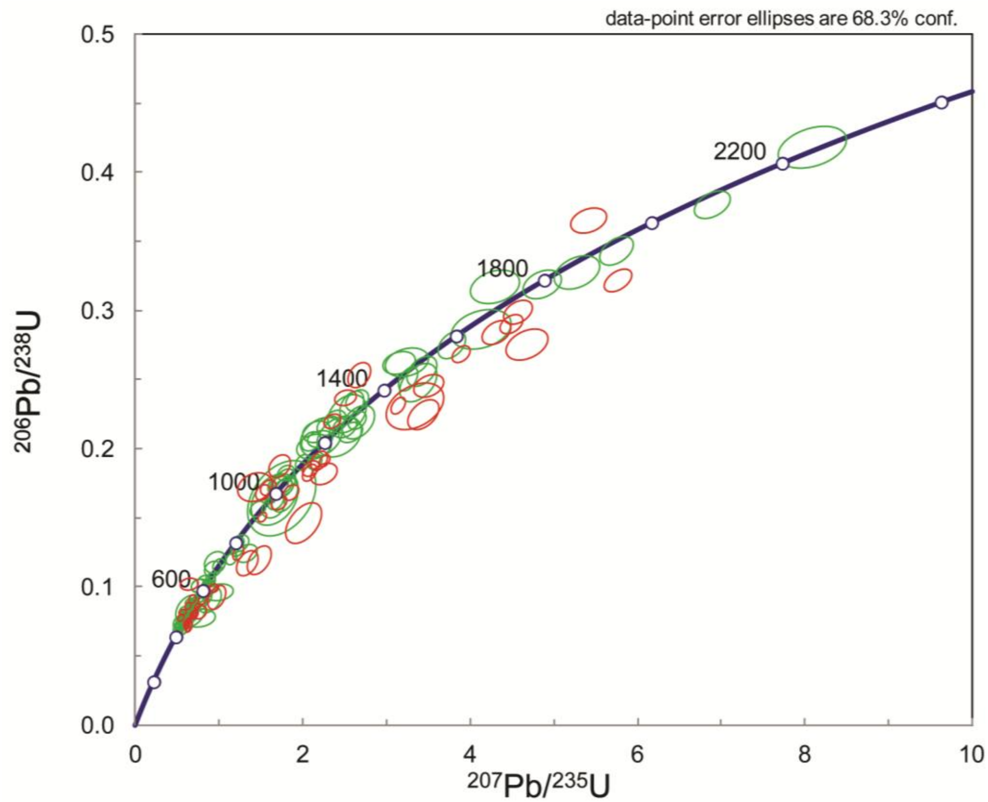

Figure 4.2 Example of a concordia diagram for the Worcester Formation Grains with a probability of concordance ≥0.05 (concordant grains) are shown in green. Grains with probability of concordance <0.05 (discordant grains) are shown in red and were not used in analysis.

To further constrain the data used for analysis, any grains with a 1σ error for $^{206}Pb/^{238}U$ or $^{207}Pb/^{206}Pb$ ages greater than 10% of the calculated age was excluded. For example, if a grain had a $^{206}Pb/^{238}U$ age of 470 Ma and a 1σ error value of 70 Ma, it was excluded as the error would be ~15% of the age.

Th/U ratios <0.1 are considered to indicate metamorphic zircons (Hoskin and Schaltegger, 2003). When P-T conditions reach upper-amphibolite to upper-granulite facies, metamorphic zircon growth occurs. These zircons record the age of the high temperature/pressure metamorphic event. The overgrowths have an age younger than the original crystallization age found in the core (Hoskin and Schaltegger, 2003; Corfu et al., 2003). If concordant metamorphic grains were present that are older than the youngest igneous-detrital age populations (see below) they were included in the detrital zircon analysis as they are detrital zircons from a metamorphic source. No metamorphic grains younger than the youngest igneous-detrital age population were observed in the concordant data used for analysis. However, several discordant grains younger than the youngest igneous-detrital age population were observed. It was assumed the younger age was the result of a late metamorphic event and that they do not represent the original age of the grain. For the young metamorphic grains a conservative approach was used. It was unclear if the young grains were metamorphic or detrital so they were not interpreted as detrital. If included, such metamorphic grains would make the sedimentary age of the rocks appear falsely young.

Concordia age has become the recommended way to report detrital zircon data because it is a mathematical combination of multiple ratios and makes optimal use of all U/Pb and Pb/Pb ($^{238}U/^{206}Pb$ to $^{207}Pb/^{206}Pb$ or the $^{235}U/^{207}Pb$ to $^{207}Pb/^{206}Pb$) ratios (Ludwig, 1998; Pollock et al., 2009). However, many of the previous studies involving detrital zircons in the Appalachians have been reported using $^{206}Pb/^{238}U$ and $^{207}Pb/^{206}Pb$ ages. For the ease of comparisons, the data in this study are reported as $^{206}Pb/^{238}U$ and $^{207}Pb/^{206}Pb$ ages. In grains <800 Ma the amount of ^{207}Pb present is low as a result of the low abundance of ^{235}U relative to ^{238}U. Thus in grains <800 Ma, the uncertainty on $^{207}Pb/^{235}U$ is large and the $^{206}Pb/^{238}U$ age is reported for grains <800 Ma (Ludwig, 2008). The $^{207}Pb/^{206}Pb$ ratio is used here for grains >800 Ma because the ^{207}Pb concentration is high enough for these older zircons and the $^{207}Pb/^{206}Pb$ is least affected by effects such as Pb-loss, mixing of age domains or fractionation (Ludwig, 2008; Barr et al., 2012).

The difference between concordia ages and $^{206}Pb/^{238}U$ ages for each grain is very small in this study. Using one reported age over another does not drastically change the overall signal of the detrital age population. Figure 4.3 shows the probability density plot for both the concordia and $^{207}Pb/^{206}Pb$ ages and $^{206}Pb/^{238}U$ and $^{207}Pb/^{206}Pb$ ages for the Worcester Formation. Figure 4.3 shows the $^{206}Pb/^{238}U$ and concordia age probability density plots are nearly identical.

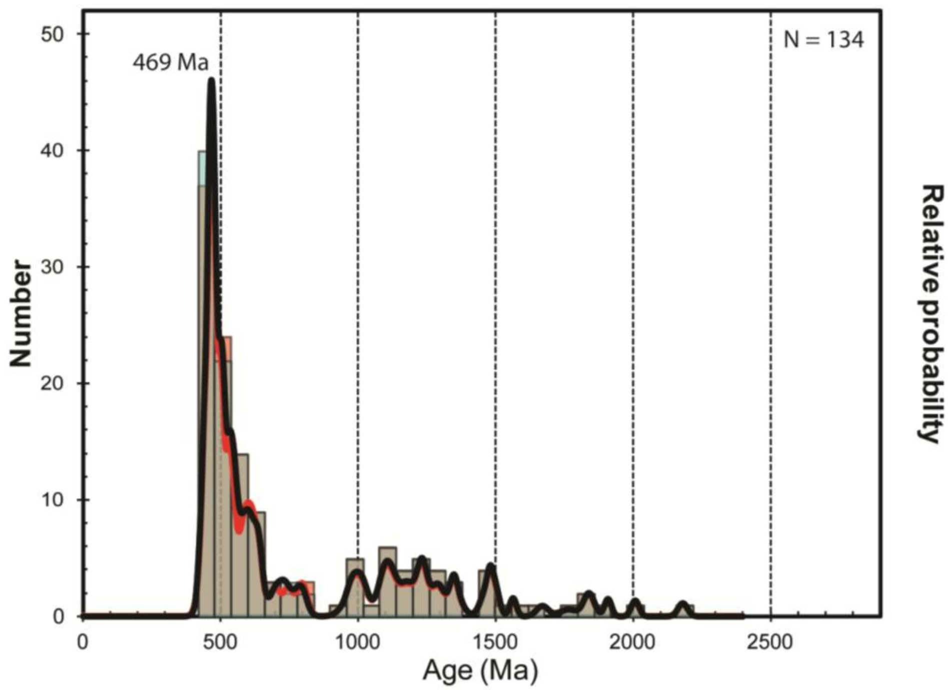

Figure 4.3 Example of a probability density plot for the Worcester Formation for the concordant grains (≥0.05 probability of concordance). The black line and blue boxes represent the $^{206}Pb/^{238}U$ age data for grains <800 Ma and the $^{207}Pb/^{206}Pb$ age data for grains > 800 Ma. The red line and red boxes represent the concordia age data for grains <800 Ma and $^{207}Pb/^{206}Pb$ age data for grains >800Ma. The gray boxes are where the red and blue boxes overlie.

Youngest Age Populations

The youngest age population for each sample was determined by taking the weighted average of the $^{206}Pb/^{238}U$ ages for a population of the youngest 3-10 zircon grains. All grains within a population were very close in age with overlapping uncertainties and Th/U ratios >0.01. When determining youngest age populations, only grains that fell between 85-115% U-Pb/Pb-Pb concordancy percent were used to ensure better accuracy. SEM images and zircon morphologies were used in addition to Th/U ratios when determining the youngest age populations to ensure that grains were not metamorphic.

Lead loss issues

As mentioned previously grains that suffer from lead loss will not plot along the concordia curve and are considered to be discordant (Faure and Mensing, 2005). One way that lead loss occurs is by radiation damage and results in fast-pathway diffusion from the more damaged portions of the zircon crystal lattice (Condon and Bowring, 2011). Lead loss results in higher U-Pb ratios and grains appear younger than the actual age (Condon and Bowring, 2011).

In CA-TIMS the zircon grains are chemically annealed to remove the radiation damaged portions of the zircon grains. During this process zircon grains are heated to very high temperatures (800-1100 °C) to anneal radiation lattice damage (Mattinson, 2005). Grains are then put through partial dissolution to remove portions of the grains with high U and Th concentrations. Dissolution removes portions of the grains that have high U and Th concentrations. With dissolution, the grain becomes more concordant, resulting in a residual zircon grain with little remaining effects of lead loss. The remaining zircon material is then dated with precision that can be better than 0.1%. (Mattinson, 2005).

Unlike CA-TIMS analysis, in LA-ICP-MS, metamict domains that have lost Pb are not removed. Therefore lead loss should be considered as a possible source of uncertainty. Typically grains that have experienced lead loss will not fall along a concordia curve. However, the large error ellipses associated with LA-ICP-MS analysis can make slightly discordant grains appear concordant (Dickin, 2005). For example, the grain with the red ellipse in Figure 4.4 has an acceptable probability of concordance of 0.12. While the grain hits the concordia line, if it had a smaller error value it would not and likely be discordant. If error values were smaller for both grains with black ellipses in Figure 4.4, both would still lay along the concordia line, making those grains truly concordant. Therefore it is a possibility that grains analyzed in this study may have suffered from lead loss and the reported ages are younger than the growth values.

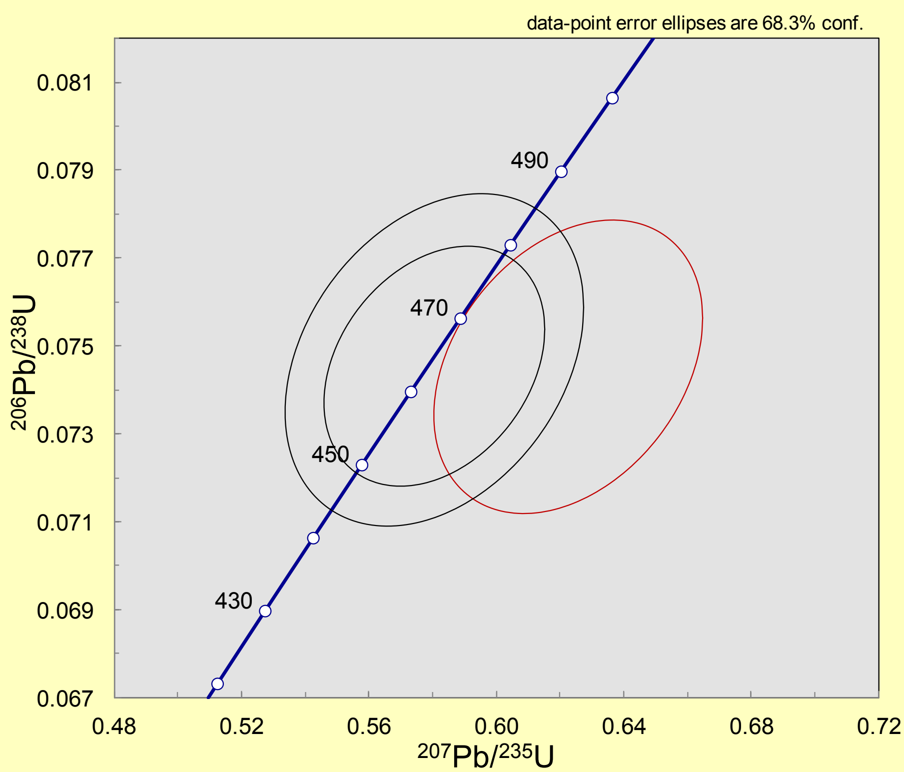

Figure 4.4 Example of how large error ellipses associated with LA-ICP-MS analysis can make discordant grains appear concordant. The grain with the red ellipse has a probability of concordance of 0.12.

Chapter 5. Results

To answer the questions of age, origin, and relations, seven bulk samples from formations in the MT were collected for zircon analysis in a N-NE trending transect in Massachusetts and southeastern New Hampshire. From NE to SW samples are the: Kittery, Eliot, Berwick, Oakdale, Tower Hill, Worcester, and Paxton Formations. Sample locations are shown in Figures 1.1 and 5.1 and the locations are given in Appendix A. Only grains with a probability of concordance ≥0.05, low error values and that met the criteria detailed in Chapter 4 are listed in Tables within this chapter. A complete list of all zircons analyzed is given in Appendix B.

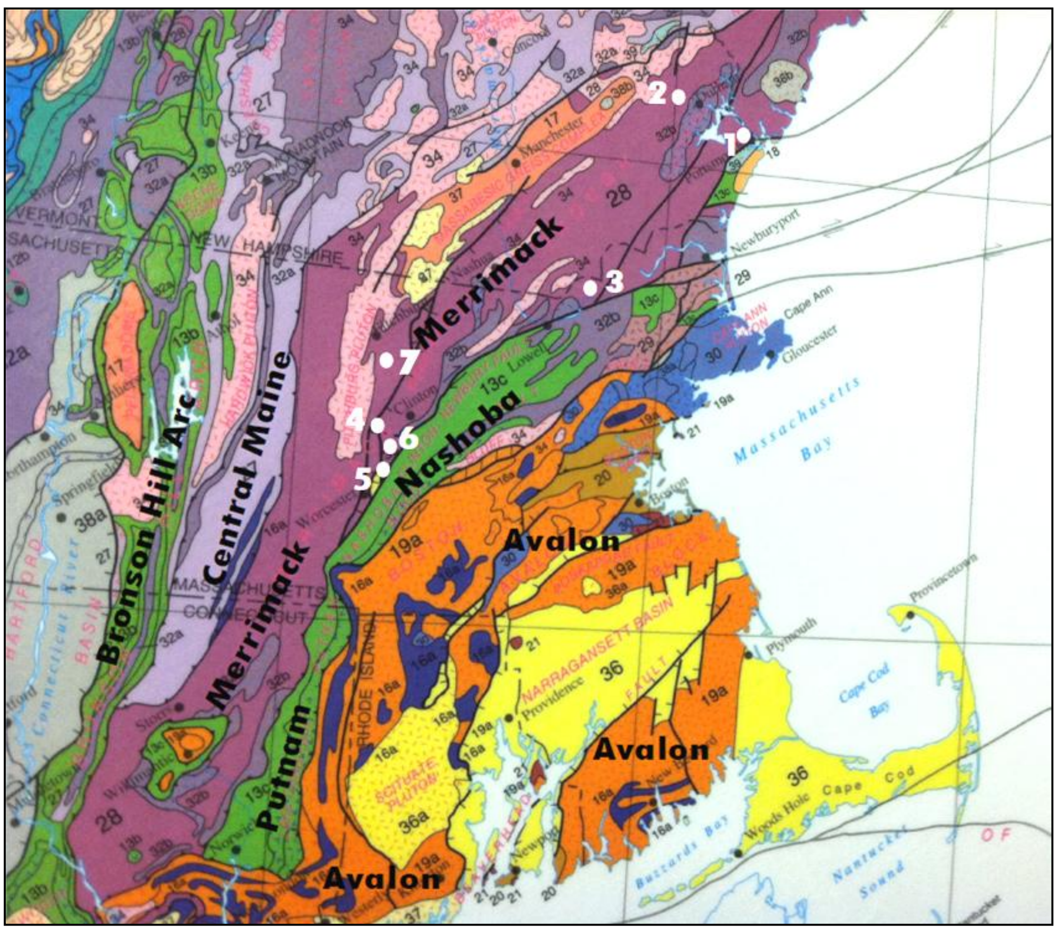

Figure 5.1 Sample locations of the MT and locations of terranes in southern New England. Samples: 1-Kittery, 2-Eliot, 3-Berwick, 4-Oakdale, 5-Tower Hill, 6-Worcester, 7-Paxton, Map modified from Hibbard et al. (2007).

Zircon morphologies

To reduce bias, zircons of all morphologies were selected. In general there were no major differences in morphologies between samples (Table 5.1). All samples contained zircon grains of the same morphologies. However, the Tower Hill Formation contained a larger amount of large, elliptical, brown, abraded grains (G) and had more cracked grains than the remainder of the MT samples.

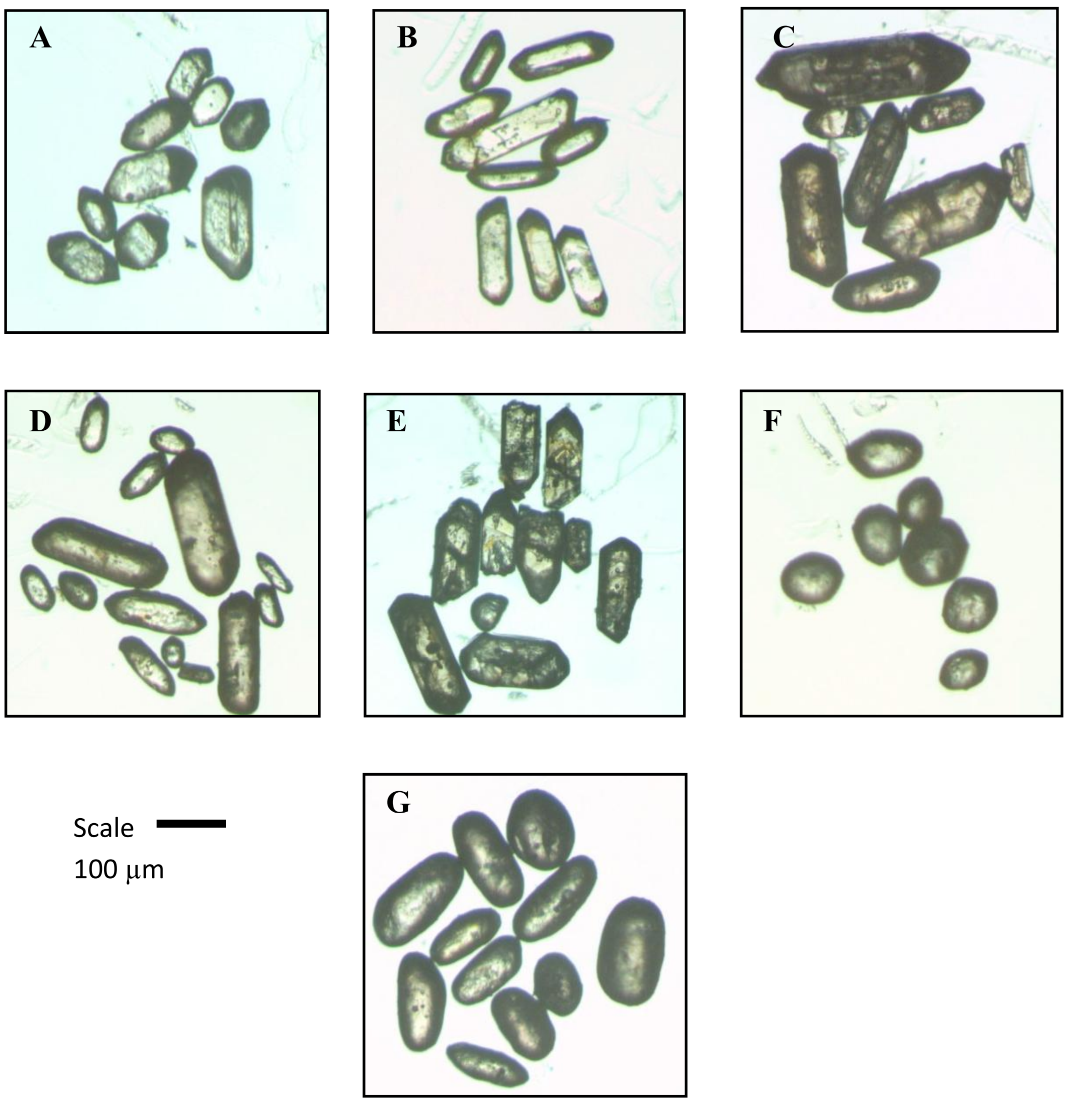

Figure 5.2 Images of the various zircon morphologies found in the MT samples. Images correspond to Table 5.1.

Table 5.1 Zircon Morphologies

Population		Sample						
		Kittery Fm.	Eliot Fm.	Berwick Fm.	Oakdale Fm.	Tower Hill Fm.	Worcester Fm.	Paxton Fm.
A	Faceted, small aspect ratio (2.5:1) colorless to cloudy	X	X	X	X	X	X	X
B	Faceted, large aspect ratio (4:1) colorless to cloudy	X	X	X	X	X	X	X
C	Abraded, large aspect ratio (4:1), cloudy to rusty	X	X	X	X	X	X	X
D	Rounded edges, long or short aspect ratio, smooth surface clear to cloudy	X	X	X	X	X	X	X
E	Round, smooth to abraded surface, clear to cloudy	X	X	X	X	X	X	X
F	Broken, large visible cracks, cloudy to rusty	X	X	X	X	X	X	X
G	Elliptical shaped (jelly bean), abraded, cloudy to brown	X	X	X	X	X	X	X

5.2 Kittery Formation – KSKTI

KSKTI sample location and description

The Kittery Formation, (sample KSKTI) was sampled from Stop 1 of the 1995 NEIGC field trip guide, trip II (Fargo and Bothner, 1995) from an outcrop on Michael Succi Drive, in Portsmouth, NH, near the National Gypsum Plant. This outcrop is across the Piscataqua River from the type locality (Katz, 1917) and is intruded by Mesozoic diabase dikes. The outcrop consists of a tan weathering, gray to purplish, massive, fine-grained, feldspathic quartzite and quartzitic phyllite. Bedding at this outcrop had a northeast strike (Fargo and Bothner, 1995). The thin section showed it is equigranular and composed largely of quartz (~55%), biotite (25%), chlorite (15%) and trace plagioclase and muscovite. The complete mode and thin section images are shown in Appendix C.

Figure 5.3 Picture of Kittery Formation (KSKTI) outcrop in Portsmouth, NH.

Kittery Formation U-Pb geochronology

For the analysis of the Kittery Formation, 100 grains (Table 5.2) were used after 60 grains were excluded due to low probability of concordance. One young grain (mr18b34) was excluded due to a low U-Pb/Pb-Pb concordancy percentage (Appendix B). Six concordant grains with varying ages were determined to be metamorphic based on their Th/U ratios (<0.01) as indicated in Table 5.2. As shown from the probability density plot (Figure 5.4) the Kittery Formation showed two major age groups: 412-544 Ma and 966-1826 Ma, a small peak in the Archean with two grains (2990 and 3037 Ma) and a small peak in the Neoproterozoic with two grains (773 and 776 Ma).

Kittery Fm. - KSKTI youngest detrital zircon age population

The youngest detrital zircon age population for the Kittery Formation was determined from a weighted average of the $^{206}Pb/^{238}U$ age of the four youngest grains that had a U-Pb/Pb-Pb concordancy percent between 85-115%, were concordant, and were not metamorphic. The weighted average was found to be 413 ± 12 Ma (1σ error). The errors of all four grains overlap in age and because a large gap in age is present between the oldest grain in this group and the next oldest grain (~21 Ma), these four grains were chosen to represent the youngest age (Figure 5.6). Although mr18a14 and mr18b19 contain cracks, they had acceptable error values and U-Pb/Pb-Pb concordancy percentage values close to 100% and thus were included in the weighted average.

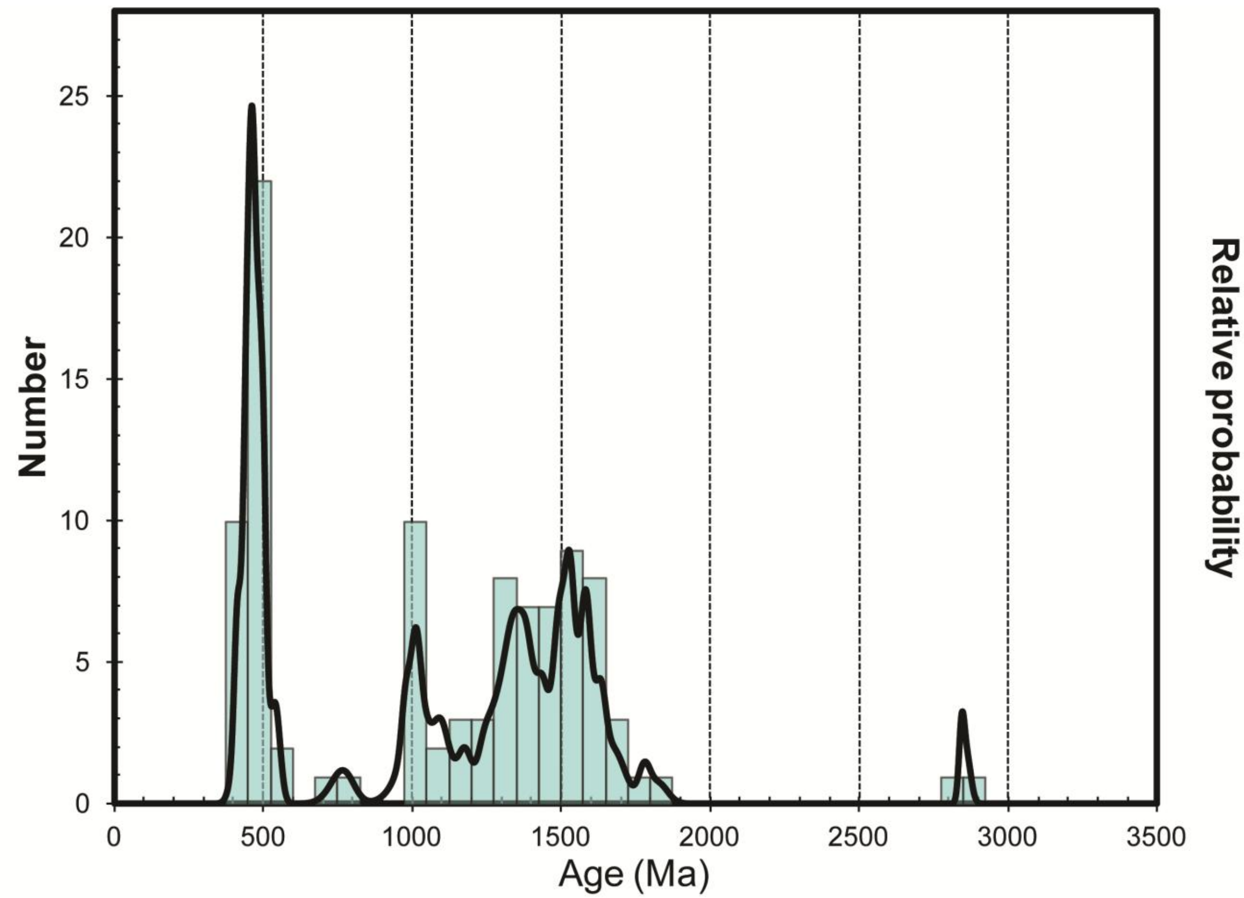

Figure 5.4 Probability density plot for the concordant grains (≥0.05 probability of concordance) for the Kittery Formation, $^{206}Pb/^{238}U$ age data for grains <800 Ma and $^{207}Pb/^{206}Pb$ age data for grains > 800 Ma.

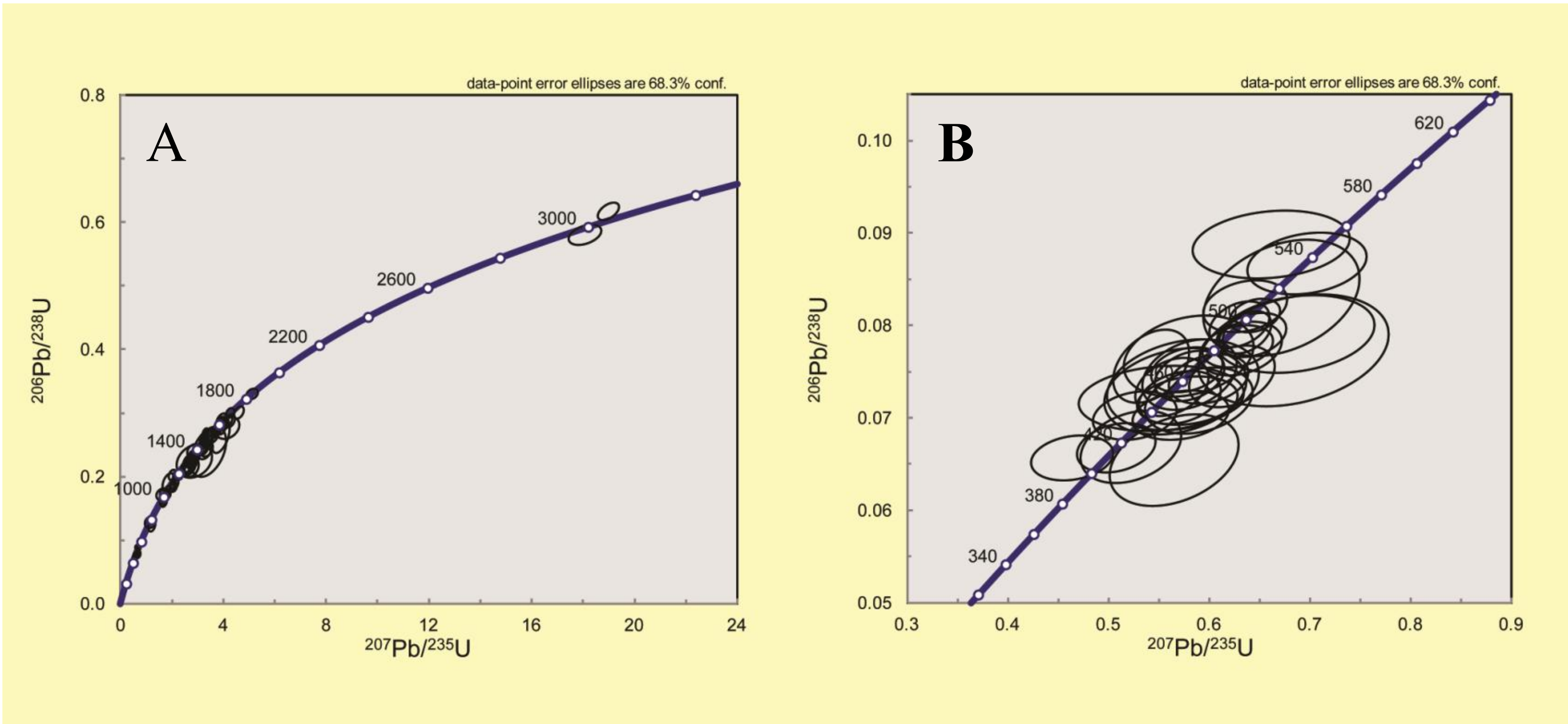

Figure 5.5 Concordia diagram for concordant data (≥0.05 probability of concordance) for the Kittery Formation A - All concordant data for the Kittery Formation B – Enlarged image of the younger age populations in the Kittery Formation

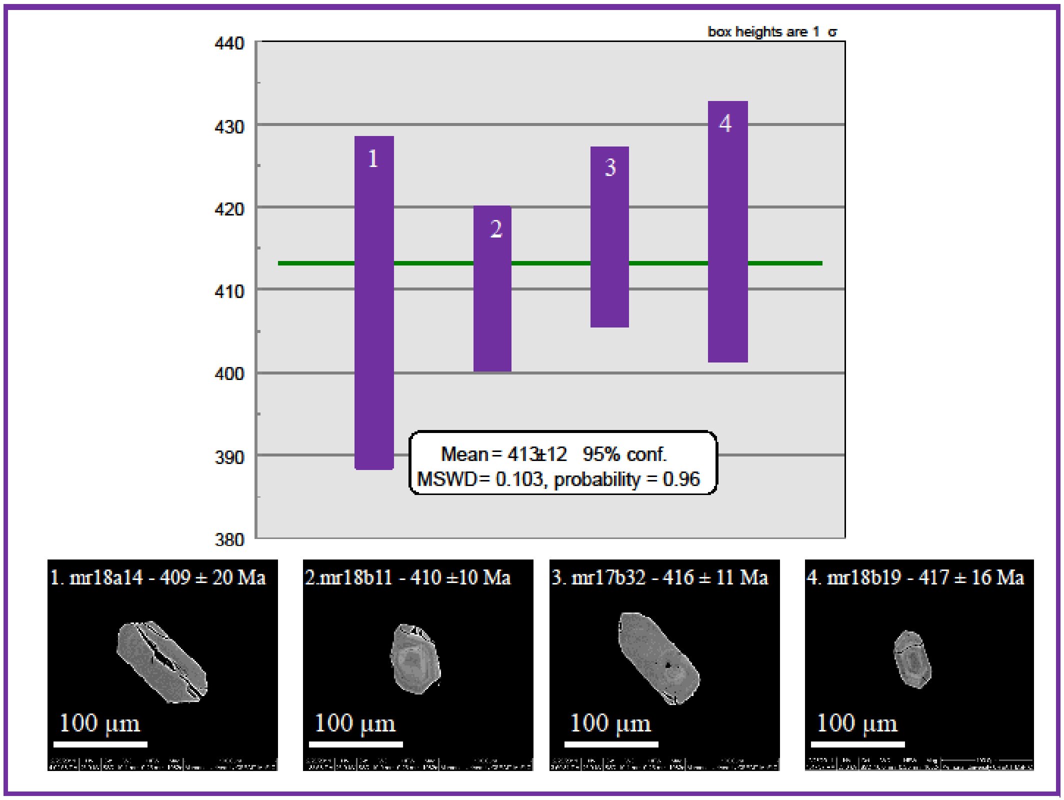

Figure 5.6 Weighted average of the four youngest detrital zircon grains for the Kittery Formation. The weighted average is based on $^{206}Pb/^{238}U$ ages and 1 sigma errors.

ID-TIMS

ID-TIMS analysis was also performed on the four youngest grains in the Kittery Formation found from LA-ICP-MS analysis for better precision. The four grains were extracted from the grain mounts used for LA-ICP-MS analysis and dated using ID-TIMS. All ages determined from ID-TIMS analysis were older than the results from LA-ICP-MS analysis. The results of the ID-TIMS analysis are shown in Table 5.3 along with the results of the same grains dated using LA-ICP-MS methods. The concordia diagram of the ID-TIMS data is shown in Figure 5.7. Table 5.3 shows that the ID-TIMS analyses have uncertainties two orders of magnitude lower than uncertainties for LA-ICP-MS analysis. The youngest detrital zircon grain found from the ID-TIMS analyses is ~432

Ma. The difference in ages between methods may be a result of lead loss. In the ID-TIMS method, the domains that lost Pb were removed through the chemical annealing technique, (Chapter 4) while there is no way to remove them in the ICP-MS analysis.

	Method			
Sample ID	**CA-TIMS**		**LA-ICP-MS**	
	$^{206}Pb/^{238}U$ (Ma)	**2s error (Ma)**	**$^{206}Pb/^{238}U$ (Ma)**	**1s error (Ma)**
mr18a14	432.19	0.68	409	20
mr18b11	461.31	0.71	410	10
mr17b32	434.26	0.46	416	11
mr18b19	473.4	1.1	417	16

Table 5.3 Table of ID-TIMS and LA-ICP-MS analysis for the four youngest detrital zircons in the Kittery Formation sample.

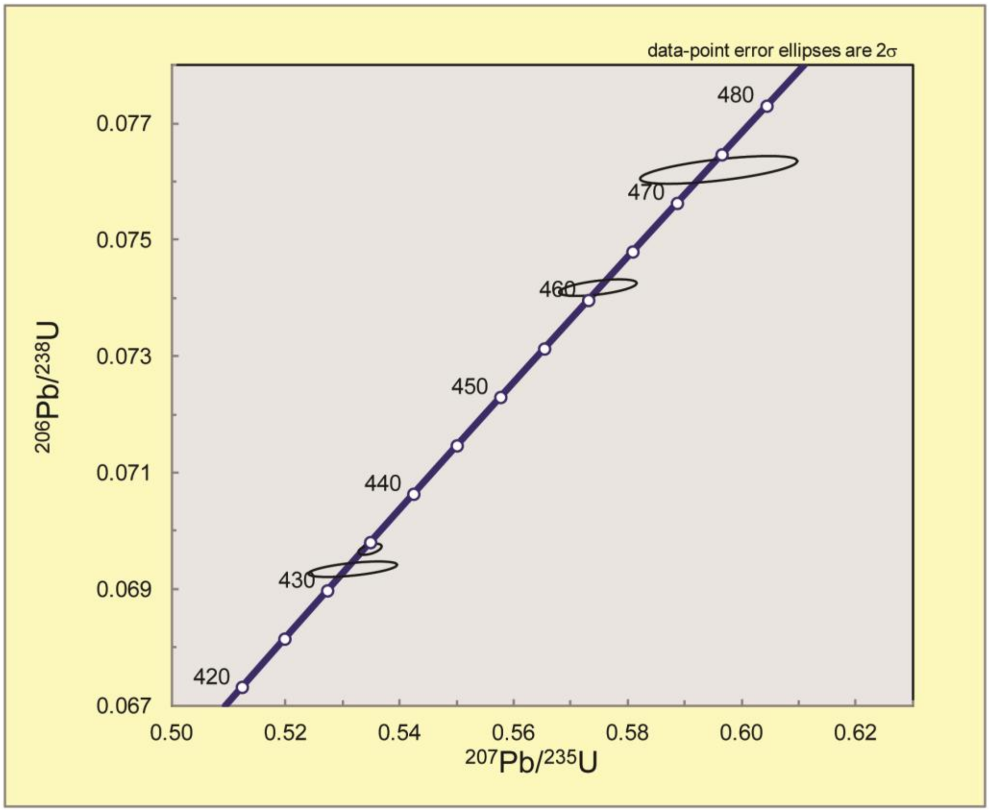

Figure 5.7 Concordia diagram of the ID-TIMS analysis of the four youngest grains in the Kittery Formation.

file name	207Pb/ 235U Ma	1s error Ma	206Pb/ 238U Ma	1s error Ma	207Pb/ 206Pb Ma	1s error Ma	U-Pb/Pb-Pb Concordancy%	Concordia age (Ma)	2s error Ma	Probability	Ratio Th/U
mr18a14	455	27	409	20	412	58	99	420	37.13	0.10	0.814
mr18b11	387	19	410	10	472	35	87	406	18.62	0.22	0.653
mr17b32	417	17	416	11	402	43	104	417	19.99	0.98	0.753
mr18b19	426	22	417	16	452	34	92	420	28.80	0.68	0.738
mr18a20	429	18	438	10	393	49	111	436	19.61	0.66	0.376
mr17a33	459	20	438	10	564	43	78	441	20.15	0.31	0.619
mr17a31	463	21	447	10	449	47	100	449	19.83	0.46	1.006
mr18b41	471	23	447	14	582	36	77	452	26.89	0.32	0.454
mr17a10	446	35	449	14	719	46	62	448	27.31	0.95	0.798
mr17b31	458	17	449	11	501	32	90	451	21.13	0.61	0.646
mr17b58	456	30	453	19	425	49	107	454	34.86	0.94	0.880
mr18a42	454	16	456	13	420	44	109	455	22.44	0.87	0.383
mr17b40	460	32	458	19	573	53	80	458	36.44	0.93	1.129
mr18a09	464	15	459	12	403	31	114	460	20.90	0.77	0.063
mr18b37	477	16	461	11	472	45	98	465	19.71	0.36	0.575
mr18a55	491	17	463	13	471	42	98	472	24.24	0.12	0.520
mr17a44	465	15	463	11	339	32	137	464	19.75	0.93	0.308
mr17a51	465	20	464	15	323	39	144	464	27.15	0.98	0.580
mr17a19	463	15	467	10	331	41	141	466	18.01	0.79	0.472
mr18a33	488	17	470	12	534	40	88	474	21.47	0.29	0.077
mr18b12	440	16	470	16	149	48	315	455	26.53	0.09	0.453
mr17a21	464	27	476	17	596	56	80	474	32.07	0.67	0.695
mr17a23	529	38	480	24	781	42	61	490	45.30	0.21	0.128
mr17b43	497	17	481	12	494	32	97	485	21.40	0.36	0.519
mr17a41	495	14	483	9	533	25	91	485	16.63	0.40	0.547
mr17b44	504	14	490	9	555	31	88	493	17.27	0.32	0.216
mr18a44	530	31	491	17	647	41	76	496	31.68	0.22	0.707
mr17a09	501	10	492	9	442	15	111	496	15.52	0.39	0.234
mr18b21	496	12	497	10	529	27	94	497	17.56	0.96	0.532

Table 5.2 U-Pb data from detrital zircon grains of the Kittery Formation with probability of concordance ≥0.05. The ages and associated error used in this study are highlighted in blue. Grains with Th/U ratios <.1 are highlighted in yellow. Grains used for the youngest age population are highlighted in pink.

file name	207Pb/ 235U Ma	1s error Ma	206Pb/ 238U Ma	1s error Ma	207Pb/ 206Pb Ma	1s error Ma	U-Pb/Pb-Pb Concordancy%	Concordia age (Ma)	2s error Ma	Probability	Ratio Th/U
mr17a07	506	10	502	7	474	22	106	503	13.05	0.75	0.460
mr17a20	499	17	509	11	576	35	88	506	20.28	0.60	0.830
mr17a28	522	31	514	25	552	31	93	516	44.31	0.81	0.170
mr18a51	537	23	536	13	658	36	81	536	24.66	0.97	0.426
mr18a21	516	31	548	14	530	50	103	544	27.61	0.30	0.406
mr17b41	805	42	749	39	904	22	83	773	67.03	0.23	0.098
mr17b38	780	65	776	33	774	73	100	776	62.53	0.95	0.524
mr17a39	1000	28	953	28	977	13	98	975	47.26	0.15	0.199
mr17a12	995	29	956	21	1127	29	85	966	37.40	0.22	0.320
mr17b54	992	36	986	29	1038	39	95	988	50.79	0.86	0.668
mr17a38	1028	15	1001	15	1009	16	99	1014	24.89	0.13	0.521
mr18b38	1040	28	1012	26	1002	36	101	1024	44.42	0.38	1.435
mr18b24	1062	25	1016	24	1047	29	97	1036	40.09	0.10	0.418
mr18a26	990	62	1019	34	983	48	104	1014	63.76	0.65	0.417
mr18b52	994	36	1033	29	1026	44	101	1019	50.52	0.33	0.799
mr17b39	1055	19	1066	23	1014	15	105	1059	34.17	0.65	0.259
mr18a43	1128	29	1083	23	1272	37	85	1097	40.47	0.16	0.453
mr17b30	1150	34	1113	32	1175	34	95	1129	53.57	0.34	0.460
mr17a18	1081	62	1116	57	977	53	114	1100	94.56	0.61	0.390
mr17a22	1162	22	1125	19	1091	24	103	1140	33.15	0.13	0.098
mr18b28	1217	21	1179	20	1178	20	100	1197	33.28	0.11	0.490
mr18a13	1163	22	1190	21	1099	22	108	1177	35.12	0.30	0.124
mr17a50	1126	33	1190	29	1012	33	118	1162	48.74	0.09	0.804
mr17a17	1299	32	1234	33	1285	37	96	1266	54.34	0.09	0.559
mr17a48	1288	24	1235	27	1237	20	100	1266	42.40	0.07	0.445
mr18b51	1347	51	1250	49	1363	29	92	1291	82.60	0.10	0.183
mr17b24	1312	51	1254	42	1366	20	92	1275	73.73	0.31	0.191
mr18b17	1288	34	1254	30	1289	27	97	1268	50.47	0.38	0.171
mr17b10	1347	30	1286	29	1415	25	91	1314	48.34	0.08	0.882

Table 5.2 continued. U-Pb data from detrital zircon grains of the Kittery Formation with probability of concordance ≥0.05. The ages and associated error used in this study are highlighted in blue. Grains with Th/U ratios <.1 are highlighted in yellow. Grains used for the youngest age population are highlighted in pink.

file name	207Pb/ 235U Ma	1s error Ma	206Pb/ 238U Ma	1s error Ma	207Pb/ 206Pb Ma	1s error Ma	U-Pb/Pb-Pb Concordancy%	Concordia age (Ma)	2s error Ma	Probability	Ratio Th/U
mr17b08	1328	49	1287	49	1344	25	96	1307	80.65	0.47	0.380
mr17b51	1330	29	1303	28	1307	24	100	1316	46.56	0.43	0.550
mr18a29	1373	120	1305	93	1431	48	91	1326	164.73	0.61	0.205
mr18a46	1363	34	1314	32	1375	30	96	1335	53.50	0.21	0.124
mr17b50	1377	23	1325	25	1322	24	100	1354	39.63	0.06	0.645
mr17b52	1379	30	1335	29	1417	23	94	1356	47.60	0.21	0.548
mr17b27	1369	21	1343	21	1347	20	100	1355	34.42	0.28	0.452
mr18a41	1356	30	1347	30	1267	25	106	1351	48.42	0.79	0.473
mr18a32	1379	30	1360	26	1435	24	95	1367	43.99	0.57	0.369
mr17b34	1510	104	1378	136	1657	68	83	1468	198.69	0.32	0.395
mr18b22	1473	40	1382	43	1548	31	89	1431	68.59	0.06	0.864
mr17b59	1365	40	1390	36	1570	46	89	1379	59.49	0.58	0.080
mr18a34	1449	22	1400	23	1526	19	92	1427	36.96	0.06	0.503
mr18b18	1493	39	1402	40	1580	20	89	1446	66.10	0.05	0.874
mr18b09	1438	18	1402	17	1385	17	101	1417	27.78	0.09	0.284
mr17b07	1463	29	1414	36	1475	19	96	1446	52.88	0.18	0.286
mr17b18	1495	33	1463	34	1482	20	99	1480	54.71	0.42	0.703
mr17b11	1474	24	1464	22	1388	25	105	1469	36.71	0.71	0.401
mr17a27	1469	26	1474	33	1347	31	109	1471	47.35	0.90	0.598
mr18b49	1617	47	1501	83	1585	14	95	1612	94.66	0.10	0.120
mr18b14	1517	22	1505	27	1442	16	104	1513	39.89	0.68	0.467
mr17a14	1531	40	1510	37	1581	31	95	1519	62.02	0.65	1.017
mr17a13	1556	15	1522	20	1490	15	102	1547	28.29	0.09	0.456
mr18a11	1479	20	1528	28	1329	22	115	1490	37.15	0.07	0.373
mr17b49	1562	20	1533	26	1515	20	101	1553	36.66	0.27	0.307
mr17b47	1592	16	1548	25	1531	13	101	1585	31.58	0.05	0.068
mr18a10	1618	23	1562	29	1628	22	96	1599	42.52	0.06	1.057
mr17a30	1667	59	1572	57	1826	32	86	1614	94.74	0.18	0.980
mr17b48	1618	22	1597	29	1575	16	101	1613	40.67	0.46	0.828

Table 5.2 continued. U-Pb data from detrital zircon grains of the Kittery Formation with probability of concordance ≥0.05. The ages and associated error used in this study are highlighted in blue. Grains with Th/U ratios <.1 are highlighted in yellow. Grains used for the youngest age population are highlighted in pink.

file name	207Pb/ 235U Ma	1s error Ma	206Pb/ 238U Ma	1s error Ma	207Pb/ 206Pb Ma	1s error Ma	U-Pb/Pb-Pb Concordancy%	Concordia age (Ma)	2s error Ma	Probability	Ratio Th/U
mr18b08	1609	31	1597	30	1703	26	94	1603	48.97	0.76	0.263
mr17b12	1642	22	1601	30	1589	18	101	1631	41.27	0.16	0.483
mr18a52	1615	19	1603	22	1497	19	107	1610	33.54	0.62	0.319
mr18a31	1627	19	1605	28	1518	21	106	1623	37.06	0.42	0.376
mr17a43	1613	29	1614	31	1537	33	105	1614	48.22	0.99	0.657
mr17a47	1626	30	1628	38	1526	27	107	1627	54.22	0.95	0.451
mr17a24	1685	27	1630	33	1671	22	98	1665	48.55	0.11	0.545
mr18b33	1673	18	1634	26	1637	16	100	1665	33.98	0.11	0.410
mr18a45	1688	20	1690	24	1533	20	110	1688	35.05	0.93	0.344
mr18a58	1749	23	1694	33	1624	21	104	1736	44.65	0.09	0.481
mr17a08	1839	25	1838	28	1779	19	103	1839	41.82	0.98	0.329
mr17a37	2993	22	2949	44	2863	14	103	2990	44.54	0.28	0.353
mr18b20	3041	14	3099	36	2846	9	109	3037	27.16	0.06	0.320

Table 5.2 continued. U-Pb data from detrital zircon grains of the Kittery Formation with probability of concordance ≥0.05. The ages and associated error used in this study are highlighted in blue. Grains with Th/U ratios <.1 are highlighted in yellow. Grains used for the youngest age population are highlighted in pink.

5.3 Eliot Formation – KSELI

KSELI Sample location and description

The Eliot Formation was sampled at Lee Five Corners in Lee, NH (Stop 5, trip A2, NEIGC field trip guide, 1995, p. A2-9) (Fargo and Bothner, 1995). The outcrop consists of generally thin bedded alterations of tan-gray weathering, turbiditic calcareous quartzite and silvery dark phyllite (Fargo and Bothner, 1995). This outcrop exhibits east-dipping cleavage and folding (Figure 5.8) as well as quartz veins throughout. Quartz veins were avoided during sample collection and removed prior to the sample being processed. The equigranular, fine-grained sample is composed primarily of quartz (55%) and carbonate (28%) and contains smaller amounts of muscovite (~15%) as shown in Appendix C.

Figure 5.8 Picture of the Eliot Formation (KSELI) outcrop in Lee, NH.

Eliot Formation U-Pb geochronology

For the analysis of the Eliot Formation 104 grains (Table 5.4) were used for analysis after 87 grains were excluded because of low probability of concordance, 13 were excluded due to high error values and 6 grains were excluded because of low U-Pb/Pb-Pb concordancy percentage values. Seven metamorphic grains were found based on Th/U ratios, with four of them being discordant and discarded from the detrital zircon analysis. The probability density plot of the Eliot Formation (Figure 5.9) shows a continuous range of grains from 413 to 1970 Ma with lows at 1773-1908 Ma and 600-800 Ma. There are also two Archean grains at 2654 and 2914 Ma.

Eliot Formation - KSELI youngest detrital zircon age population

The youngest detrital zircon age population for the Eliot Formation was determined from a weighted average of the $^{206}Pb/^{238}U$ ages of the four youngest grains that had a U-Pb/Pb-Pb concordancy percent between 85-115%, were concordant, and were not metamorphic. The weighted average was determined to be 409 ± 19 Ma (1σ error). Eight younger grains outside of the 85-115% U-Pb/Pb-Pb concordancy percentage range were excluded. The four youngest grains are similar in age and the ages overlap within error value. Although mr10b83 contains a crack and mr10b121 and mr10b108 appear to have irregular surfaces, all have low error values and U-Pb/Pb-Pb concordancy percents within 85-115%, thus were included in the youngest zircon age population.

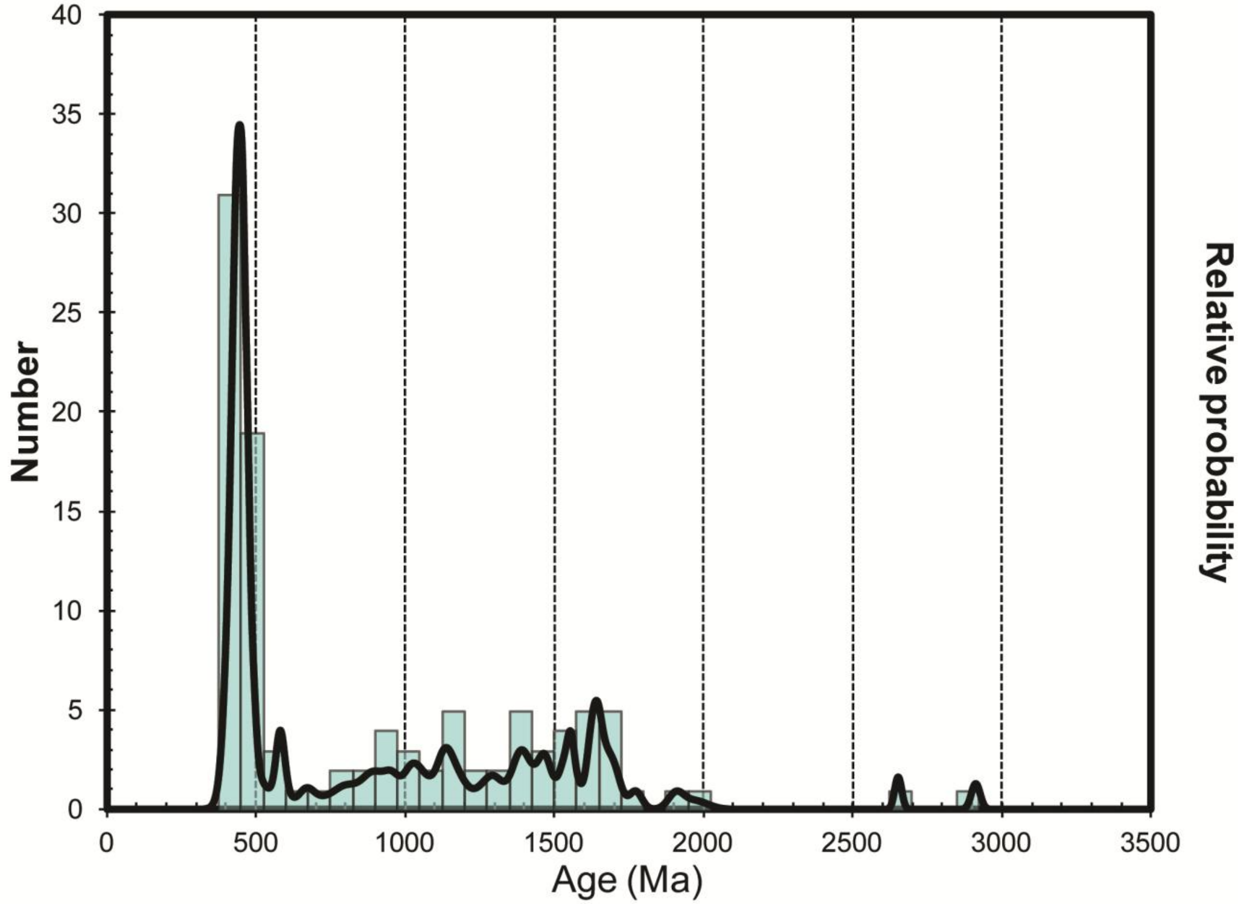

Figure 5.9 Probability density plot for the concordant grains (≥0.05 probability of concordance) for the Eliot Formation, $^{206}Pb/^{238}U$ age data for grains <800 Ma and $^{207}Pb/^{206}Pb$ age data for grains > 800 Ma.

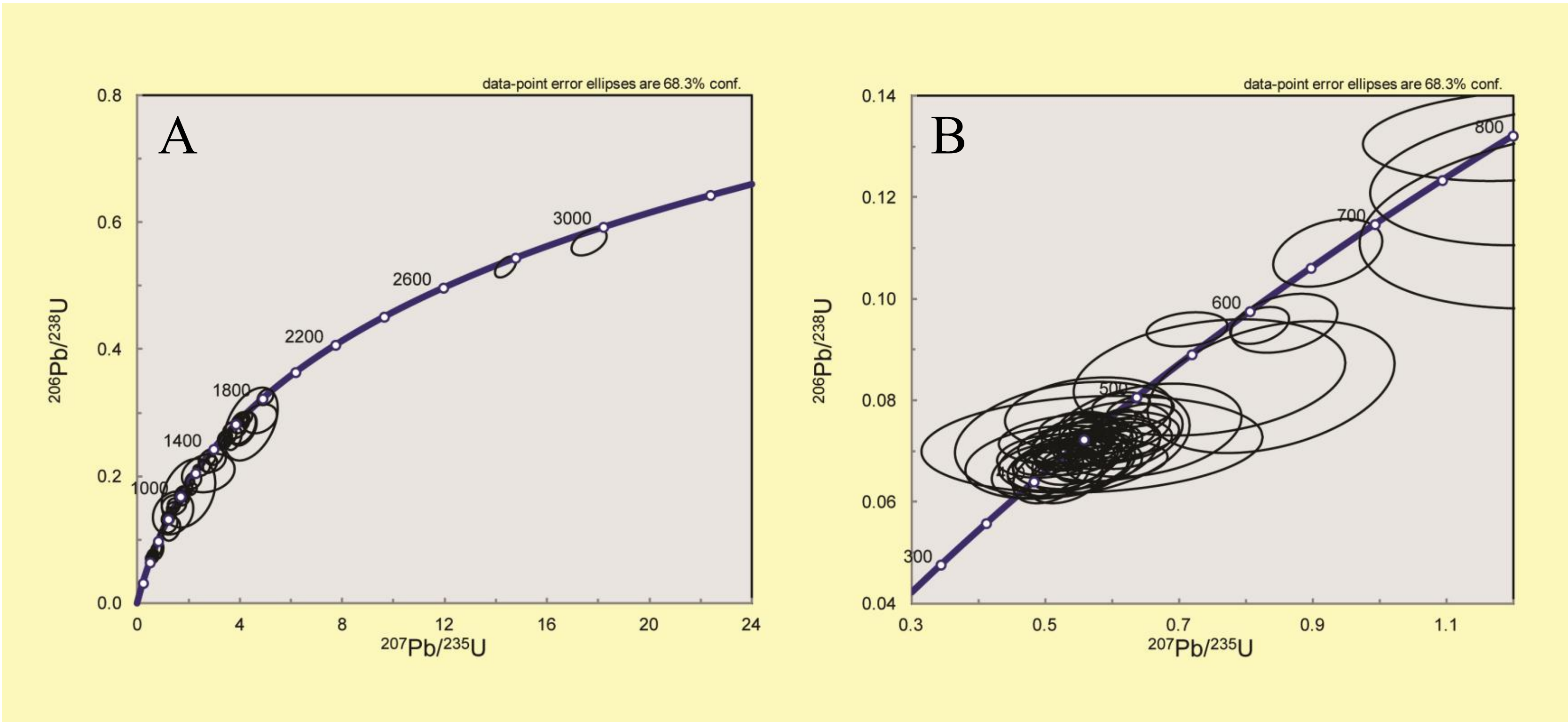

Figure 5.10 Concordia diagram for concordant data (≥0.05 probability of concordance) for the Eliot Formation A - All concordant data for the Eliot Formation B - Enlarged image of the younger age populations in the Eliot Formation

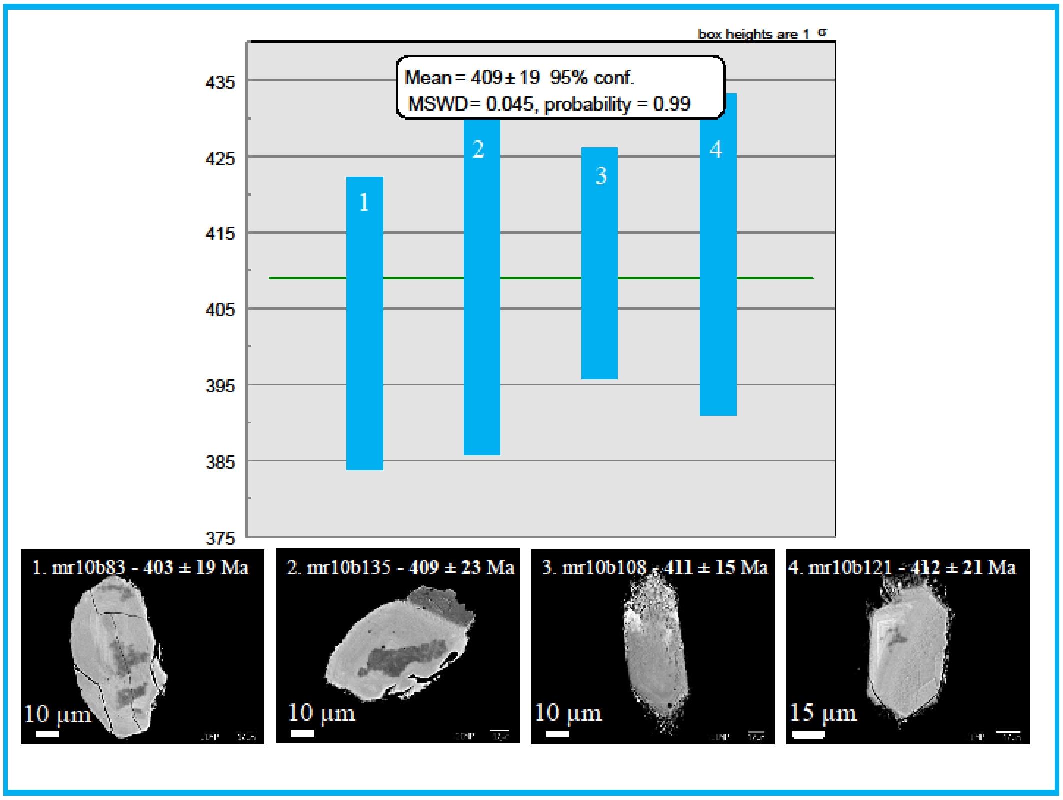

Figure 5.11 Weighted average of the four youngest detrital zircon grains for the Eliot Formation The weighted average is based upon $^{206}Pb/^{238}U$ ages and 1 sigma

file name	207Pb/ 235U Ma	1s error Ma	206Pb/ 238U Ma	1s error Ma	207Pb/ 206Pb Ma	1s error Ma	U-Pb/Pb-Pb Concordancy%	Concordia age (Ma)	2s error Ma	Probability	Ratio Th/U
mr10b83	432	24	403	19	461	24	87	412	35.09	0.244	0.309
mr10b135	418	26	409	23	355	29	115	413	40.77	0.729	0.390
mr10b108	435	24	411	15	374	37	110	416	28.60	0.339	0.661
mr10b121	404	31	412	21	372	30	111	410	39.03	0.798	0.353
mr10b118	423	32	416	18	590	27	71	417	33.36	0.836	0.238
mr10c07	434	39	416	23	493	35	84	420	43.64	0.657	0.557
mr09b07	410	18	421	9	493	37	85	420	17.45	0.529	0.506
mr10a23	444	42	422	20	477	34	88	425	39.16	0.605	0.598
mr09b94	417	56	423	28	580	56	73	422	54.43	0.917	0.756
mr10b119	431	43	423	23	723	37	59	424	43.94	0.851	0.528
mr09b69	440	27	423	18	484	35	88	427	33.34	0.551	0.737
mr10a22	470	40	425	16	610	38	70	428	31.79	0.262	0.534
mr09b11	421	12	428	9	302	34	142	426	16.64	0.573	0.392
mr10b126	454	22	428	19	459	27	93	438	33.93	0.269	0.297
mr10b120	414	34	430	17	671	41	64	428	31.96	0.642	0.164
mr10b18	438	30	432	16	452	42	95	433	30.51	0.829	0.911
mr09b80	437	23	432	13	468	38	92	433	24.53	0.855	0.218
mr10b11	428	19	433	8	488	33	89	433	14.96	0.794	0.645
mr10b10	466	20	437	14	542	22	81	444	26.22	0.165	0.009
mr10b125	477	30	437	25	551	37	79	451	45.28	0.193	0.280
mr09b49	462	10	441	8	418	22	105	447	14.19	0.051	0.465
mr11a21	423	26	442	14	546	36	81	439	25.75	0.472	0.248
mr10c12	443	29	442	18	547	29	81	443	34.17	0.993	0.424
mr10b24	449	15	444	10	445	26	100	445	18.64	0.735	0.117
mr10b79	458	109	444	38	668	35	66	445	73.78	0.900	0.317
mr11a22	464	24	445	16	552	33	81	449	29.52	0.439	0.296
mr09b35	449	19	446	10	454	39	98	446	19.40	0.851	0.405
mr09b61	453	35	446	17	572	54	78	447	32.91	0.838	0.304
mr09b50	484	26	448	15	683	47	66	454	28.79	0.168	0.838

Table 5.4. U-Pb data from detrital zircon grains of the Eliot Formation with probability of concordance ≥0.05. The ages and associated error used in this study are highlighted in blue. Grains with Th/U ratios <0.1 are highlighted in yellow. Grains used for the youngest age population are highlighted in pink.

file name	207Pb/ 235U Ma	1s error Ma	206Pb/ 238U Ma	1s error Ma	207Pb/ 206Pb Ma	1s error Ma	U-Pb/Pb-Pb Concordancy%	Concordia age (Ma)	2s error Ma	Probability	Ratio Th/U
mr09b21	474	15	449	10	565	31	79	455	19.28	0.114	0.695
mr10b51	452	56	450	21	432	41	104	450	40.77	0.971	0.377
mr11a19	439	76	451	44	478	49	94	448	83.66	0.882	0.651
mr10b33	466	11	453	7	465	21	97	455	13.25	0.250	0.606
mr09b68	497	31	453	26	595	47	76	468	46.24	0.178	0.608
mr09b13	486	21	455	10	648	39	70	459	20.22	0.147	0.691
mr09b55	453	29	455	15	631	50	72	454	28.92	0.957	0.810
mr10b14	443	16	456	7	520	32	88	454	12.94	0.426	0.784
mr10a19	485	37	456	18	490	41	93	459	34.41	0.448	0.323
mr10b127	509	58	461	37	698	33	66	470	69.16	0.420	0.448
mr09b09	460	16	463	9	520	34	89	462	16.57	0.899	0.293
mr10b53	445	25	464	13	391	33	119	461	24.36	0.469	0.497
mr09b93	480	35	464	20	762	43	61	467	37.49	0.666	0.166
mr09b79	452	11	468	8	76	34	613	463	14.51	0.163	0.676
mr10b45	484	16	471	8	479	30	98	473	15.60	0.437	0.245
mr09b59	483	11	473	9	366	31	129	476	15.56	0.368	0.180
mr09b99	455	53	481	28	334	64	144	477	53.22	0.627	0.643
mr09b76	504	20	484	12	504	27	96	488	23.04	0.347	0.123
mr09b65	486	18	490	10	506	35	97	489	19.43	0.822	0.308
mr10b107	618	67	512	51	739	26	69	538	95.23	0.130	0.091
mr11a14	566	78	523	45	851	40	61	530	85.77	0.596	0.569
mr10b22	546	24	579	13	695	36	83	572	24.74	0.178	0.703
mr09b38	609	16	583	14	591	34	99	593	25.13	0.149	0.748
mr10b07	629	29	586	23	708	28	83	599	40.91	0.162	0.331
mr09b41	664	28	667	26	502	58	133	666	44.00	0.901	0.896
mr10b100	857	103	709	69	1297	28	55	737	131.21	0.178	0.322
mr10a16	832	83	755	52	858	31	88	770	98.01	0.387	0.307
mr09b62	803	70	799	33	1257	46	64	800	63.86	0.957	0.332
mr09b60	818	48	828	49	851	43	97	823	79.89	0.849	0.367

Table 5.4 continued. U-Pb data from detrital zircon grains of the Eliot Formation with probability of concordance ≥0.05. The ages and associated error used in this study are highlighted in blue. Grains with Th/U ratios <0.1 are highlighted in yellow. Grains used for the youngest age population are highlighted in pink.

file name	207Pb/ 235U Ma	1s error Ma	206Pb/ 238U Ma	1s error Ma	207Pb/ 206Pb Ma	1s error Ma	U-Pb/Pb-Pb Concordancy%	Concordia age (Ma)	2s error Ma	Probability	Ratio Th/U
mr09b39	1004	25	1011	28	876	36	115	1007	43.66	0.813	0.695
mr09b08	888	31	854	34	903	32	95	874	54.71	0.347	0.457
mr10a21	1041	53	1024	38	904	39	113	1029	68.34	0.760	0.692
mr09b52	957	24	919	22	955	27	96	934	37.93	0.165	0.820
mr09b42	884	32	872	23	960	27	91	875	41.43	0.726	0.595
mr09b70	1029	21	983	20	1013	23	97	1003	34.01	0.058	0.386
mr10b71	1016	32	986	33	1031	32	96	1001	53.90	0.402	1.302
mr10b75	1028	25	1013	21	1041	27	97	1019	37.20	0.608	0.796
mr09b43	790	69	811	39	1071	42	76	807	73.05	0.763	0.816
mr09b29	1117	31	1051	31	1094	37	96	1082	52.06	0.068	0.551
mr10b52	1161	20	1126	17	1129	22	100	1139	29.50	0.119	0.250
mr09b32	888	64	901	33	1134	39	79	899	62.96	0.850	0.336
mr10b98	1158	43	1067	33	1143	25	93	1093	58.92	0.052	0.326
mr10b50	898	132	924	60	1168	35	79	920	114.43	0.847	0.253
mr10b64	1121	26	1068	24	1178	30	91	1089	40.54	0.076	0.474
mr09b97	1029	74	1023	46	1237	41	83	1025	85.21	0.938	0.727
mr10b109	882	222	857	128	1271	31	67	862	240.01	0.917	0.156
mr10b19	1222	27	1240	20	1299	26	95	1234	35.03	0.556	0.746
mr10c19	1033	62	972	32	1334	41	73	981	60.51	0.358	0.827
mr10b128	1116	235	1028	197	1384	28	74	1058	348.58	0.737	0.121
mr10b09	1373	29	1317	26	1385	24	95	1340	44.27	0.089	0.305
mr11a23	1292	48	1245	43	1388	39	90	1264	73.73	0.397	0.395
mr10c08	893	63	939	29	1408	49	67	932	55.98	0.478	0.492
mr09b95	1174	67	1142	47	1415	27	81	1150	84.81	0.661	0.280
mr10c17	1365	48	1270	46	1466	23	87	1311	77.45	0.089	0.399
mr10a10	1387	91	1308	64	1466	30	89	1328	115.87	0.435	0.587
mr10c13	1422	49	1349	55	1470	20	92	1389	86.22	0.220	0.755
mr10b13	1520	26	1458	31	1523	20	96	1495	46.82	0.057	0.578
mr09b96	1534	20	1510	28	1538	16	98	1528	38.46	0.372	0.108

Table 5.4 continued. U-Pb data from detrital zircon grains of the Eliot Formation with probability of concordance ≥0.05. The ages and associated error used in this study are highlighted in blue. Grains with Th/U ratios <0.1 are highlighted in yellow. Grains used for the youngest age population are highlighted in pink.

file name	207Pb/ 235U Ma	1s error Ma	206Pb/ 238U Ma	1s error Ma	207Pb/ 206Pb Ma	1s error Ma	U-Pb/Pb-Pb Concordancy%	Concordia age (Ma)	2s error Ma	Probability	Ratio Th/U
mr11a11	1565	27	1503	38	1555	11	97	1550	51.22	0.086	0.414
mr10b48	1512	39	1468	44	1567	17	94	1493	68.39	0.355	0.305
mr10a15	1349	181	1202	108	1583	40	76	1227	204.15	0.464	0.662
mr10b132	1639	47	1609	55	1623	17	99	1627	82.92	0.611	1.019
mr09b12	1659	20	1631	21	1629	17	100	1646	32.88	0.246	0.348
mr10b78	1695	21	1649	28	1630	16	101	1681	39.88	0.104	0.959
mr11a09	1585	45	1483	62	1647	13	90	1557	87.15	0.088	0.881
mr09b81	1671	22	1626	30	1656	17	98	1658	40.94	0.122	0.595
mr10b116	1591	63	1557	47	1668	34	93	1567	83.17	0.623	0.560
mr10b130	1507	42	1491	37	1672	20	89	1497	63.01	0.736	0.766
mr10c18	1655	67	1573	86	1693	22	93	1628	124.89	0.349	0.463
mr11a13	1664	66	1562	87	1709	22	91	1633	124.72	0.237	1.005
mr10b137	1718	130	1600	191	1773	21	90	1692	255.47	0.510	0.629
mr09b30	1822	35	1811	42	1908	26	95	1817	61.77	0.809	0.027
mr10b23	1780	78	1641	75	1970	44	83	1700	126.04	0.135	1.109
mr09b24	2775	18	2740	45	2654	12	103	2777	35.46	0.368	0.693
mr09b20	2971	25	2899	57	2914	15	99	2972	49.85	0.153	0.475

Table 5.4 continued. U-Pb data from detrital zircon grains of the Eliot Formation with probability of concordance ≥0.05. The ages and associated error used in this study are highlighted in blue. Grains with Th/U ratios <0.1 are highlighted in yellow. Grains used for the youngest age population are highlighted in pink.

5.4 Berwick Formation – KSBWI

KSBWI Sample location and description

The Berwick Formation was sampled at an outcrop located at the MSPCA/Nevins Farm on Route 28 in Methuen, MA. The outcrop was located near the rear of the property next to a storage facility and hiking trails. The outcrop consists of a fine-grained, light-gray to purplish gray calcareous metasiltstone with beds centimeters to 1 meter thick and interbeds of a dark-gray micaceous phyllite (Bedrock Map of the Lawrence Quadrangle, Castle et al., 2005, in review). The rock is fine-grained, equigranular with ~60% quartz, ~20% muscovite, ~15% carbonate and has a small amount of iron oxides, that have led to iron staining as noted in Appendix C.

Figure 5.12 Picture of the Berwick Formation (KSBWI) outcrop in Methuen, MA.

Berwick Formation U-Pb geochronology

For the analysis of the Berwick Formation 128 grains (Table 5.5) were used for analysis after 61 grains were excluded for low probability of concordance, four grains were excluded for high error values, and four grains were excluded for the U-Pb/Pb-Pb concordancy percentage values being either too high or too low. Of the 128 grains used for analysis four were metamorphic grains based on Th/U ratios. The probability density plot (Figure 5.13) of the Berwick Formation shows a continuous range of grains from 412-1826 Ma with a low 705-922 Ma. There is also one outlier grain in the Paleoproterozoic at 2285 Ma and three Archean grains aged 2708, 2729 and 2790 Ma forming a minor peak.

Berwick Formation. - KSBWI youngest detrital zircon age populations

The Berwick Formation has a continuous age input from ~402 Ma until~480 Ma. After four young grains outside of the 85-115% U-Pb/Pb-Pb concordancy percent range were excluded, the five remaining youngest grains provided a weighted mean of 409 ± 11 Ma (1σ error and $^{206}Pb/^{238}U$ ages). Although mr05a47, mr05a133 and mr09a11 contain cracks, they had acceptable error values and U-Pb/Pb-Pb concordancy percentage values close to 100%.

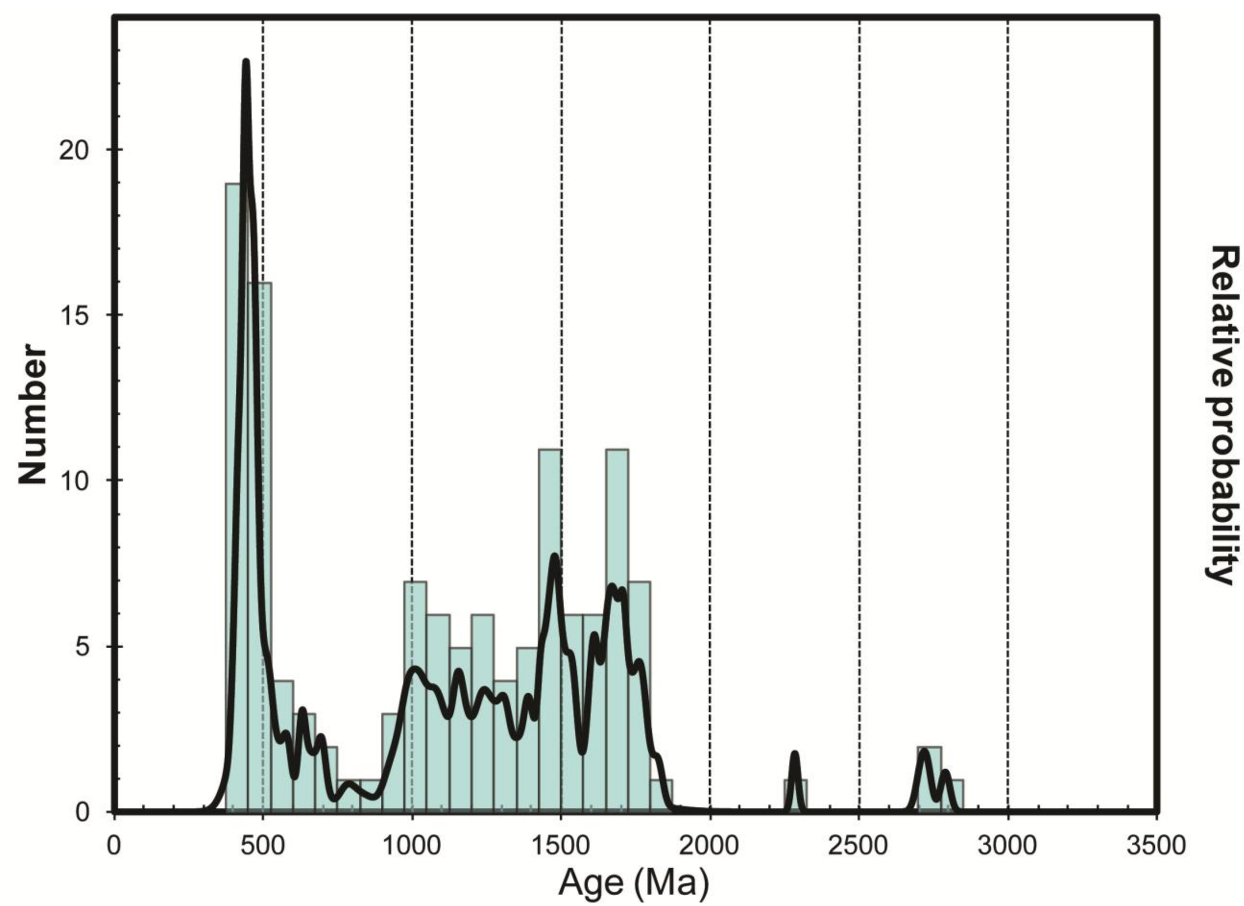

Figure 5.13 Probability density plot for the concordant grains (≥0.05 probability of concordance) for the Berwick Formation, $^{206}Pb/^{238}U$ age data for grains <800 Ma and $^{207}Pb/^{206}Pb$ age data for grains > 800 Ma.

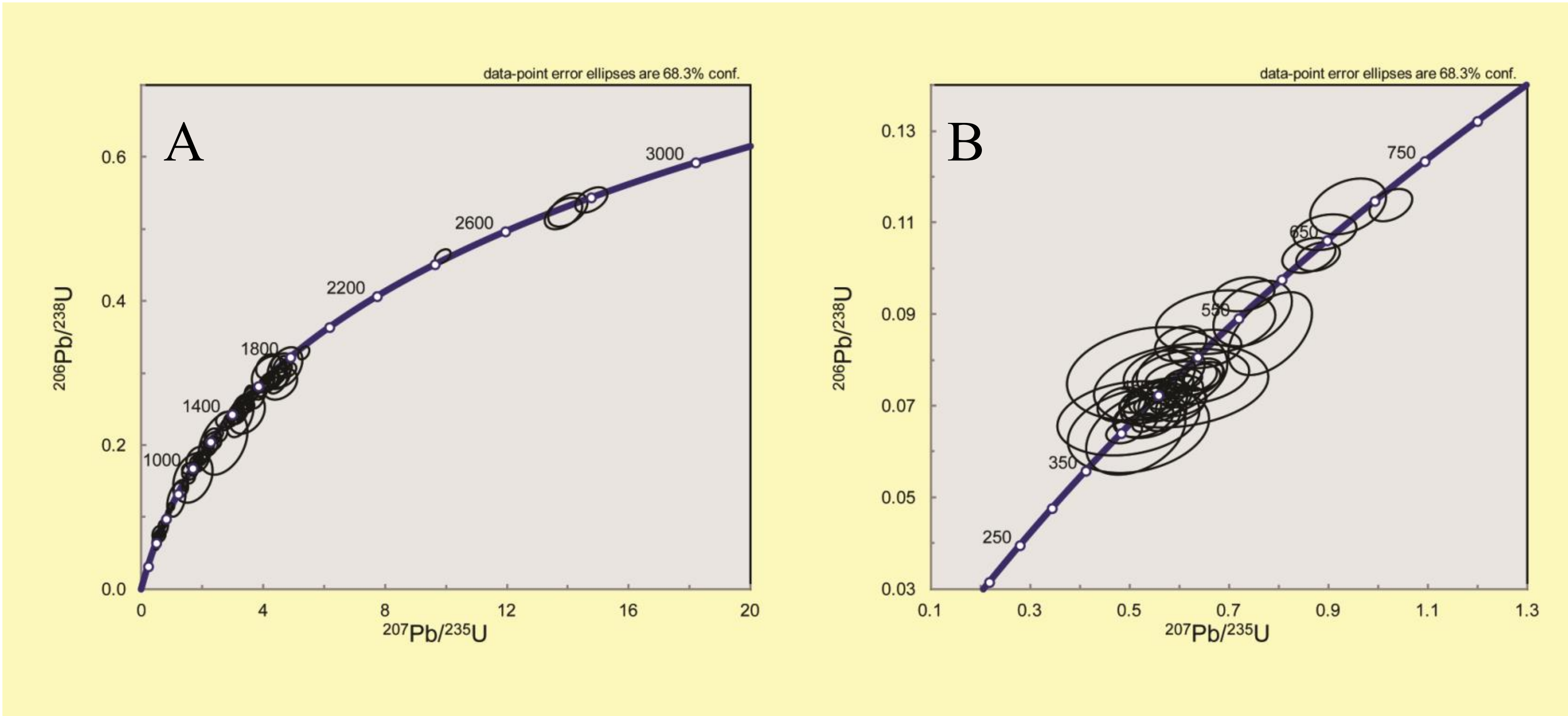

Figure 5.14 Concordia diagram for concordant data (≥0.05 probability of concordance) for the Berwick Formation A - All concordant data for the Berwick Formation B - Enlarged image of the younger age populations in the Berwick Formation

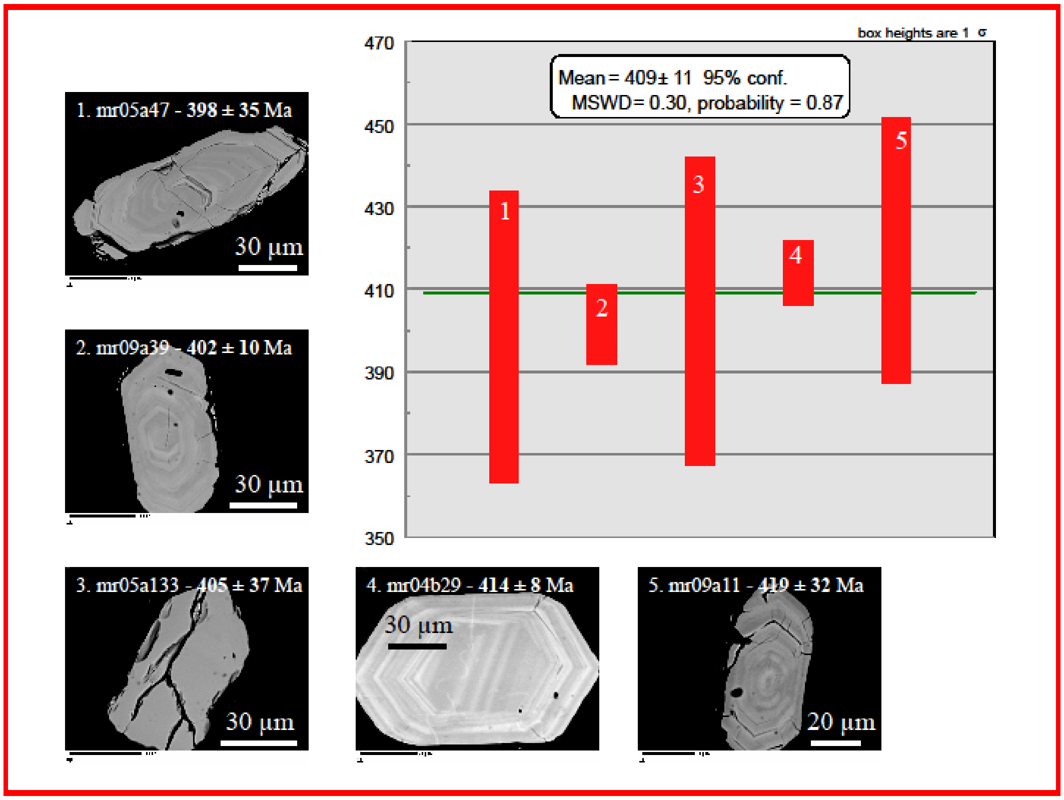

Figure 5.15. Weighted average of the five youngest detrital zircon grains for the Berwick Formation. The weighted average is based on $^{206}Pb/^{238}U$ ages and 1 sigma errors.

file name	207Pb/ 235U Ma	1s error Ma	206Pb/ 238U Ma	1s error Ma	207Pb/ 206Pb Ma	1s error Ma	U-Pb/Pb-Pb concordancy%	Concordia age (Ma)	2s error Ma	Probability	Ratio Th/U
mr05a47	421	44	398	35	412	23	97	406	64	0.63	0.566
mr09a39	404	16	402	10	359	25	112	402	18	0.86	0.989
mr05a133	424	63	405	37	417	45	97	408	71	0.76	0.551
mr04b29	432	11	414	8	398	22	104	419	14	0.11	0.689
mr09a11	411	64	419	32	373	39	112	418	62	0.89	1.280
mr09a19	436	29	420	17	450	28	93	423	33	0.59	0.327
mr09a10	430	26	420	17	383	30	110	422	31	0.70	0.523
mr04b12	458	19	425	14	485	27	88	434	26	0.09	0.715
mr04b59	427	18	432	13	452	42	95	430	23	0.82	1.233
mr04b73	401	22	438	15	327	41	134	428	27	0.10	0.623
mr04b10	446	18	438	10	548	25	80	439	18	0.67	0.965
mr04b14	479	21	439	15	606	33	72	449	28	0.06	0.833
mr05a146	432	22	439	14	418	42	105	437	26	0.74	0.369
mr05a130	438	23	439	17	470	26	93	439	31	0.96	0.207
mr05a46	419	13	440	9	358	24	123	435	16	0.11	0.465
mr05a139	456	21	441	17	531	27	83	446	30	0.49	0.537
mr05a37	476	24	442	13	424	39	104	447	25	0.17	0.919
mr05a63	455	11	443	8	464	28	95	446	14	0.32	0.868
mr05a113	453	27	446	17	494	29	90	448	32	0.82	0.586
mr04b94	460	18	453	14	458	30	99	455	25	0.68	0.659
mr04b40	479	19	454	14	517	33	88	461	25	0.21	0.646
mr05a87	466	11	458	9	436	21	105	460	16	0.45	0.620
mr09a15	480	73	463	37	709	44	65	465	70	0.82	0.713
mr05a57	474	14	465	9	461	27	101	467	16	0.54	0.672
mr04b75	483	16	471	9	486	26	97	473	18	0.46	0.507
mr05a67	482	31	471	15	452	46	104	472	29	0.74	0.600
mr04b35	503	14	474	11	494	22	96	483	21	0.05	0.474
mr05a119	492	49	474	24	783	45	61	476	46	0.72	0.486
mr05a106	503	19	474	16	483	16	98	484	28	0.16	0.241
mr04b28	508	17	475	12	648	37	73	484	22	0.06	0.755
mr05a108	451	31	478	20	444	177	108	471	37	0.41	0.811
mr05a124	435	70	478	40	417	42	115	469	75	0.55	0.275

Table 5.5 U-Pb data from detrital zircon grains of the Berwick Formation with probability of concordance ≥0.05. The ages and associated error used in this study are highlighted in blue. Grains with Th/U ratios <0.1 are highlighted in yellow. Grains used for the youngest age population are highlighted in pink.

file name	207Pb/ 235U Ma	1s error Ma	206Pb/ 238U Ma	1s error Ma	207Pb/ 206Pb Ma	1s error Ma	U-Pb/Pb-Pb concordancy%	Concordia age (Ma)	2s error Ma	Probability	Ratio Th/U
mr05a70	466	29	481	21	356	47	135	477	38	0.60	0.789
mr05a110	510	29	511	17	575	41	89	510	31	0.98	0.778
mr04b79	479	22	517	15	341	35	152	506	27	0.09	0.663
mr05a116	587	32	531	35	495	37	107	564	58	0.10	0.475
mr05a91	523	48	545	27	517	42	105	540	51	0.66	0.757
mr04b62	567	30	556	28	478	39	116	561	48	0.75	0.609
mr04b34	557	24	581	14	437	30	133	576	26	0.32	0.727
mr05a62	641	16	629	12	626	22	101	633	22	0.50	0.127
mr04b96	631	19	631	15	588	43	107	631	26	0.99	0.435
mr05a69	648	22	660	15	801	35	82	657	28	0.59	0.394
mr05a78	673	26	693	24	742	45	93	685	40	0.48	0.605
mr04b63	716	14	695	14	697	25	100	705	23	0.17	0.427
mr05a105	841	72	840	46	838	40	100	840	84	0.99	0.472
mr04b95	908	27	883	35	923	24	96	901	52	0.45	0.354
mr04b82	912	23	890	22	779	28	114	900	37	0.41	0.681
mr04b33	974	41	926	28	1030	19	90	938	52	0.27	1.095
mr05a147	1005	163	927	126	1237	25	75	950	228	0.66	0.209
mr04b09	1004	28	973	21	1102	26	88	983	37	0.30	0.787
mr05a13	1003	25	978	20	1003	30	97	987	35	0.35	0.323
mr05a23	968	68	978	44	965	37	101	976	81	0.88	1.396
mr05a81	994	21	986	20	1010	25	98	990	33	0.74	0.318
mr05a80	987	23	988	20	964	27	102	987	34	0.98	0.359
mr09a18	945	52	997	26	1164	41	86	989	49	0.33	0.491
mr04b39	1038	24	1002	23	987	23	101	1018	38	0.18	0.342
mr05a39	995	25	1006	28	981	32	103	1000	43	0.70	0.287
mr05a31	1057	37	1036	50	1101	42	94	1052	71	0.65	0.571
mr05a79	1008	30	1049	26	1009	29	104	1032	44	0.22	0.605
mr05a89	1071	16	1061	16	1071	22	99	1066	27	0.56	0.272
mr09a29	1063	88	1065	62	1079	79	99	1065	112	0.98	12.698
mr05a51	1116	27	1068	28	1099	25	97	1093	45	0.12	0.566
mr04b68	1125	33	1069	23	1171	34	91	1084	42	0.12	0.624
mr04b57	1089	22	1077	22	1070	25	101	1083	36	0.63	0.386

Table 5.5 continued. U-Pb data from detrital zircon grains of the Berwick Formation with probability of concordance ≥0.05. The ages and associated error used in this study are highlighted in blue. Grains with Th/U ratios <0.1 are highlighted in yellow. Grains used for the youngest age population are highlighted in pink.

file name	207Pb/ 235U Ma	1s error Ma	206Pb/ 238U Ma	1s error Ma	207Pb/ 206Pb Ma	1s error Ma	U-Pb/Pb-Pb concordancy%	Concordia age (Ma)	2s error Ma	Probability	Ratio Th/U
mr05a135	1065	32	1081	27	1161	27	93	1075	47	0.65	0.344
mr04b53	1132	26	1093	27	1050	23	104	1112	44	0.20	1.003
mr05a144	1151	34	1102	35	1247	21	88	1126	57	0.22	0.417
mr04b23	1154	26	1110	25	1229	32	90	1130	42	0.14	0.295
mr05a42	1158	18	1139	21	1152	16	99	1151	32	0.36	0.077
mr05a41	1207	46	1167	48	1286	23	91	1188	78	0.46	0.178
mr04b24	1210	20	1170	18	1231	25	95	1187	31	0.07	0.380
mr05a40	1138	22	1177	20	1163	25	101	1161	33	0.12	0.595
mr05a30	1250	37	1189	32	1355	17	88	1212	55	0.14	0.284
mr09a22	1323	147	1189	157	1397	18	85	1256	258	0.44	0.080
mr09a24	1221	57	1198	51	1204	36	100	1208	86	0.72	0.379
mr05a128	1222	54	1236	42	1380	35	90	1231	73	0.81	1.003
mr04b18	1287	25	1254	23	1275	19	98	1268	39	0.25	0.303
mr04b72	1310	34	1257	37	1312	26	96	1286	58	0.19	0.805
mr04b67	1352	30	1330	31	1312	23	101	1341	50	0.55	0.487
mr09a08	1341	55	1362	36	1714	53	79	1356	66	0.73	0.313
mr09a31	1394	43	1365	36	1438	26	95	1376	62	0.55	0.467
mr05a56	1400	23	1372	25	1497	27	92	1389	39	0.30	0.652
mr05a107	1469	70	1384	99	1387	14	100	1448	136	0.36	0.378
mr05a126	1521	88	1400	93	1760	16	80	1460	152	0.26	0.999
mr05a92	1458	28	1401	45	1531	24	92	1452	55	0.14	0.927
mr09a13	1448	35	1408	30	1448	19	97	1424	52	0.33	0.029
mr05a138	1449	49	1409	50	1548	23	91	1429	81	0.49	1.167
mr05a141	1482	29	1412	35	1525	20	93	1456	53	0.06	0.632
mr05a49	1422	23	1418	19	1420	41	100	1420	33	0.87	0.612
mr04b49	1456	19	1444	29	1312	17	110	1454	37	0.64	0.325
mr04b60	1503	28	1453	36	1475	17	99	1487	52	0.16	0.362
mr05a43	1514	39	1455	29	1535	107	95	1473	52	0.18	0.297
mr05a109	1490	50	1467	51	1480	21	99	1479	82	0.71	0.249
mr05a33	1493	27	1473	32	1494	17	99	1486	48	0.55	1.014
mr04b11	1515	21	1482	29	1431	10	104	1507	39	0.23	0.076
mr04b58	1534	22	1499	26	1462	15	102	1520	39	0.20	0.344

Table 5.5 continued. U-Pb data from detrital zircon grains of the Berwick Formation with probability of concordance ≥0.05. The ages and associated error used in this study are highlighted in blue. Grains with Th/U ratios <0.1 are highlighted in yellow. Grains used for the youngest age population are highlighted in pink.

file name	207Pb/ 235U Ma	1s error Ma	206Pb/ 238U Ma	1s error Ma	207Pb/ 206Pb Ma	1s error Ma	U-Pb/Pb-Pb concordancy%	Concordia age (Ma)	2s error Ma	Probability	Ratio Th/U
mr05a76	1538	15	1512	26	1478	12	102	1537	30	0.23	0.347
mr05a117	1596	35	1521	50	1540	15	99	1578	68	0.11	0.307
mr05a53	1539	18	1529	24	1490	16	103	1536	34	0.69	0.310
mr05a145	1543	35	1536	38	1609	18	95	1540	59	0.87	0.239
mr04b83	1615	29	1550	30	1667	21	93	1583	49	0.06	0.952
mr05a61	1532	17	1567	25	1452	14	108	1539	33	0.14	0.211
mr05a140	1623	27	1579	34	1669	17	95	1609	50	0.20	0.300
mr05a36	1599	25	1585	25	1650	18	96	1592	40	0.63	0.820
mr09a09	1741	66	1616	71	1716	22	94	1680	114	0.13	1.037
mr05a129	1657	35	1623	44	1695	18	96	1646	64	0.45	1.187
mr04b08	1666	24	1628	28	1517	21	107	1652	42	0.20	0.352
mr05a123	1681	31	1637	50	1609	17	102	1675	61	0.32	0.595
mr05a115	1723	41	1637	58	1666	16	98	1701	80	0.12	0.524
mr09a32	1685	35	1639	38	1670	23	98	1663	60	0.29	0.301
mr05a38	1697	31	1644	31	1785	25	92	1671	50	0.15	0.997
mr05a68	1657	14	1646	20	1614	12	102	1655	26	0.56	0.402
mr05a59	1665	19	1657	26	1595	15	104	1663	36	0.76	0.999
mr04b84	1718	36	1665	38	1756	23	95	1692	60	0.23	0.913
mr05a104	1732	45	1666	55	1704	18	98	1708	81	0.25	0.491
mr05a134	1670	73	1685	83	1643	16	103	1676	125	0.86	0.198
mr05a48	1777	40	1714	35	1769	101	97	1738	59	0.18	0.875
mr09a25	1768	28	1716	31	1688	16	102	1745	48	0.15	0.665
mr05a73	1746	34	1732	49	1732	16	100	1743	64	0.77	0.735
mr05a136	1769	68	1733	91	1777	17	98	1759	127	0.70	0.410
mr05a103	1668	52	1734	55	1629	36	106	1697	85	0.30	2.027
mr05a71	1761	13	1749	21	1709	10	102	1759	26	0.50	0.129
mr09a14	1748	41	1758	43	1754	30	100	1753	67	0.84	0.610
mr05a15	1873	19	1828	28	1826	16	100	1862	37	0.10	0.293
mr04b22	2425	15	2449	28	2285	11	107	2427	30	0.36	0.995
mr04b51	2741	28	2706	60	2708	18	100	2740	56	0.51	1.773
mr05a60	2750	29	2727	63	2729	16	100	2750	58	0.69	0.615
mr05a93	2801	22	2784	49	2791	16	100	2801	45	0.69	1.198

Table 5.5 continued. U-Pb data from detrital zircon grains of the Berwick Formation with probability of concordance ≥0.05. The ages and associated error used in this study are highlighted in blue. Grains with Th/U ratios <0.1 are highlighted in yellow. Grains used for the youngest age population are highlighted in pink.

5.5 Oakdale Formation – KSOKI

KSOKI Sample location and description

The Oakdale Formation was sampled from an outcrop located near the type locality from the 1976 NEIGC field trip guide, trip F2, stop 2, p. 373 (Hepburn, 1976). It was located along the railroad tracks about 150 meters west of Prescott St. in W. Boylston, MA. This outcrop is a gray-weathering, light gray phyllite and quartz-rich phyllite, interbedded with tan to gray-green weathering beds of meta-siltstone and impure quartzite. It is fine-grained and equigranular composed largely of quartz, roughly 55%, with the remainder of the sample being composed of 25% carbonate, 13% muscovite and other minor minerals. The modal composition and images of thin sections of the sample are shown in Appendix C.

Figure 5.16 Picture of the Oakdale Formation (KSOKI) outcrop in W. Boylston, MA.

Oakdale Formation U-Pb geochronology

One hundred and one grains were used for analysis of the Oakdale Formation (Table 5.6) after 62 grains were excluded for low probability of concordance, three grains were excluded for high error values and four young grains were excluded for U-Pb/Pb-Pb concordancy percentage values too high or low. Three of the grains excluded were interpreted as metamorphic based on Th/U ratios. Seven concordant grains were also interpreted as metamorphic and were included in this study. Two main age populations were 432 to 683 Ma and 997 to 1903 Ma (Figure 5.17). Only three grains fell between the two age ranges at: 749, 780 and 878 Ma, and two grains fell outside of these ranges at 2022 and 2745 Ma.

Oakdale Formation - KSOKI youngest detrital zircon age populations

The youngest detrital zircon age population for the Oakdale Formation was determined from a weighted average of the $^{206}Pb/^{238}U$ age of the four youngest grains and was 431 ± 12 Ma (1σ error). After seven young grains were excluded due to low/high U-Pb/Pb-Pb concordancy percent values, the four youngest grains were used to determine a weighted mean and provided the best interpretation. Although mr16b23 and mr16b24 contain cracks and mr16b23 appears to have an irregular surface, all are concordant, have acceptable U-Pb/Pb-Pb concordancy percentage values and low error values

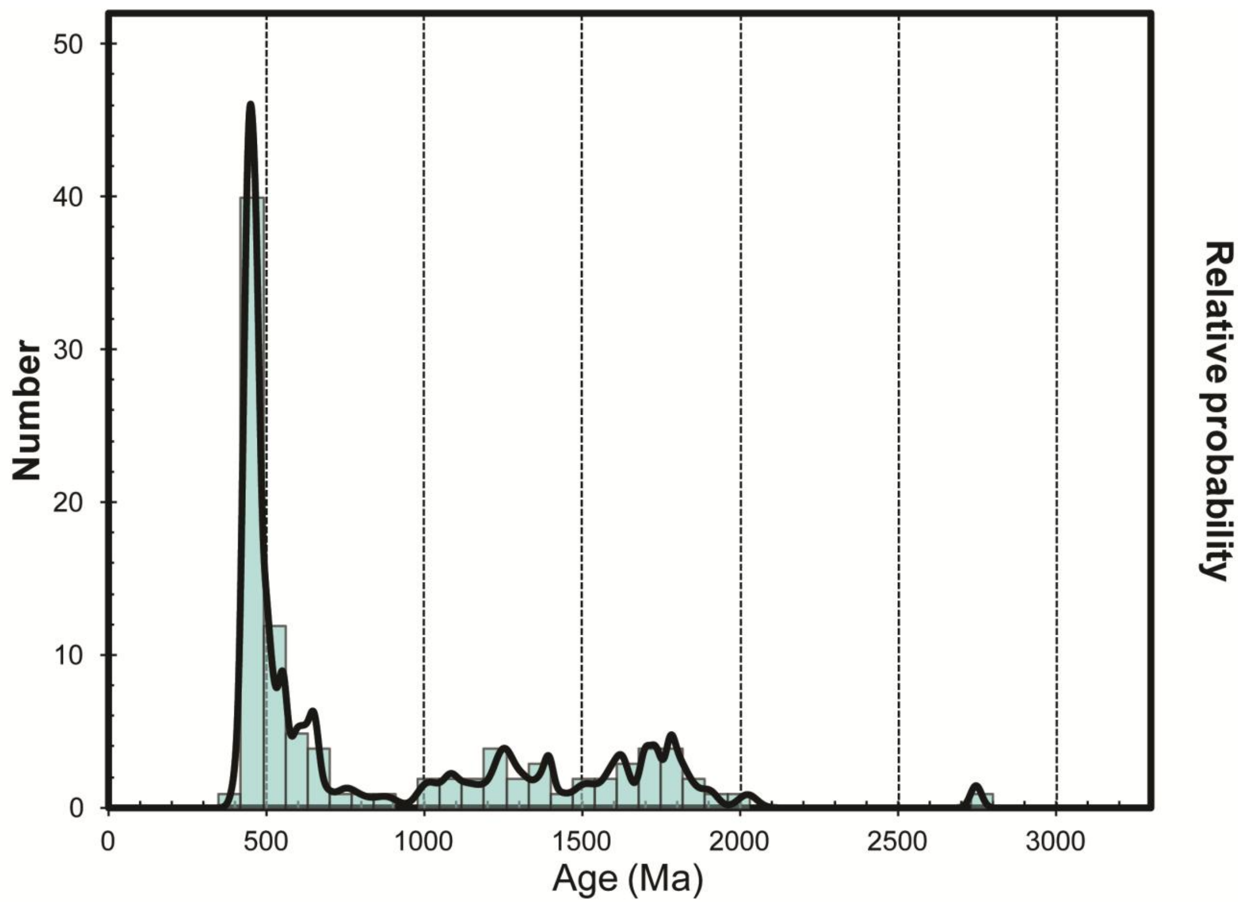

Figure 5.17 Probability density plot for the concordant grains (≥0.05 probability of concordance) for the Oakdale Formation, $^{206}Pb/^{238}U$ age data for grains <800 Ma and $^{207}Pb/^{206}Pb$ age data for grains > 800 Ma.

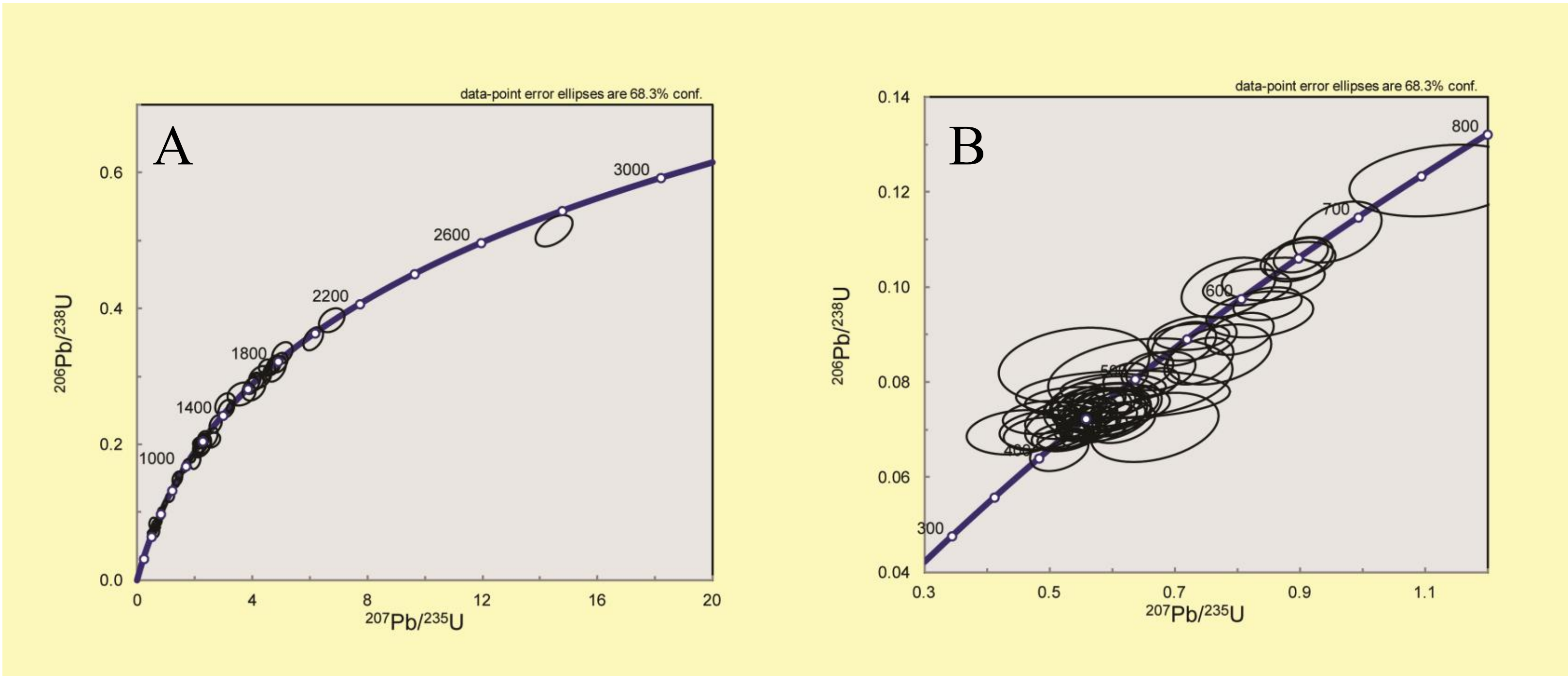

Figure 5.18 Concordia diagram for concordant data (≥0.05 probability of concordance) for the Oakdale Formation A - All concordant data for the Oakdale Formation B - Enlarged image of the younger age populations in the Oakdale Formation

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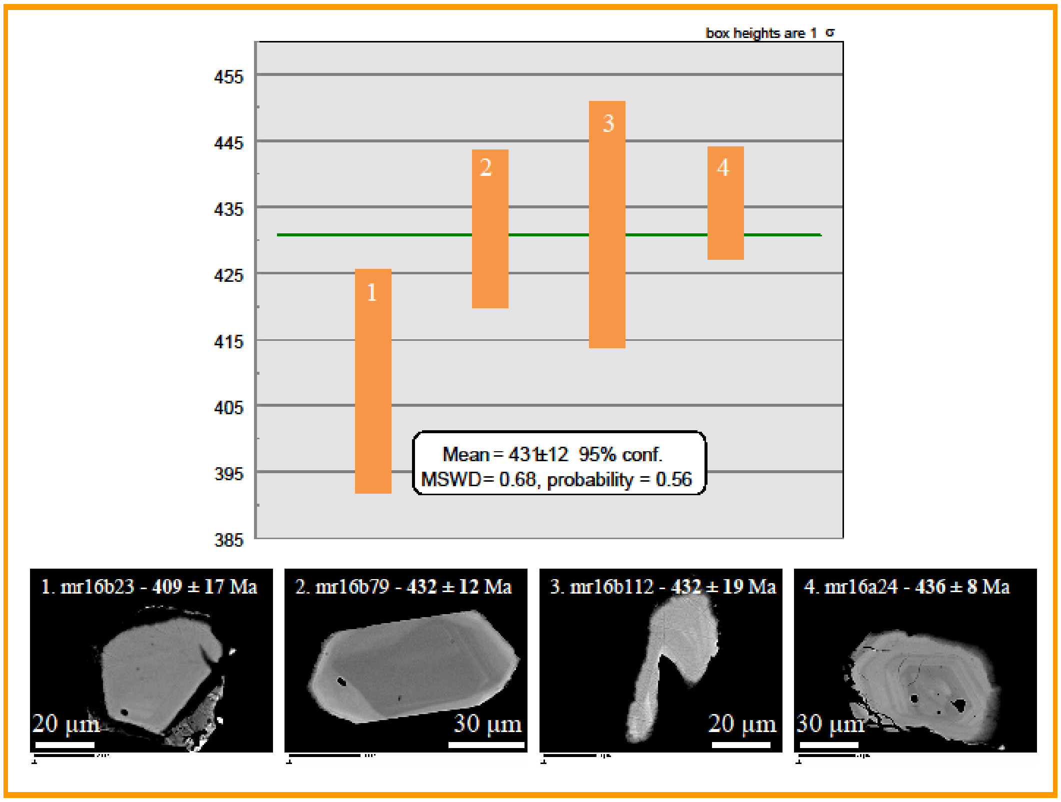

Figure 5.19 Weighted average of the four youngest detrital zircon grains for the Oakdale Formation. The weighted average is based upon $^{206}Pb/^{238}U$ ages and 1 sigma errors.

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file name	207Pb/ 235U Ma	1s error Ma	206Pb/ 238U Ma	1s error Ma	207Pb/ 206Pb Ma	1s error Ma	U-Pb/Pb-Pb concordancy%	Concordia age (Ma)	2s error Ma	Probability	Ratio Th/U
mr16b23	422	21	409	17	392	49	104	413	30	0.54	0.312
mr16a31	427	18	425	9	546	26	78	425	17	0.90	0.440
mr16a33	426	22	427	12	536	27	80	427	23	0.97	1.322
mr12c38	399	25	430	14	366	56	118	425	26	0.22	0.735
mr16b79	445	14	432	12	432	36	100	437	21	0.35	0.233
mr16b112	376	37	432	19	439	50	98	423	35	0.14	0.320
mr16a24	436	12	436	8	392	24	111	436	16	0.99	0.708
mr16c12	408	33	436	17	576	47	76	432	32	0.41	0.496
mr16b24	447	16	438	11	390	36	112	441	21	0.60	0.094
mr16b125	427	27	439	19	370	36	118	435	34	0.67	0.241
mr16b22	519	41	439	29	720	60	61	456	54	0.06	0.511
mr12c37	442	13	440	9	381	34	115	440	17	0.85	0.715
mr16b100	463	20	440	13	560	39	79	445	24	0.26	0.222
mr16b53	455	18	440	13	467	39	94	444	23	0.42	0.391
mr12c27	455	21	445	13	619	45	72	447	25	0.64	0.662
mr16a18	486	23	445	17	587	28	76	456	31	0.08	0.732
mr16b72	466	12	446	8	488	25	91	451	16	0.10	0.415
mr16b115	427	27	448	16	356	37	126	444	30	0.44	0.161
mr16b86	450	17	449	10	472	34	95	449	19	0.94	0.196
mr16b121	403	28	452	13	468	33	96	444	26	0.08	0.072
mr16a40	473	20	453	11	787	32	58	456	21	0.32	0.481
mr12c14	486	16	454	11	491	39	92	462	21	0.06	0.303
mr12c19	469	32	454	21	667	61	68	458	40	0.66	1.336
mr16b116	482	20	454	17	474	34	96	464	31	0.20	0.586
mr12c30	454	19	455	13	384	35	119	455	23	0.95	0.174
mr16b95	447	13	457	11	305	36	150	453	19	0.49	0.204
mr12c43	467	34	461	19	622	50	74	462	36	0.86	0.487
mr12c39	463	13	461	10	455	31	101	462	18	0.91	0.056
mr16b111	439	22	465	11	578	34	80	461	21	0.26	0.123
mr16a29	468	40	465	25	626	32	74	466	47	0.95	0.162
mr16b61	467	19	465	14	482	37	97	466	25	0.92	0.220
mr16b64	476	40	467	18	881	46	53	468	35	0.83	0.159
mr16b103	474	18	468	14	393	40	119	470	25	0.73	0.851

Table 5.6 U-Pb data from detrital zircon grains of the Oakdale Formation with probability of concordance ≥0.05. The ages and associated error used in this study are highlighted in blue. Grains with Th/U ratios <0.1 are highlighted in yellow. Grains used for the youngest age population are highlighted in pink.

file name	207Pb/ 235U Ma	1s error Ma	206Pb/ 238U Ma	1s error Ma	207Pb/ 206Pb Ma	1s error Ma	U-Pb/Pb-Pb concordancy%	Concordia age (Ma)	2s error Ma	Probability	Ratio Th/U
mr16b12	474	34	468	18	474	50	99	469	35	0.87	0.601
mr12c42	471	24	468	12	779	51	60	469	24	0.91	0.130
mr16a12	441	19	470	17	457	31	103	457	29	0.16	0.280
mr16a30	438	34	471	12	657	52	72	469	24	0.34	0.261
mr16b17	489	17	473	9	415	41	114	475	18	0.35	0.153
mr16b38	463	18	473	10	543	41	87	471	20	0.58	0.415
mr16a17	488	71	480	20	469	42	102	481	39	0.91	0.316
mr16a11	478	35	488	12	805	52	61	487	24	0.78	0.307
mr16b81	520	15	495	12	536	28	92	503	22	0.13	0.373
mr16b114	505	60	501	33	777	34	64	502	63	0.95	0.023
mr16a19	491	15	501	12	344	26	146	498	21	0.50	0.107
mr12c18	526	22	510	16	429	44	119	515	30	0.51	0.516
mr16a20	512	17	511	15	532	38	96	511	26	0.95	0.761
mr16c08	438	52	517	31	418	55	124	499	58	0.14	0.525
mr16b40	561	21	523	19	616	55	85	538	34	0.09	0.788
mr16b91	581	31	531	25	757	29	70	546	45	0.13	0.149
mr16a38	548	20	544	18	375	37	145	546	31	0.86	0.482
mr16b28	555	28	551	18	686	44	80	552	34	0.89	0.479
mr16b18	555	23	553	11	584	34	95	553	21	0.93	0.769
mr16b59	599	20	557	17	631	25	88	572	31	0.05	0.507
mr16b10	617	31	581	19	791	47	73	587	36	0.27	0.197
mr16b66	624	20	594	13	779	31	76	601	25	0.15	0.851
mr16c23	589	28	613	24	463	35	132	603	42	0.42	0.029
mr16b74	606	26	614	15	703	41	87	613	28	0.75	1.100
mr12c29	629	30	624	17	513	44	122	625	32	0.89	0.815
mr16b54	650	21	647	15	661	33	98	648	27	0.88	0.253
mr16b113	651	19	649	18	698	21	93	650	31	0.92	0.242
mr16b52	652	15	653	14	542	33	121	653	24	0.95	0.004
mr16b20	683	24	682	24	530	56	129	683	41	0.97	0.576
mr16b33	764	45	745	29	834	40	89	749	53	0.68	0.570
mr12c08	879	28	869	27	790	38	110	874	45	0.76	0.306
mr16b90	910	29	922	21	878	37	105	919	38	0.70	0.203
mr16b11	992	29	988	24	997	28	99	989	42	0.90	0.738

Table 5.6 continued. U-Pb data from detrital zircon grains of the Oakdale Formation with probability of concordance ≥0.05. The ages and associated error used in this study are highlighted in blue. Grains with Th/U ratios <0.1 are highlighted in yellow. Grains used for the youngest age population are highlighted in pink.

file name	207Pb/ 235U Ma	1s error Ma	206Pb/ 238U Ma	1s error Ma	207Pb/ 206Pb Ma	1s error Ma	U-Pb/Pb-Pb concordancy%	Concordia age (Ma)	2s error Ma	Probability	Ratio Th/U
mr12c33	1017	29	1019	23	1031	32	99	1018	41	0.94	0.903
mr16c20	887	49	899	40	1078	43	83	895	70	0.83	0.592
mr12c13	1089	24	1062	23	1083	21	98	1074	38	0.33	0.471
mr16b30	1162	31	1132	24	1129	27	100	1142	43	0.38	0.497
mr12c21	1214	42	1229	34	1177	30	104	1224	59	0.75	0.337
mr16a34	1180	54	1189	30	1222	44	97	1187	55	0.87	0.372
mr16b37	1167	30	1122	32	1234	25	91	1146	51	0.19	0.641
mr16b08	1124	38	1038	39	1255	27	83	1081	65	0.05	0.254
mr16b124	1193	61	1158	54	1257	28	92	1172	92	0.62	0.646
mr12c09	1204	31	1204	27	1274	27	95	1204	46	0.99	0.636
mr16b122	1188	42	1162	36	1311	24	89	1172	62	0.59	0.228
mr16c13	1334	38	1336	44	1344	27	99	1335	66	0.97	0.981
mr16c21	1300	37	1234	45	1375	21	90	1277	68	0.15	0.421
mr16a09	1460	15	1460	21	1394	14	105	1460	29	1.00	0.499
mr16b109	1199	61	1174	56	1425	29	82	1185	95	0.72	0.192
mr16b58	1304	51	1209	37	1496	29	81	1235	68	0.09	0.286
mr16c19	1418	56	1483	55	1532	43	97	1451	87	0.33	0.767
mr16c25	1430	44	1451	45	1560	35	93	1439	72	0.69	0.588
mr12c07	1722	27	1766	32	1592	22	111	1739	47	0.21	0.086
mr16c07	1644	30	1649	45	1619	26	102	1645	57	0.91	0.302
mr16b43	1773	23	1770	41	1625	18	109	1773	46	0.93	0.349
mr12c24	1627	35	1623	39	1655	28	98	1625	59	0.93	0.728
mr16a27	1734	17	1702	28	1694	15	100	1730	34	0.21	0.665
mr16c11	1774	31	1773	47	1710	19	104	1774	59	0.98	0.694
mr16c10	1645	53	1605	62	1723	25	93	1629	93	0.54	0.731
mr16a21	1749	25	1744	31	1734	15	101	1747	45	0.87	0.338
mr12c41	1825	40	1857	53	1772	40	105	1834	72	0.55	1.235
mr16a08	1808	34	1791	48	1778	14	101	1804	64	0.72	0.296
mr16c22	1686	49	1687	52	1791	24	94	1686	81	0.99	0.553
mr16b110	1657	38	1649	42	1794	31	92	1654	65	0.86	0.719
mr16b50	1787	41	1745	61	1826	39	96	1778	79	0.47	1.233
mr16c14	1554	71	1564	57	1835	33	85	1560	98	0.90	0.507
mr16b48	1993	32	1960	53	1903	27	103	1989	63	0.50	0.753

Table 5.6 continued. U-Pb data from detrital zircon grains of the Oakdale Formation with probability of concordance ≥0.05. The ages and associated error used in this study are highlighted in blue. Grains with Th/U ratios <0.1 are highlighted in yellow. Grains used for the youngest age population are highlighted in pink.

file name	207Pb/ 235U Ma	1s error Ma	206Pb/ 238U Ma	1s error Ma	207Pb/ 206Pb Ma	1s error Ma	U-Pb/Pb-Pb concordancy%	Concordia age (Ma)	2s error Ma	Probability	Ratio Th/U
mr12c28	2080	39	2090	53	2022	30	103	2083	72	0.85	0.996
mr16b09	2782	28	2674	64	2745	18	97	2786	56	0.05	0.385

Table 5.6 continued. U-Pb data from detrital zircon grains of the Oakdale Formation with probability of concordance ≥0.05. The ages and associated error used in this study are highlighted in blue. Grains with Th/U ratios <0.1 are highlighted in yellow. Grains used for the youngest age population are highlighted in pink.

Tower Hill Formation – KSTHI

KSTHI Sample location and description

The Tower Hill Formation sample KSTHI was sampled from an outcrop located directly behind the Boylston Fire Station off of Main St. in Boylston, MA on Diamond Hill. It consists of a fine-grained, light to dark gray, massive quartzite. It is equigranular and composed of nearly all quartz, ~94% and has only minor amounts of muscovite, ~5% and 1% of other accessory minerals.

Tower Hill Formation U-Pb geochronology

Grains excluded from the Tower Hill Formation included 87 grains for low probability of concordance and five grains for high error values. After those grains were excluded, 104 grains were used for the analysis of the Tower Hill Formation (Table 5.7), five of which were determined to be metamorphic. The density probability plot of the Tower Hill Formation (Figure 5.20) shows a continuous range of grains from 515-1742 Ma with a low between 1551-1652 Ma. Three grains from the Paleoproterozoic fall outside of this range at 2103, 2116, and 2402 Ma and one grain was determined to be Archean at 2906 Ma.

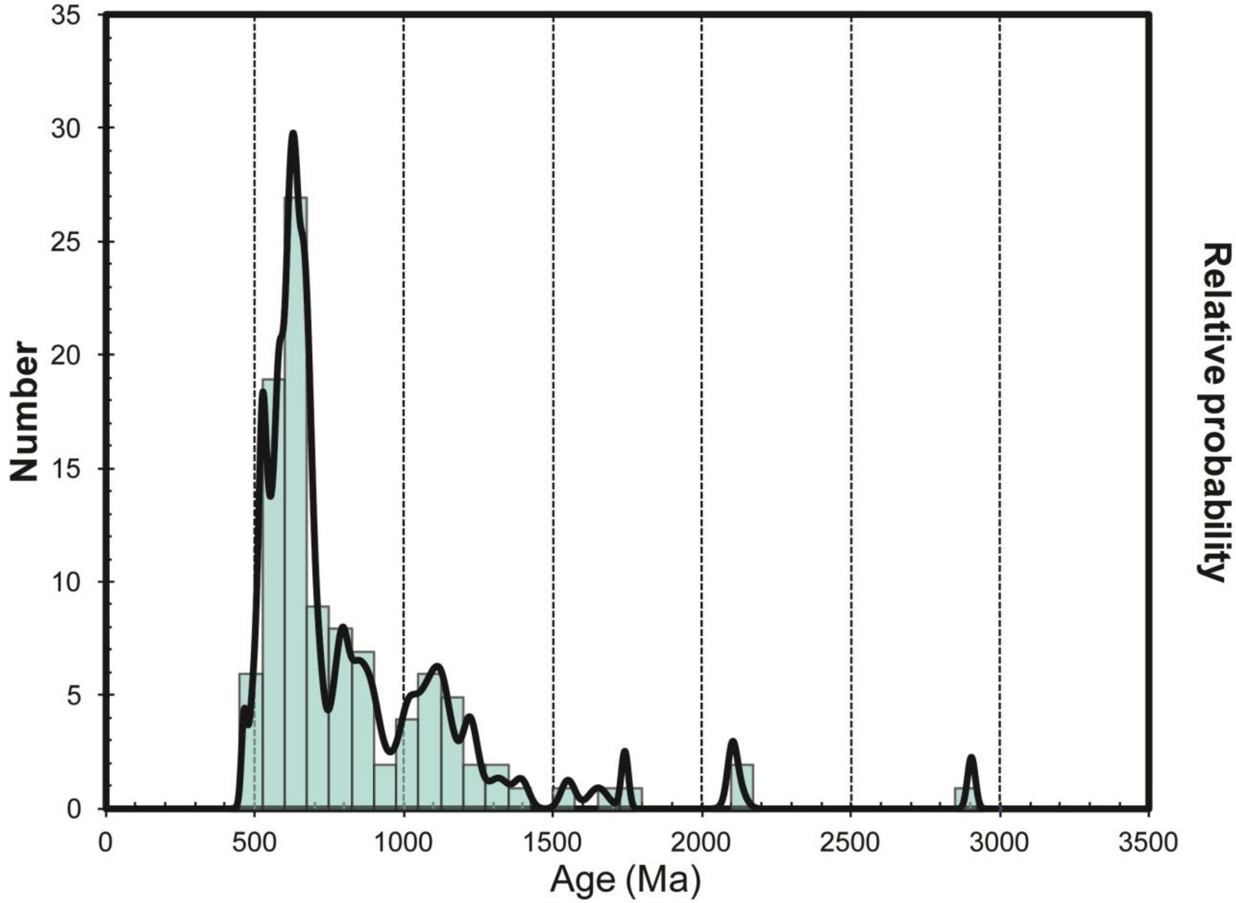

Figure 5.20 Probability density plot for the concordant grains (≥0.05 probability of concordance) for the Tower Hill Formation. $^{206}Pb/^{238}U$ age data for grains <800 Ma and $^{207}Pb/^{206}Pb$ age data for grains > 800 Ma.

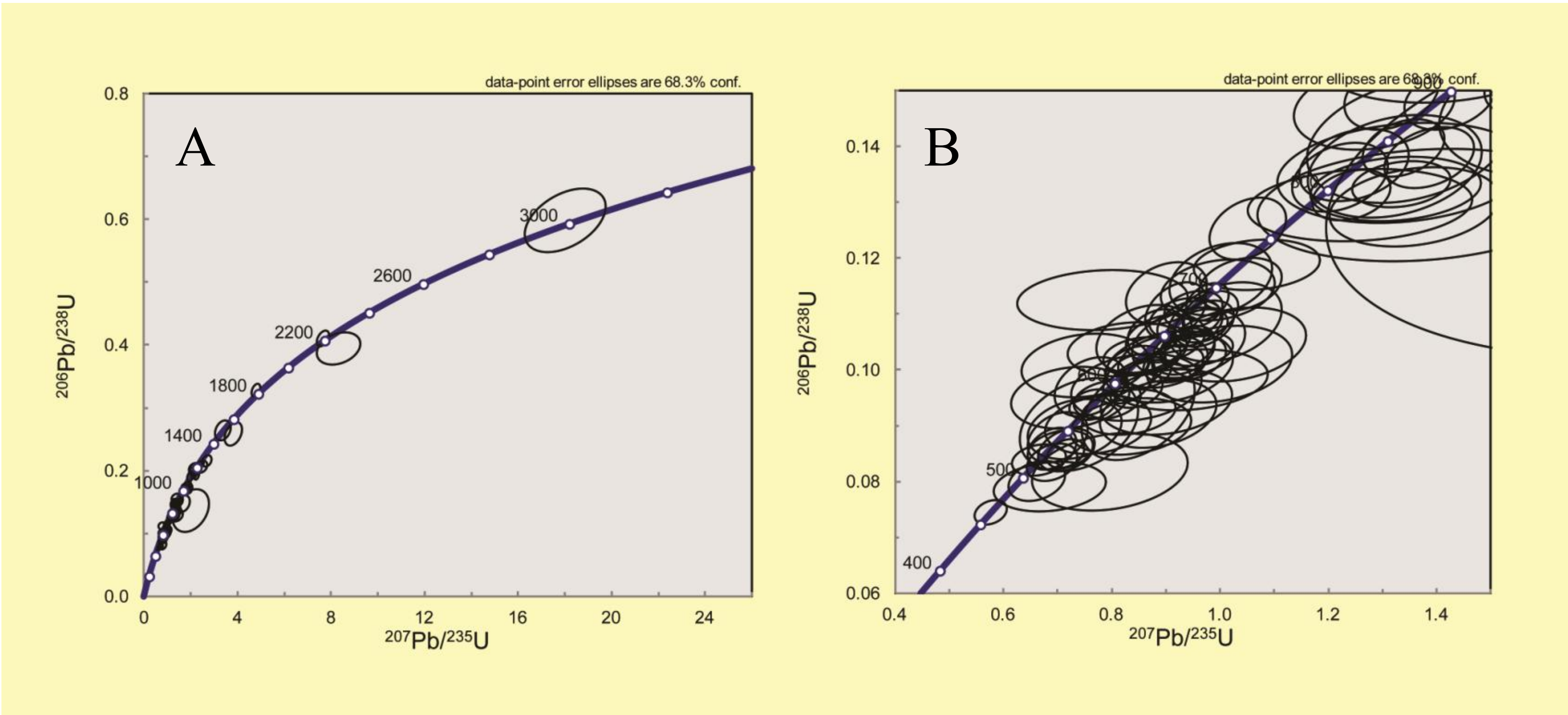

Figure 5.21 Concordia diagram for concordant data (≥0.05 probability of concordance) for the Tower Hill Formation. A - All concordant data for the Tower Hill Formation B - Enlarged image of the younger age populations in the Tower Hill Formation

Tower Hill Formation - KSTHI youngest detrital zircon age populations

The youngest detrital zircon age population for the Tower Hill Formation was determined to be 513 ± 15 Ma (1σ error) from a weighted average of $^{206}Pb/^{238}U$ ages for three grains. However, it should be noted that a grain, mr12a30, dated at 463 ± 9 Ma ($^{206}Pb/^{238}U$ age, 1 sigma) is also present and concordant. Mr12a30 was not used as the youngest detrital zircon grain because it is much younger than the next oldest grain (~27 Ma difference) and does not form a population. Given the uncertainties associated with each age, a weighted mean is considered to be a better method for age approximation than relying on only one grain. Therefore, once mr12a30 was excluded along with two other grains for low U-Pb/Pb-Pb concordancy percentage values, the weighted mean of the three youngest detrital zircon ages was taken and used as the best interpretation.

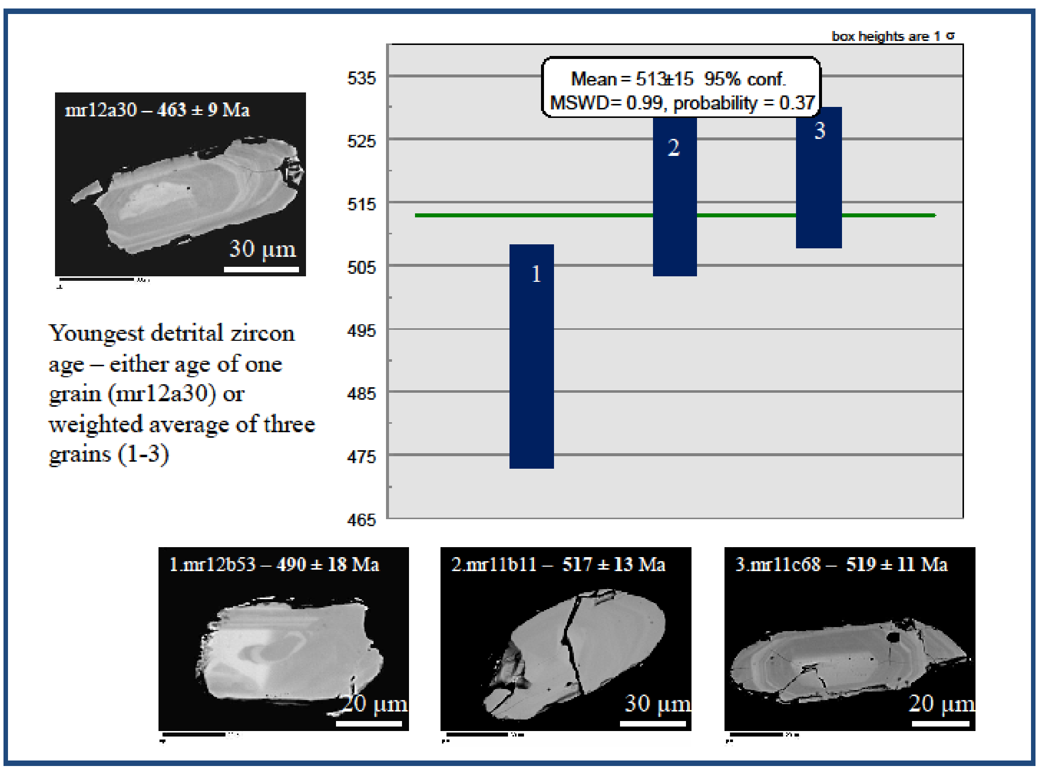

Figure 5.22 Weighted average of the three youngest detrital zircon grains for the Tower Hill Formation and the age of mr12a30. The weighted average is based upon $^{206}Pb/^{238}U$ ages and 1 sigma errors.

file name	207Pb/ 235U Ma	1s error Ma	206Pb/ 238U Ma	1s error Ma	207Pb/ 206Pb Ma	1s error Ma	U-Pb/Pb-Pb concordancy %	Concordia age (Ma)	2s error Ma	Probability	Ratio Th/U
mr12a30	462	13	463	9	472	28	98	463	16	0.94	0.501
mr12b53	531	41	490	18	530	41	93	494	34	0.34	1.247
mr11c23	515	21	497	14	601	24	83	501	26	0.40	0.957
mr12b16	595	53	506	27	782	45	65	516	53	0.11	0.650
mr11b11	533	19	517	13	476	28	108	521	24	0.40	1.403
mr11c68	518	20	519	11	583	33	89	519	21	0.98	2.675
mr11c83	547	14	526	10	509	24	103	532	18	0.13	0.484
mr12a42	542	24	530	14	576	31	92	532	26	0.62	0.985
mr11c64	549	20	530	15	633	40	84	535	27	0.38	0.658
mr11b43	533	18	531	14	310	37	171	532	26	0.94	0.910
mr11b07	539	22	543	18	546	45	100	542	31	0.85	1.041
mr12a08	558	34	552	21	694	35	80	553	39	0.87	0.635
mr12b30	617	41	555	20	707	33	78	562	39	0.15	0.266
mr11c72	583	37	556	20	925	47	60	560	39	0.49	1.444
mr11c38	563	42	557	33	640	42	87	558	59	0.89	0.824
mr12a53	644	38	568	24	666	40	85	582	45	0.06	0.169
mr12b08	614	32	570	16	537	54	106	575	30	0.17	1.365
mr11c63	624	38	572	35	726	65	79	593	61	0.20	1.605
mr11c73	577	16	578	11	535	32	108	578	20	0.96	0.373
mr12b61	652	43	580	23	781	45	74	590	44	0.11	0.825
mr11c27	592	23	583	13	660	29	88	584	25	0.70	0.369
mr12b36	553	43	585	22	509	50	115	580	41	0.46	0.737
mr11b17	622	17	593	12	680	25	87	601	23	0.12	0.946
mr12b07	622	44	596	23	699	47	85	600	44	0.56	0.577
mr11b54	574	25	597	21	468	44	127	588	36	0.41	0.776
mr12b60	674	50	604	21	857	50	70	610	42	0.18	0.819
mr12a09	615	18	605	17	578	24	105	610	29	0.61	0.844
mr11b28	635	15	612	11	555	27	110	618	19	0.13	0.555
mr11b29	622	20	617	14	562	32	110	619	26	0.83	0.613
mr12b48	655	42	618	24	735	42	84	624	46	0.39	0.014
mr11c54	569	45	619	22	674	39	92	611	42	0.27	0.314
mr12a64	704	45	620	26	793	31	78	634	50	0.08	0.259

Table 5.7 U-Pb data from detrital zircon grains of the Tower Hill Formation with probability of concordance ≥0.05. The ages and associated error used in this study are highlighted in blue. Grains with Th/U ratios <.1 are highlighted in yellow. Grains used for the youngest age population are highlighted in pink, the dark pink color represents a young concordant grain not used for the youngest detrital zircon age population.

file name	207Pb/ 235U Ma	1s error Ma	206Pb/ 238U Ma	1s error Ma	207Pb/ 206Pb Ma	1s error Ma	U-Pb/Pb-Pb concordancy %	Concordia age (Ma)	2s error Ma	Probability	Ratio Th/U
mr11c65	659	19	621	13	733	38	85	629	24	0.06	0.424
mr12b63	649	29	623	18	628	39	99	628	34	0.40	0.710
mr11c31	674	23	627	16	782	36	80	638	30	0.06	0.616
mr11c39	628	26	629	13	855	34	74	629	25	0.99	1.333
mr11b19	669	20	633	16	639	26	99	644	28	0.10	1.137
mr12a55	613	40	636	19	694	62	92	633	36	0.57	0.595
mr12b59	682	23	636	12	793	39	80	642	22	0.06	0.639
mr11c59	673	17	638	15	670	28	95	650	26	0.06	0.384
mr12a54	718	43	641	26	793	28	81	654	49	0.09	0.381
mr12b28	674	36	643	24	385	40	167	650	45	0.41	0.875
mr11c60	630	32	647	23	722	45	90	642	42	0.63	1.072
mr11c50	651	26	647	17	658	33	98	648	31	0.87	0.460
mr11c51	642	19	654	16	657	30	99	649	27	0.56	0.530
mr12a38	686	17	660	11	612	30	108	667	21	0.14	0.525
mr11b41	689	18	663	16	697	20	95	673	28	0.18	0.102
mr11c13	675	21	663	16	611	31	109	667	28	0.56	0.858
mr12a14	708	35	665	27	688	40	97	678	49	0.24	1.465
mr12a05	670	23	668	14	736	28	91	668	26	0.91	0.757
mr11c10	695	17	673	15	735	23	92	682	27	0.26	0.149
mr11b10	661	20	676	19	504	32	134	669	32	0.48	0.683
mr12a07	678	19	677	13	659	24	103	677	23	0.94	0.145
mr11c43	692	13	685	13	665	22	103	688	22	0.64	0.485
mr12a67	587	59	687	21	689	59	100	678	40	0.09	0.164
mr11c45	653	26	694	21	576	42	121	679	37	0.14	0.729
mr11c42	702	35	698	21	800	40	87	698	39	0.91	0.601
mr11c74	723	25	703	18	780	29	90	709	33	0.46	1.234
mr11c80	705	32	709	25	775	43	91	707	44	0.91	1.106
mr12b58	738	38	723	17	840	44	86	725	33	0.71	0.572
mr11c52	730	23	761	21	772	39	99	747	35	0.23	0.583
mr12b17	871	45	783	27	881	31	89	798	50	0.06	0.716
mr12a58	877	86	785	38	906	45	87	794	73	0.31	0.166

Table 5.7 continued. U-Pb data from detrital zircon grains of the Tower Hill Formation with probability of concordance ≥0.05. The ages and associated error used in this study are highlighted in blue. Grains with Th/U ratios <0.1 are highlighted in yellow. Grains used for the youngest age population are highlighted in pink.

file name	207Pb/ 235U Ma	1s error Ma	206Pb/ 238U Ma	1s error Ma	207Pb/ 206Pb Ma	1s error Ma	U-Pb/Pb-Pb concordancy %	Concordia age (Ma)	2s error Ma	Probability	Ratio Th/U
mr12b18	828	61	785	24	923	37	85	789	47	0.50	0.421
mr11c30	820	22	795	17	842	20	94	803	30	0.29	0.096
mr11b09	853	25	897	24	650	29	138	877	39	0.12	0.366
mr12b26	862	66	818	34	804	42	102	824	64	0.52	0.455
mr12a43	863	22	843	19	811	26	104	851	33	0.41	0.129
mr12a21	822	30	826	24	814	41	101	824	43	0.92	0.348
mr11c35	811	27	814	23	842	22	97	812	40	0.92	0.198
mr12a52	892	61	933	29	849	46	110	927	55	0.52	0.742
mr11b14	1099	24	1125	29	858	31	131	1108	43	0.37	0.870
mr11b55	861	26	806	15	880	33	92	816	29	0.05	0.391
mr11c18	883	23	834	20	886	29	94	853	36	0.05	0.226
mr12a32	899	23	893	21	889	34	101	896	36	0.82	0.416
mr12a10	839	44	885	29	894	48	99	873	52	0.32	0.276
mr11c33	977	25	968	24	908	31	107	972	40	0.76	0.679
mr12a34	1005	23	999	22	964	28	104	1002	37	0.84	0.291
mr11b53	1023	24	1012	20	1008	24	100	1016	35	0.69	0.628
mr11b08	960	22	911	22	1017	28	89	933	37	0.05	0.953
mr12a20	1092	34	1020	28	1020	33	100	1044	49	0.05	1.032
mr11b56	856	46	825	35	1023	56	81	834	63	0.53	0.763
mr11b37	1156	32	1177	28	1058	31	111	1169	47	0.56	0.282
mr11b12	1059	23	1022	22	1065	29	96	1038	37	0.17	0.365
mr12b32	998	67	888	49	1080	38	82	916	91	0.13	0.382
mr11c34	1007	26	1026	20	1098	27	93	1019	36	0.52	0.378
mr11b42	867	54	850	41	1104	59	77	855	74	0.76	1.048
mr12a57	1057	44	1044	22	1108	29	94	1046	42	0.78	0.289
mr12a13	1161	26	1151	29	1129	23	102	1157	45	0.75	0.271
mr11c09	1064	35	1005	27	1135	39	89	1023	48	0.12	0.548
mr11b44	1199	26	1140	30	1141	32	100	1176	47	0.06	0.615
mr12b33	856	46	801	22	1174	48	68	808	42	0.25	0.308
mr12a40	1259	46	1210	35	1194	38	101	1225	63	0.33	0.283
mr11c40	1176	21	1159	25	1216	19	95	1170	38	0.52	0.446

Table 5.7 continued. U-Pb data from detrital zircon grains of the Tower Hill Formation with probability of concordance ≥0.05. The ages and associated error used in this study are highlighted in blue. Grains with Th/U ratios <0.1 are highlighted in yellow. Grains used for the youngest age population are highlighted in pink.

file name	207Pb/ 235U Ma	1s error Ma	206Pb/ 238U Ma	1s error Ma	207Pb/ 206Pb Ma	1s error Ma	U-Pb/Pb-Pb concordancy %	Concordia age (Ma)	2s error Ma	Probability	Ratio Th/U
mr11b20	1258	20	1232	20	1236	21	100	1245	33	0.28	0.314
mr12b21	1168	52	1191	32	1277	49	93	1186	59	0.68	0.796
mr12b09	1324	36	1257	31	1325	32	95	1282	54	0.11	0.246
mr11c53	1500	52	1508	53	1395	25	108	1504	84	0.90	0.106
mr12b51	1108	176	823	128	1551	24	53	871	245	0.15	0.145
mr12a35	1598	51	1484	63	1652	32	90	1555	94	0.08	1.241
mr11c58	1781	22	1825	33	1742	12	105	1789	42	0.16	0.195
mr11c55	2190	20	2216	37	2103	15	105	2192	40	0.45	0.276
mr12b40	2265	67	2143	79	2116	26	101	2214	119	0.16	0.486
mr12b38	2991	61	3025	134	2906	13	104	2992	122	0.78	0.109

Table 5.7 continued. U-Pb data from detrital zircon grains of the Tower Hill Formation with probability of concordance ≥0.05. The ages and associated error used in this study are highlighted in blue. Grains with Th/U ratios <0.1 are highlighted in yellow. Grains used for the youngest age population are highlighted in pink.

5.7 Worcester Formation – KSWSI

KSWSI sample location and description

The Worcester Formation was sampled at an outcrop on the shore of the Wachusett reservoir on the east side of Shalon Point in Boylston, MA. This outcrop was trip F-2, stop 1, p. 372, in the 1976 NEIGC field trip guide trip (Hepburn, 1976). This sample is a gray weathering, light gray, fine-grained, fissile phyllite with interbedded meta-sandstone and siltstone a few cm to ½ meter of thickness. The metamorphic grade is biotite grade or less (Hepburn, 1976) and there is an abundance of small quartz veins throughout the outcrop and abundant folding. Some areas are schistose, others are somewhat quartzitic. Samples were taken largely from the turbiditic sandy layers within the outcrop. The rock is equigranular and composed primarily of quartz (~70%) and smaller equal amounts of muscovite and chlorite (12% each), along with several accessory minerals (Appendix C).

Figure 5.23 Picture of the folded Worcester Formation in Boylston, MA showing folding and quartz veins.

Worcester Formation U-Pb geochronology

For the analysis of the Worcester Formation 134 grains (Table 5.8) were used after 56 grains were excluded for low probability of concordance, 10 were excluded due to large error values, and two young grains were excluded due to low U-Pb/Pb-Pb concordancy percentage values. Three concordant grains were determined to be older metamorphic grains based on the Th/U ratios and have been included in the analysis. As shown from the density probability plot (Figure 5.24) the Worcester Formation has approximately two main age groups: 436 to 784 Ma and 953 to 1367 Ma. A smaller age group 1455-1908 Ma and two outlying Paleoproterozoic grains at 2007 and 2180 Ma are also present.

Worcester Formation - KSWSI youngest detrital zircon age populations

The youngest detrital zircon age population for the Worcester Formation was determined from a weighted average of the $^{206}Pb/^{238}U$ ages of the four youngest grains and was 436 ± 9 Ma (1σ error). After three grains were excluded due to low U-Pb/Pb-Pb concordancy percents and mr02a123 was excluded due to a low probability of concordance, the weighted mean of the four youngest zircons was taken and used as the best interpretation. Mr02a117 and mr03a45 were still included although they contain cracks because of acceptable U-Pb/Pb-Pb concordancy percentage and error values.

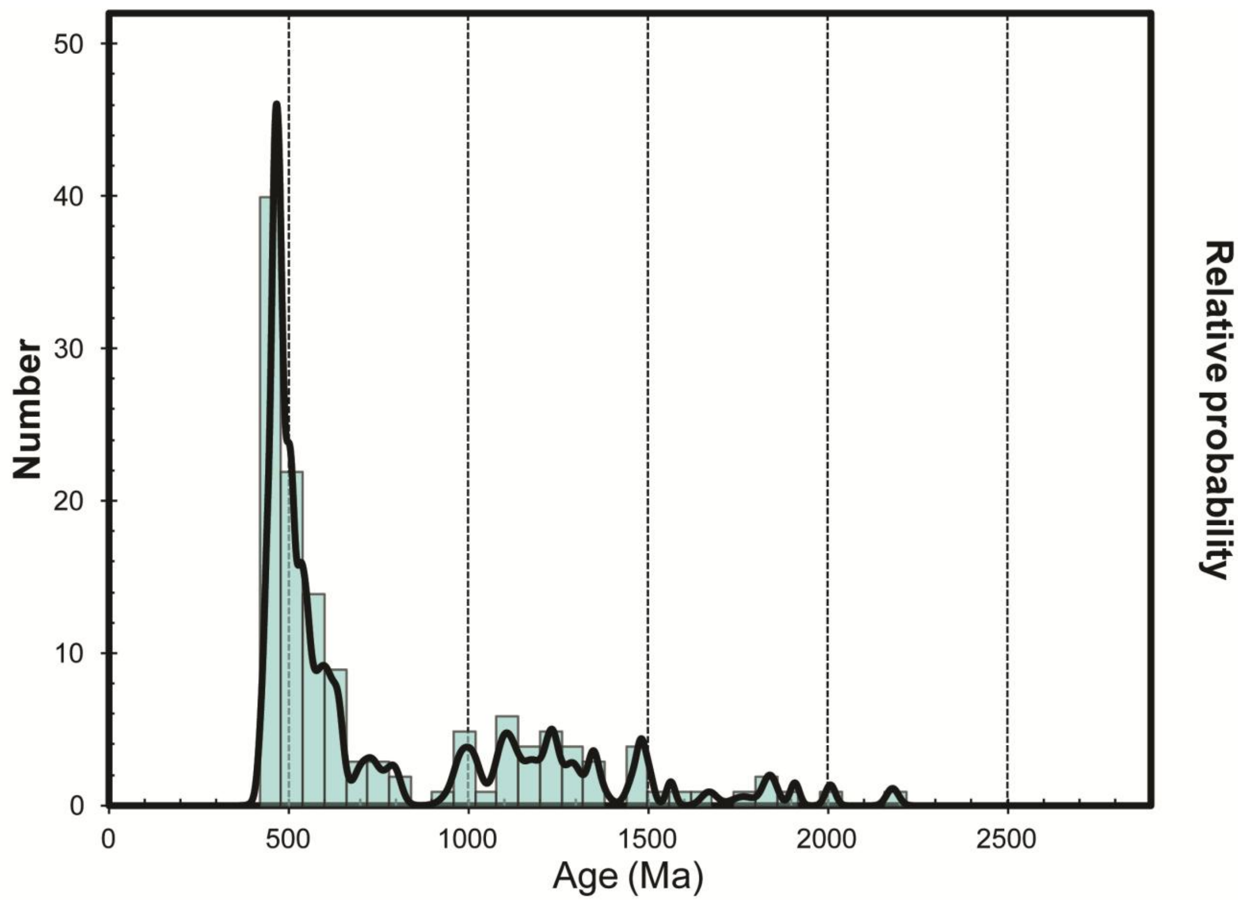

Figure 5.24 Probability density plot for the concordant grains (≥0.05 probability of concordance) for the Worcester Formation, $^{206}Pb/^{238}U$ age data for grains <800 Ma and $^{207}Pb/^{206}Pb$ age data for grains > 800 Ma.

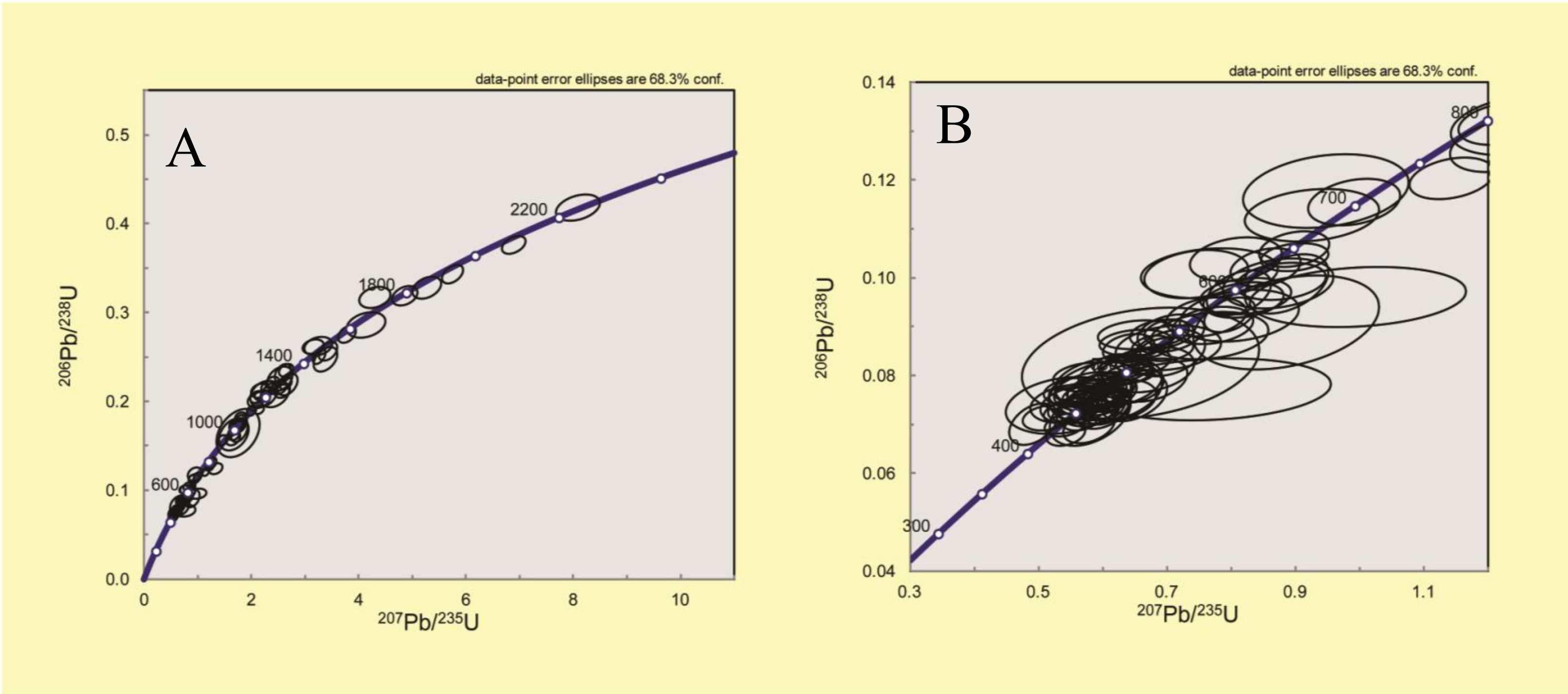

Figure 5.25 Concordia diagram for concordant data (≥0.05 probability of concordance) for the Worcester Formation. A - All concordant data for the Worcester Formation. B - Enlarged image of the younger age populations in the Worcester Formation.

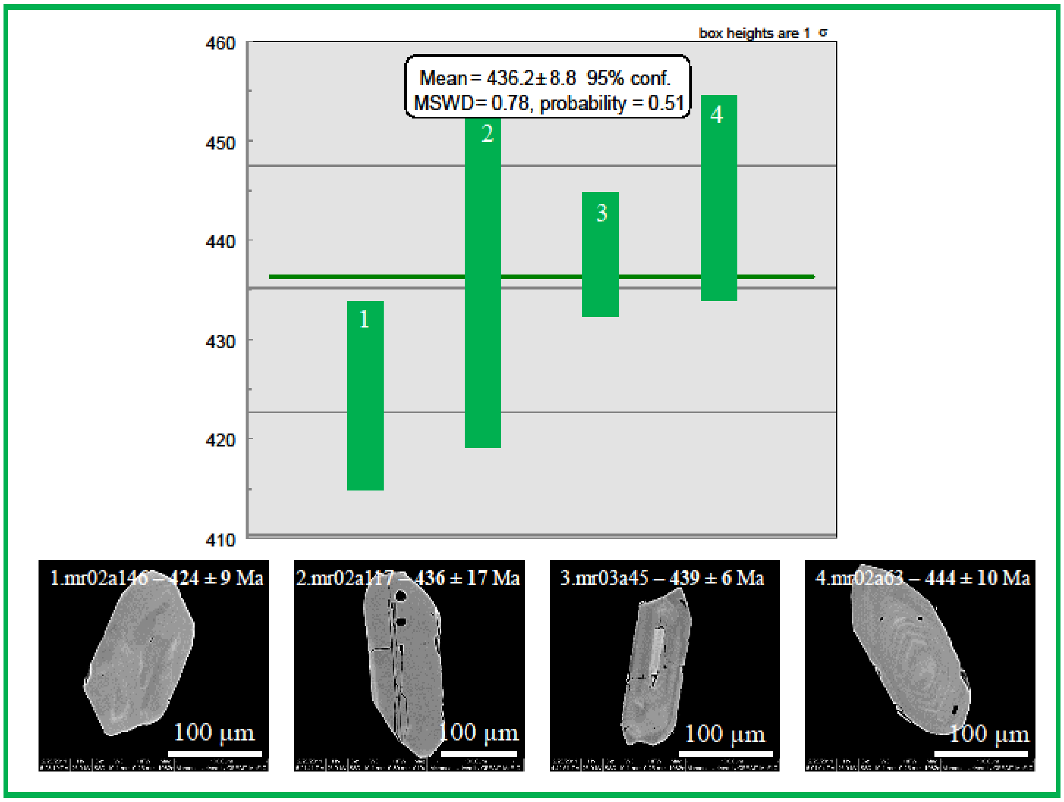

Figure 5.26 Weighted average of the four youngest detrital zircon grains for the Worcester Formation. The weighted average is based upon $^{206}Pb/^{238}U$ ages and 1 sigma errors.

file name	207Pb/ 235U Ma	1s error Ma	206Pb/ 238U Ma	1s error Ma	207Pb/ 206Pb Ma	1s error Ma	U-Pb/Pb-Pb concordancy%	Concordia age (Ma)	2s error Ma	Probability	Ratio Th/U
mr02a146	440	13	424	9	447	23	95	428	17	0.25	0.14
mr02a123	464	17	434	14	480	19	90	444	25	0.09	0.19
mr02a142	439	14	435	9	532	25	82	436	17	0.77	0.45
mr02a117	406	17	436	17	412	39	106	420	28	0.10	0.99
mr03a45	454	11	439	6	448	24	98	441	12	0.18	1.05
mr02a63	421	17	444	10	423	28	105	439	19	0.18	0.50
mr02a122	465	27	448	25	421	25	106	455	43	0.55	0.17
mr02a84	435	12	450	8	417	18	108	446	15	0.21	0.13
mr03a75	471	15	453	8	515	29	88	456	16	0.24	1.37
mr02a38	444	14	454	9	538	22	84	451	17	0.49	0.84
mr02a99	479	18	455	16	496	21	92	465	28	0.21	0.17
mr02a24	450	12	456	9	494	17	92	454	16	0.67	0.08
mr03a30	467	22	456	15	527	21	87	459	28	0.64	0.37
mr02a107	481	14	457	13	487	25	94	467	23	0.10	0.38
mr03a85	474	12	459	8	486	31	94	462	14	0.21	0.60
mr03a31	438	39	460	23	558	42	82	455	43	0.59	0.81
mr03a91	468	9	460	6	447	18	103	462	11	0.42	0.08
mr02a67	451	24	461	15	437	25	105	459	29	0.71	0.77
mr03a86	459	15	461	9	412	33	112	461	17	0.89	0.71
mr02a62	442	26	462	15	468	31	99	458	29	0.46	0.59
mr04a22	481	12	465	9	453	18	103	469	16	0.19	0.21
mr02a113	492	25	466	17	586	35	79	472	32	0.31	0.43
mr04a21	475	14	466	9	431	27	108	469	17	0.54	0.85
mr03a70	483	15	467	10	504	19	93	471	18	0.30	0.28
mr03a48	472	13	468	10	406	25	115	469	19	0.76	0.62
mr04a19	466	15	469	9	453	27	103	468	17	0.87	1.25
mr03a26	508	21	469	19	536	27	88	485	33	0.08	0.77
mr02a58	456	13	470	8	492	19	96	467	16	0.27	0.14
mr03a106	477	12	472	7	487	27	97	473	14	0.65	0.62

Table 5.8 U-Pb data from detrital zircon grains of the Worcester Formation with probability of concordance ≥0.05. The ages and associated error used in this study are highlighted in blue. Grains with Th/U ratios <0.1 are highlighted in yellow. Grains used for the youngest age population are highlighted in pink.

file name	207Pb/ 235U Ma	1s error Ma	206Pb/ 238U Ma	1s error Ma	207Pb/ 206Pb Ma	1s error Ma	U-Pb/Pb-Pb concordancy%	Concordia age (Ma)	2s error Ma	Probability	Ratio Th/U
mr03a79	480	14	475	12	424	20	112	476	21	0.72	0.13
mr02a109	491	13	475	11	494	21	96	482	20	0.22	0.62
mr02a90	457	19	475	8	461	28	103	473	16	0.35	0.85
mr03a24	480	37	476	26	529	24	90	477	47	0.91	0.83
mr02a120	450	18	476	12	432	19	110	470	22	0.16	0.12
mr02a28	464	15	476	9	539	26	88	474	16	0.41	0.52
mr02a108	467	25	477	15	536	22	89	475	29	0.71	0.68
mr02a64	447	20	477	11	517	28	92	471	21	0.14	0.59
mr02a16	475	21	477	14	525	26	91	476	26	0.91	0.41
mr02a140	580	70	479	25	1083	39	44	484	49	0.17	0.55
mr02a112	481	19	480	14	534	21	90	480	25	0.95	0.13
mr03a56	512	16	483	13	514	24	94	493	24	0.07	0.26
mr02a77	477	15	485	10	496	26	98	483	18	0.60	0.57
mr02a79	483	35	487	21	580	32	84	487	39	0.90	0.67
mr02a74	523	24	491	17	652	37	75	500	32	0.19	0.49
mr02a97	462	22	494	12	489	51	101	489	22	0.15	0.54
mr02a100	477	15	495	13	425	22	117	488	22	0.26	0.56
mr03a46	504	15	498	8	534	28	93	499	14	0.72	0.99
mr04a27	499	17	500	10	518	24	97	500	19	0.97	1.12
mr03a21	521	29	504	18	596	41	84	507	34	0.56	1.10
mr02a41	499	17	506	11	505	22	100	504	20	0.70	0.12
mr04a24	493	13	506	8	431	29	117	503	15	0.33	0.70
mr02a104	490	14	509	9	453	22	112	504	17	0.17	0.53
mr03a78	514	75	511	45	670	30	76	512	84	0.97	0.10
mr02a50	520	15	513	10	549	21	93	515	18	0.65	0.15
mr02a98	507	11	513	8	553	21	93	512	15	0.57	1.05
mr02a59	540	22	524	19	578	24	91	530	33	0.49	0.29
mr03a107	538	17	528	9	440	29	120	530	18	0.54	0.95
mr02a144	540	32	529	18	539	37	98	531	34	0.74	1.00

Table 5.8 continued. U-Pb data from detrital zircon grains of the Worcester Formation with probability of concordance ≥0.05. The ages and associated error used in this study are highlighted in blue. Grains with Th/U ratios <0.1 are highlighted in yellow. Grains used for the youngest age population are highlighted in pink.

file name	207Pb/ 235U Ma	1s error Ma	206Pb/ 238U Ma	1s error Ma	207Pb/ 206Pb Ma	1s error Ma	U-Pb/Pb-Pb concordancy%	Concordia age (Ma)	2s error Ma	Probability	Ratio Th/U
mr02a83	503	17	530	12	500	23	106	522	21	0.12	0.48
mr02a23	524	12	531	9	535	22	99	529	16	0.59	0.71
mr02a20	510	23	536	11	790	29	68	532	21	0.26	0.48
mr04a20	578	35	545	19	457	120	119	550	36	0.37	0.92
mr02a33	512	25	546	12	482	28	113	541	23	0.19	0.48
mr03a71	534	20	546	11	380	43	144	544	22	0.54	0.59
mr02a81	542	20	548	15	510	22	107	546	27	0.80	0.11
mr02a70	538	14	549	10	551	24	100	546	18	0.46	0.59
mr03a58	580	24	557	15	658	37	85	562	28	0.35	1.05
mr03a44	644	51	561	38	896	24	63	582	70	0.12	0.13
mr03a95	575	24	567	16	614	36	92	569	29	0.75	0.86
mr02a31	604	34	569	21	717	33	79	576	39	0.33	0.57
mr02a10	596	15	570	14	702	19	81	581	24	0.11	0.51
mr03a96	607	23	588	14	658	41	89	592	27	0.41	0.87
mr02a121	702	56	591	24	1307	33	45	600	46	0.06	1.25
mr03a25	609	26	592	15	762	37	78	595	28	0.54	0.61
mr03a60	604	19	597	18	470	25	127	600	30	0.73	0.31
mr02a43	644	23	607	23	862	31	70	625	39	0.14	1.61
mr03a77	637	31	607	20	662	35	92	614	37	0.35	1.51
mr03a105	640	25	610	15	677	34	90	616	28	0.26	1.95
mr02a42	565	31	618	19	540	34	115	606	35	0.10	0.36
mr02a44	578	40	619	20	579	35	107	613	37	0.31	0.58
mr02a09	627	20	627	15	651	22	96	627	27	0.99	0.36
mr02a71	601	27	637	17	567	34	112	628	32	0.20	0.41
mr04a13	651	18	639	11	648	33	99	641	20	0.52	0.74
mr03a54	651	19	649	14	630	23	103	649	26	0.91	0.22
mr03a27	665	36	689	21	799	29	86	684	39	0.53	0.29
mr02a40	699	24	704	18	769	28	92	703	32	0.84	0.35
mr03a20	677	44	717	29	710	39	101	707	53	0.38	0.97

Table 5.8 continued. U-Pb data from detrital zircon grains of the Worcester Formation with probability of concordance ≥0.05.The ages and associated error used in this study are highlighted in blue. Grains with Th/U ratios <0.1 are highlighted in yellow. Grains used for the youngest age population are highlighted in pink.

file name	207Pb/ 235U Ma	1s error Ma	206Pb/ 238U Ma	1s error Ma	207Pb/ 206Pb Ma	1s error Ma	U-Pb/Pb-Pb concordancy%	Concordia age (Ma)	2s error Ma	Probability	Ratio Th/U
mr04a31	774	20	732	16	776	19	94	745	29	0.06	0.41
mr02a60	767	29	744	23	844	26	91	750	40	0.33	0.50
mr03a87	810	24	771	20	836	30	92	785	36	0.14	0.79
mr03a49	821	31	795	23	780	37	102	802	41	0.43	0.80
mr04a29	811	21	797	16	704	31	113	801	29	0.52	0.54
mr02a118	915	25	936	20	954	25	98	928	36	0.47	0.39
mr02a52	982	18	986	17	974	17	101	984	29	0.85	0.30
mr02a111	1010	31	1032	28	986	19	105	1022	47	0.53	0.33
mr04a07	990	35	947	29	1006	18	94	963	51	0.26	0.36
mr02a69	1038	33	1039	37	1009	22	103	1038	58	0.99	0.51
mr03a22	996	70	975	67	1020	57	96	984	112	0.79	0.47
mr03a94	1036	28	1024	20	1024	19	100	1027	37	0.68	0.21
mr02a87	1001	23	967	22	1086	24	89	983	37	0.18	0.59
mr03a23	1026	98	980	99	1090	21	90	1002	164	0.68	0.29
mr02a11	1045	24	1080	19	1097	22	98	1067	33	0.18	0.28
mr02a07	1115	20	1121	20	1111	21	101	1118	32	0.80	0.34
mr02a92	1171	35	1240	27	1117	24	111	1214	47	0.07	0.18
mr02a82	1148	25	1202	24	1118	23	107	1175	39	0.07	0.38
mr04a14	1184	31	1212	21	1141	20	106	1204	38	0.39	0.18
mr02a91	1160	44	1183	31	1162	30	102	1176	56	0.63	0.40
mr03a89	1162	18	1124	17	1172	17	96	1141	29	0.07	0.37
mr02a110	1189	52	1219	51	1189	19	103	1204	83	0.62	0.32
mr02a18	1215	27	1263	24	1219	19	104	1242	40	0.12	0.61
mr02a72	1295	27	1341	36	1222	26	110	1308	51	0.20	0.39
mr02a102	1238	25	1287	24	1232	17	105	1263	39	0.09	0.58
mr02a93	1281	44	1309	48	1235	15	106	1293	75	0.60	0.09
mr03a97	1319	35	1276	43	1245	26	102	1304	64	0.32	0.41
mr02a103	1314	25	1359	26	1265	28	107	1335	41	0.13	0.49
mr03a32	1254	52	1221	52	1290	18	95	1237	85	0.58	0.71

Table 5.8 continued. U-Pb data from detrital zircon grains of the Worcester Formation with probability of concordance ≥0.05. The ages and associated error used in this study are highlighted in blue. Grains with Th/U ratios <0.1 are highlighted in yellow. Grains used for the youngest age population are highlighted in pink.

file name	207Pb/ 235U Ma	1s error Ma	206Pb/ 238U Ma	1s error Ma	207Pb/ 206Pb Ma	1s error Ma	U-Pb/Pb-Pb concordancy%	Concordia age (Ma)	2s error Ma	Probability	Ratio Th/U
mr02a30	1023	31	1033	23	1297	30	80	1030	41	0.77	0.92
mr02a17	1038	38	996	46	1314	28	76	1023	70	0.36	0.65
mr02a61	1313	20	1283	23	1347	13	95	1301	35	0.22	0.35
mr02a53	1471	18	1441	29	1353	18	107	1467	36	0.24	0.89
mr02a145	1273	28	1259	27	1367	25	92	1266	44	0.66	0.85
mr02a101	1446	31	1500	27	1455	19	103	1476	45	0.13	0.69
mr02a39	1292	26	1237	25	1468	17	84	1262	42	0.07	0.62
mr02a143	1501	34	1425	47	1481	11	96	1482	65	0.09	0.35
mr02a32	1467	41	1502	36	1489	18	101	1487	59	0.46	0.33
mr02a78	1510	26	1470	36	1503	14	98	1500	50	0.26	0.51
mr02a51	1589	23	1568	33	1563	12	100	1584	44	0.51	0.33
mr02a94	1693	37	1775	39	1670	21	106	1729	60	0.07	0.96
mr03a65	1662	47	1623	47	1765	33	92	1642	76	0.49	1.53
mr03a67	1865	29	1828	39	1832	18	100	1854	54	0.35	0.77
mr02a08	1796	27	1783	34	1847	18	97	1792	48	0.72	1.01
mr02a68	1938	20	1901	33	1908	13	100	1934	39	0.22	1.03
mr04a11	2098	18	2059	31	2007	14	103	2093	36	0.17	0.48
mr03a34	2240	30	2251	45	2180	17	103	2243	57	0.81	0.38

Table 5.8 continued. U-Pb data from detrital zircon grains of the Worcester Formation with probability of concordance ≥0.05. The ages and associated error used in this study are highlighted in blue. Grains with Th/U ratios <0.1 are highlighted in yellow. Grains used for the youngest age population are highlighted in pink.

5.8 Paxton Formation – KSPXIII

KSPXIII Sample location and description

The Paxton Formation was sampled at an outcrop at Barrett Park located off Chestnut St. in Leominster, MA. The outcrop was located along the edge of the parking lot near the information center of the park. This outcrop is composed of a low grade (garnet or lower) laminated, slabby, quartz-rich, purple-gray phyllite with some of it being schistose. The sample is fine-grained, equigranular and is composed of largely quartz (~65%) and also contains 20% biotite, 15% carbonate and minor amounts of other minerals (Appendix C).

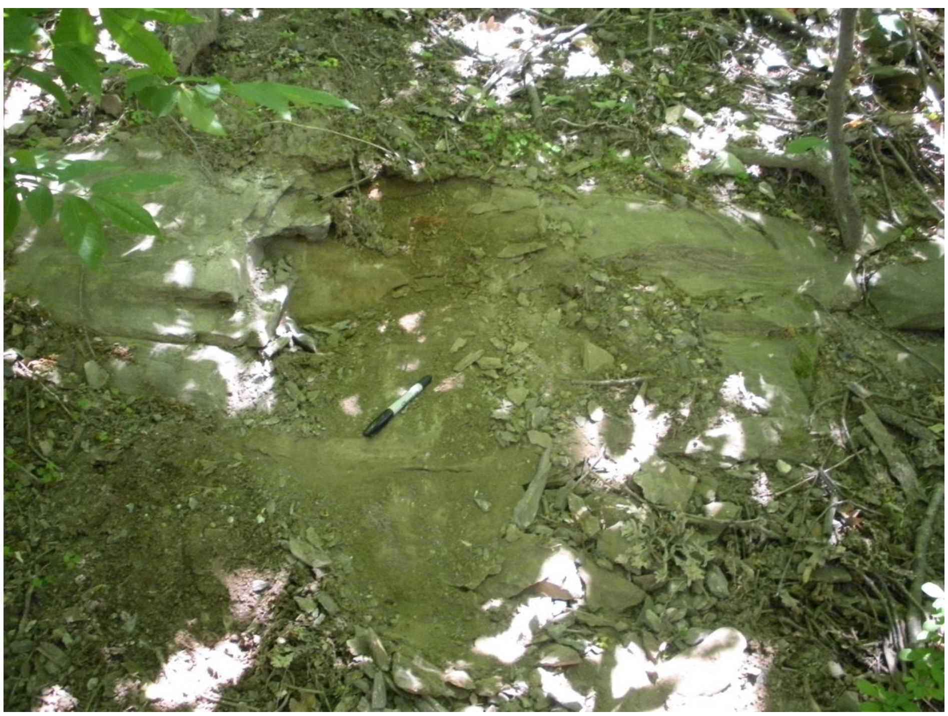

Figure 5.27 Photo of the Paxton Formation from Barret Park in Leominster, MA

Paxton Formation U-Pb geochronology

Excluded grains from the Paxton Formation included 34 grains for low probability of concordance and one grain for a low U-Pb/Pb-Pb concordancy percentage value. In total 112 grains were used for the analysis of the Paxton Formation (Table 5.9). Six concordant grains were determined to be metamorphic based on the Th/U ratios and are included in this study. As shown in the density probability plot (Figure 5.28) the Paxton Formation approximates 2 main age groups: 428 to 643 Ma and 901 to 1818 Ma, with three grains falling outside of these ranges at 773, 2662 and 2686 Ma.

Paxton Formation - KSPXIII youngest detrital zircon age populations

The youngest detrital zircon age population for the Paxton Formation was determined from a weighted average of the $^{206}Pb/^{238}U$ ages of the ten youngest grains and was 426 ± 6 Ma (1σ error). After one grain was excluded for a low U-Pb/Pb-Pb concordancy percentage the weighted mean of the ten youngest detrital zircon ages was taken and used as the best interpretation.

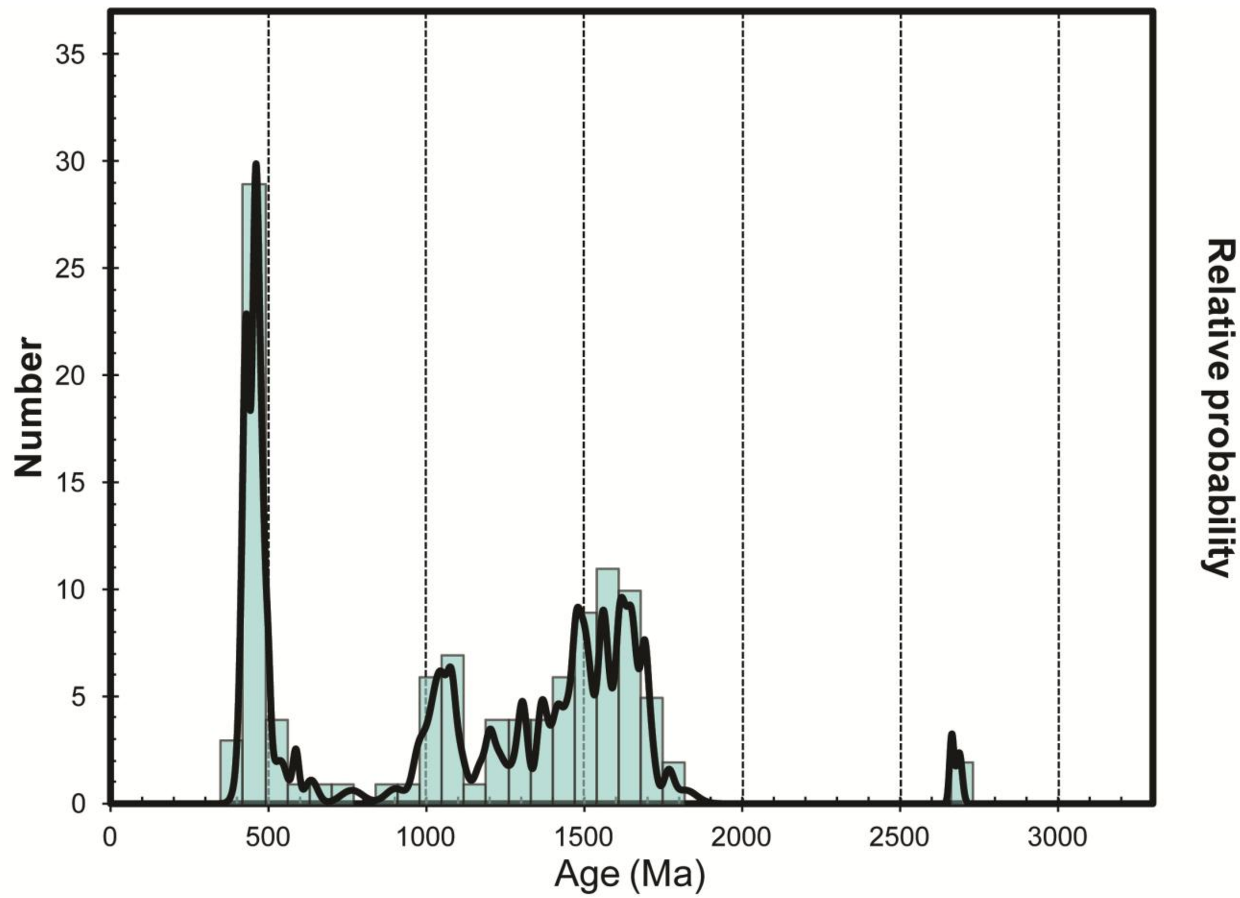

Figure 5.28 Probability density plot for the concordant grains (≥0.05 probability of concordance) for the Paxton Formation, $^{206}Pb/^{238}U$ age data for grains <800 Ma and $^{207}Pb/^{206}Pb$ age data for grains > 800 Ma.

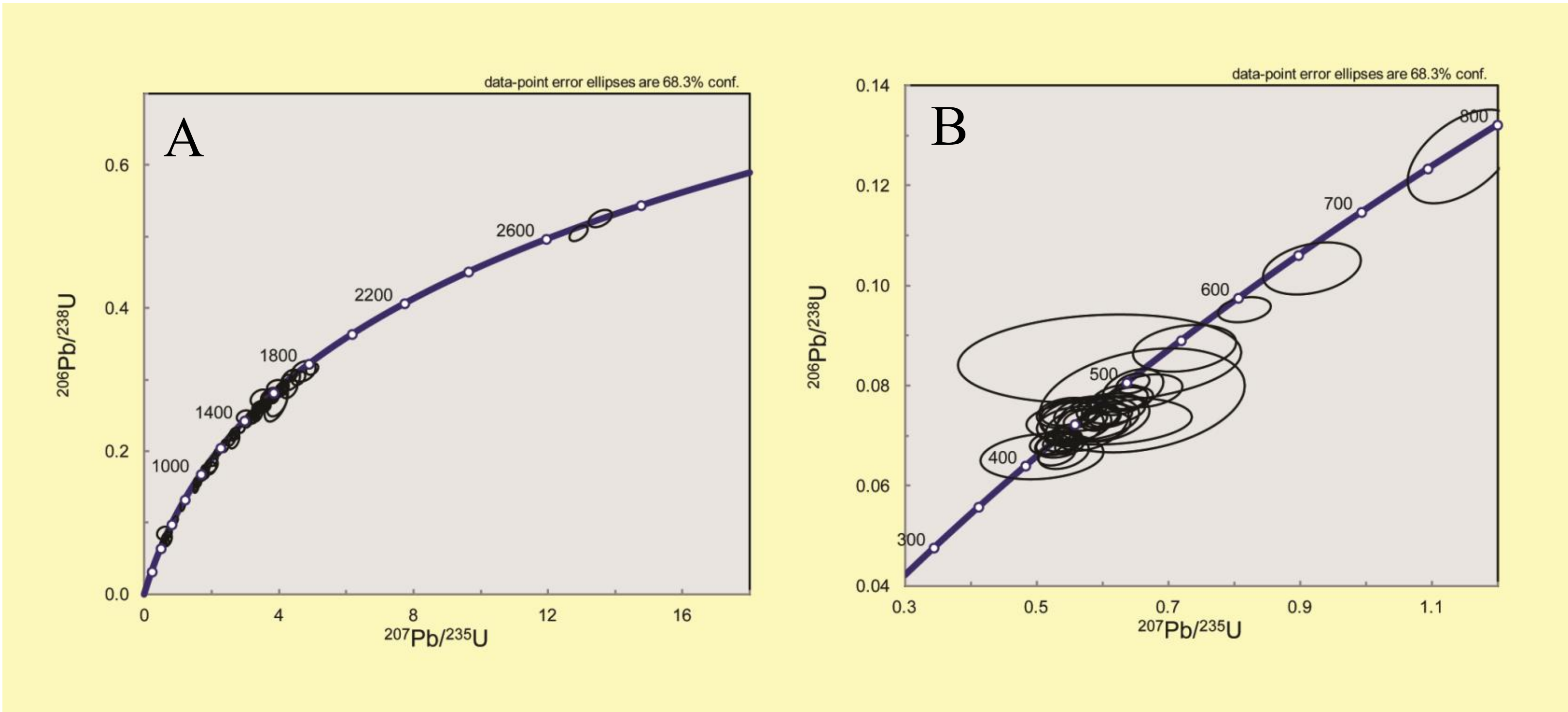

Figure 5.29 Concordia diagram for concordant data (≥0.05 probability of concordance) for the Paxton Formation A - All concordant data for the Paxton Formation. B - Enlarged image of the younger age populations in the Paxton Formation.

Images of the individual youngest grains for the Paxton Fm are unavailable. This sample was processed at a later time than the rest of the MT samples and zircon images were not linked to individual analysis. The ages of the youngest grains are listed below:

au26a47- 412 ± 18 Ma
se09a13 – 414 ± 9 Ma
au26a57 – 415 ± 12 Ma
se08b31 – 425 ± 7 Ma
se07b14 – 426 ± 10 Ma
se07b15 - 427 ± 9 Ma
au26a61 – 428 ± 9 Ma
se09a34 – 428 ± 8 Ma
se07b13 – 428 ± 9 Ma
se08b34 – 435 ± 7 Ma

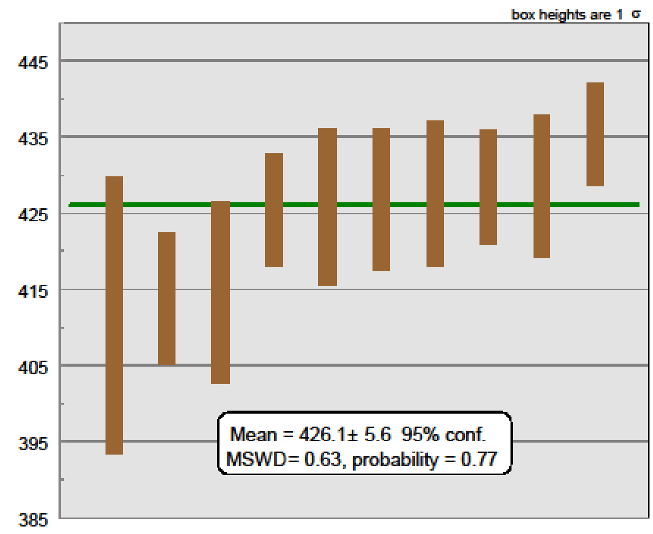

Figure 5.30 Weighted average of the ten youngest detrital zircon grains for the Paxton Formation. The weighted average is based on $^{206}Pb/^{238}U$ ages and 1 sigma errors.

file name	207Pb/ 235U Ma	1s error Ma	206Pb/ 238U Ma	1s error Ma	207Pb/ 206Pb Ma	1s error Ma	U-Pb/Pb-Pb concordancy %	Concordia age (Ma)	2s error Ma	Probability	Ratio Th/U
au26a47	417	41	412	18	479	56	86	412	35	0.89	0.763
se09a13	432	12	414	9	415	26	100	418	16	0.17	0.643
au26a57	439	17	415	12	380	42	109	421	22	0.15	0.905
se08b31	425	9	425	7	427	19	100	425	13	0.98	0.522
se07b14	435	16	426	10	443	31	96	428	19	0.58	0.804
se07b15	433	14	427	9	445	20	96	428	17	0.69	0.622
au26a61	429	16	428	10	464	22	92	428	18	0.93	0.630
se09a34	437	12	428	8	470	27	91	430	14	0.49	0.489
se07b13	444	9	428	9	430	25	100	437	15	0.11	0.948
se08b34	434	8	435	7	444	18	98	435	12	0.85	0.913
au26a52	450	19	445	15	415	21	107	447	27	0.82	0.524
au26a64	475	19	448	12	622	40	72	453	22	0.16	0.932
au26a60	466	24	450	21	454	46	99	456	37	0.51	0.518
se08b14	450	24	450	14	462	43	98	450	26	0.98	0.416
se07b12	484	52	454	19	656	35	69	456	37	0.58	0.546
se09a14	460	14	455	9	414	28	110	456	16	0.72	0.840
au26a33	465	32	457	17	518	37	88	458	33	0.81	0.139
se09a63	476	13	457	10	510	23	90	463	18	0.17	0.589
au26a17	478	29	458	19	624	30	73	462	35	0.49	0.149
au26a12	475	13	458	8	465	26	99	462	15	0.21	0.431
se09a52	474	13	459	10	489	22	94	464	18	0.25	0.365
au26a19	485	14	460	9	526	22	87	466	18	0.09	0.600
se08b17	453	15	463	11	446	20	104	460	20	0.54	0.234
se08b30	443	20	463	12	442	41	105	459	23	0.33	0.747
se09a46	441	16	463	10	434	31	107	459	18	0.16	0.082
au26a63	488	20	468	11	615	39	76	471	21	0.33	0.522
se09a21	467	10	469	9	440	17	106	468	15	0.86	0.008
se09a22	515	63	479	41	809	26	59	486	77	0.58	0.175
au26a13	493	18	479	12	544	41	88	482	22	0.45	0.670

Table 5.9 U-Pb data from detrital zircon grains of the Paxton Formation with probability of concordance ≥0.05. The ages and associated error used in this study are highlighted in blue. Grains with Th/U ratios <0.1 are highlighted in yellow. Grains used for the youngest age population are highlighted in pink.

file name	207Pb/ 235U Ma	1s error Ma	206Pb/ 238U Ma	1s error Ma	207Pb/ 206Pb Ma	1s error Ma	U-Pb/Pb-Pb concordancy %	Concordia age (Ma)	2s error Ma	Probability	Ratio Th/U
se07b11	502	16	481	10	535	23	90	485	18	0.19	0.075
se07b19	501	13	481	9	578	32	83	485	16	0.14	0.834
au26a09	520	21	490	13	691	38	71	496	24	0.16	0.820
se09a67	506	19	492	16	544	34	90	497	28	0.49	0.583
se08b12	507	10	499	8	508	20	98	501	14	0.47	0.541
se08b11	474	90	528	35	714	53	74	523	67	0.55	0.103
se09a28	553	30	541	18	647	28	84	543	34	0.69	0.081
se09a09	605	15	586	10	677	25	87	591	18	0.23	1.340
au26a11	661	26	635	20	697	24	91	643	36	0.34	0.021
se08b21	775	26	764	35	752	18	102	773	50	0.71	0.064
au26a41	951	26	945	22	902	32	105	948	38	0.84	0.440
se07b28	1007	16	979	22	972	17	101	999	31	0.17	0.572
au26a30	944	21	899	16	989	26	91	913	29	0.05	0.387
se09a07	987	22	953	16	1008	29	95	963	30	0.16	1.120
se07b24	955	26	932	20	1011	25	92	939	36	0.42	0.389
au26a54	1058	21	1029	21	1033	21	100	1043	34	0.23	0.607
se09a43	1033	17	1041	17	1045	19	100	1037	28	0.68	0.583
se09a61	1024	22	1023	23	1049	28	98	1024	37	0.96	0.755
au26a43	1050	25	996	22	1051	31	95	1017	39	0.05	0.337
se09a30	1000	21	996	18	1051	26	95	998	31	0.87	0.399
se07b25	957	31	933	24	1066	39	88	941	43	0.49	0.773
se09a33	1090	13	1069	16	1079	11	99	1082	24	0.19	0.933
se08b33	1032	29	996	29	1085	28	92	1013	48	0.28	0.335
au26a58	1102	36	1046	31	1087	34	96	1067	55	0.16	0.384
se07b22	1062	19	1042	15	1103	23	94	1048	27	0.34	0.420
se08b41	1175	20	1167	22	1170	17	100	1172	35	0.75	0.285
au26a14	1110	46	1069	38	1199	35	89	1083	66	0.42	0.732
se09a54	1140	23	1112	31	1200	12	93	1132	44	0.36	0.353
se09a27	1231	16	1231	18	1222	19	101	1231	27	0.99	0.699

Table 5.9 continued. U-Pb data from detrital zircon grains of the Paxton Formation with probability of concordance ≥0.05. The ages and associated error used in this study are highlighted in blue. Grains with Th/U ratios <0.1 are highlighted in yellow. Grains used for the youngest age population are highlighted in pink.

file name	207Pb/ 235U Ma	1s error Ma	206Pb/ 238U Ma	1s error Ma	207Pb/ 206Pb Ma	1s error Ma	U-Pb/Pb-Pb concordancy %	Concordia age (Ma)	2s error Ma	Probability	Ratio Th/U
se08b19	945	21	895	27	1246	27	72	929	40	0.05	0.225
se07b10	1297	27	1267	36	1282	28	99	1290	51	0.39	0.853
au26a20	1323	26	1309	26	1300	22	101	1316	42	0.65	0.532
au26a67	1330	21	1293	23	1304	16	99	1313	36	0.14	0.718
se09a53	1308	12	1281	18	1305	13	98	1303	23	0.09	0.317
au26a50	1441	14	1417	17	1361	13	104	1432	26	0.19	0.453
se08b23	1245	22	1215	29	1361	23	89	1237	41	0.27	0.797
au26a27	1376	17	1337	17	1368	15	98	1355	28	0.05	0.394
se08b22	1393	12	1393	16	1382	14	101	1393	22	1.00	0.460
se09a58	1321	27	1252	38	1406	14	89	1306	52	0.05	0.204
se09a29	1447	15	1443	16	1420	15	102	1445	25	0.83	0.401
se08a07	1479	19	1429	31	1424	18	100	1473	39	0.07	0.117
au26a28	1403	38	1431	28	1441	27	99	1422	50	0.50	0.354
se08b08	1480	18	1472	23	1450	14	102	1477	33	0.74	0.356
au26a59	1422	20	1383	23	1453	16	95	1406	35	0.11	0.848
se09a48	1468	12	1439	20	1472	12	98	1465	24	0.11	0.736
se08b39	1453	16	1445	20	1473	11	98	1450	29	0.71	0.792
se09a62	1504	17	1499	28	1482	14	101	1504	34	0.83	0.282
se08b38	1520	17	1509	26	1492	15	101	1518	32	0.63	0.325
se09a47	1506	18	1487	31	1497	12	99	1505	36	0.49	0.110
au26a37	1539	22	1520	22	1499	19	101	1530	35	0.47	0.581
se09a32	1454	25	1414	28	1501	23	94	1437	43	0.19	0.295
se08a08	1541	22	1505	25	1507	24	100	1527	38	0.18	0.962
se09a44	1498	21	1447	34	1516	12	95	1493	41	0.09	0.275
se08b20	1554	27	1546	39	1541	23	100	1552	52	0.83	0.176
se08a10	1551	18	1561	21	1550	12	101	1555	31	0.65	0.299
se09a31	1578	36	1572	34	1556	42	101	1575	56	0.88	0.507
au26a23	1619	47	1523	85	1558	24	98	1618	93	0.18	0.281
se08b10	1532	15	1507	20	1559	13	97	1525	28	0.20	0.482

Table 5.9 continued. U-Pb data from detrital zircon grains of the Paxton Formation with probability of concordance ≥0.05. The ages and associated error used in this study are highlighted in blue. Grains with Th/U ratios <0.1 are highlighted in yellow. Grains used for the youngest age population are highlighted in pink.

file name	207Pb/ 235U Ma	1s error Ma	206Pb/ 238U Ma	1s error Ma	207Pb/ 206Pb Ma	1s error Ma	U-Pb/Pb-Pb concordancy %	Concordia age (Ma)	2s error Ma	Probability	Ratio Th/U
se08b32	1596	17	1585	27	1563	11	101	1595	34	0.64	0.450
se08b18	1583	31	1578	38	1575	19	100	1581	56	0.90	0.625
se09a23	1700	36	1689	47	1582	20	107	1696	66	0.82	0.603
au26a38	1516	44	1559	41	1582	42	99	1539	67	0.40	0.965
au26a18	1624	40	1525	62	1605	16	95	1608	79	0.07	0.331
au26a44	1671	14	1638	19	1608	10	102	1663	26	0.08	0.399
au26a07	1614	34	1643	30	1620	25	101	1631	50	0.46	0.913
se07b18	1614	15	1602	21	1620	13	99	1611	29	0.59	0.720
se07b09	1661	19	1626	25	1624	14	100	1650	35	0.16	0.435
se08a11	1643	17	1629	22	1629	14	100	1639	31	0.53	0.847
se09a59	1599	19	1560	23	1632	17	96	1584	35	0.11	0.932
se09a24	1666	12	1657	19	1647	11	101	1665	23	0.63	0.282
se07b20	1640	16	1599	20	1648	16	97	1626	29	0.05	0.263
se08b27	1679	14	1697	17	1655	13	103	1685	25	0.30	1.270
au26a22	1694	32	1630	43	1667	16	98	1677	60	0.13	0.441
se08b37	1523	42	1501	28	1671	21	90	1507	51	0.63	0.727
au26a29	1662	22	1639	27	1685	21	97	1654	40	0.42	0.953
se08b09	1664	17	1617	26	1690	10	96	1656	33	0.05	0.339
se08b07	1716	14	1716	24	1693	14	101	1716	27	0.98	0.576
au26a40	1747	23	1702	31	1698	21	100	1734	43	0.13	0.711
se07b21	1652	22	1638	26	1710	16	96	1646	39	0.60	0.359
au26a68	1817	21	1763	27	1766	16	100	1798	39	0.06	0.911
au26a10	1772	42	1747	47	1819	35	96	1761	71	0.63	0.294
se08a09	2673	13	2635	31	2662	7	99	2675	26	0.16	0.463
se08b24	2719	16	2723	34	2686	9	101	2719	33	0.89	0.475

Table 5.9 continued. U-Pb data from detrital zircon grains of the Paxton Formation with probability of concordance ≥0.05. The ages and associated error used in this study are highlighted in blue. Grains with Th/U ratios <0.1 are highlighted in yellow. Grains used for the youngest age population are highlighted in pink.

6.0 Discussion

Age of metasediments

Eastern Samples – Kittery, Eliot, & Berwick Formations

Youngest zircon age populations – eastern samples

The youngest zircon age populations of the Kittery, Eliot and Berwick Formations are all within error of each other. The youngest grains of the Kittery, Eliot, and Berwick Formations are, 413 ± 12 Ma, 409 ± 19 Ma, and 409 ± 11 Ma, respectively (all $^{206}Pb/^{238}U$ ages and 1σ errors). While the youngest zircons of the Kittery Formation may be older, as indicated by the ID-TIMS analyses, it is striking that the ICP-MS analyses of these three samples yield youngest zircon population ages that are essentially identical. Based on the consistency of the ages of the youngest age populations between the three samples, the preferred interpretation is that the youngest zircon age population of the eastern portion of the MT is 411 ± 15 Ma and that the three samples were deposited at approximately the same time or received the same detrital source material.

Kittery ID-TIMS data

ID-TIMS analysis was performed on the four youngest grains in the Kittery Formation to better constrain the error values. The results of the ID-TIMS analysis were older than the LA-ICP-MS data, probably because the effects of Pb-loss were "erased" by the chemical annealing method (see methods). However, it is also possible that the ID-TIMS analyses incorporated older cores that were missed in the ICP-MS analyses and that the ages therefore appear older. The ID-TIMS results (432 ± 0.68 Ma) suggest a maximum age of deposition of Early Silurian for the Kittery Formation. This value is roughly similar to the upper error limit value for the LA-ICP-MS results for the Kittery

Formation. Thus ~426 Ma will be the maximum depositional age accepted here for the Kittery Formation. Because the Eliot and Berwick Formations youngest zircon age populations are similar to that of the Kittery Formation, the upper error limit will be used for determining the youngest age populations for these formations as well. Therefore, the maximum depositional age of the eastern MT formations is ~426 Ma.

Depositional age of the eastern MT samples

The Kittery and Eliot Formations are intruded by the Exeter pluton (407 Ma) and the Newburyport Complex (418 Ma) constraining the minimum age of the Kittery and Eliot Formations to be Late Silurian (Bothner et al., 1993; Bothner et al., 2009). Thus, based on similarities between youngest age populations, ID-TIMS analysis and cross-cutting plutons, the Kittery, Eliot, and Berwick Formations were deposited in the Mid-to Late Silurian.

Western Samples – Oakdale, Worcester, & Paxton Formations

Youngest zircon age population

The youngest zircon age populations for the western samples are all similar in age: Oakdale Formation, 431 ± 12 Ma, Worcester Formation, 436 ± 9 Ma, and Paxton Formation, 426 ± 6 Ma, (all $^{206}Pb/^{238}U$ ages and 1σ errors). All are within error of each other, received similar detrital source material and were likely deposited at nearly the same time. Therefore, all three can be averaged to give the youngest zircon age population of the western portion of the MT in Massachusetts of 429 ± 9 Ma ($^{206}Pb/^{238}U$ ages and 1σ errors). The youngest zircon age population of the Tower Hill Quartzite does not fit with these units and will be discussed later.

Depositional age of the western MT samples

The Ayer granite intrudes both the Oakdale and Berwick Formations. Recent U-Pb age dating of the Ayer yields an age of 407 Ma (Walsh et al., 2008). This constrains the age of deposition for the Oakdale Formation to be at least pre-Early Devonian. By analogy to the above TIMS data for the eastern MT samples, it is probable that lead loss was not accounted for in the LA-ICP-MS analysis for the western MT samples as well. Thus, it is possible that the youngest detrital zircon populations are approximately as old as the maximum error limit value, ~438 Ma. To remain consistent with the eastern samples, and because all three youngest age populations for the western samples are similar in age, an age using the maximum error limit value for the western samples will be used (~438 Ma). Based on cross-cutting plutons and the maximum error limit values of the LA-ICP-MS youngest age populations, the western samples of the MT were deposited between the Early and Late Silurian.

Tower Hill Formation

Youngest zircon age population and depositional age

The Tower Hill Formations youngest zircon age population is 513 ± 15 Ma ($^{206}Pb/^{238}U$ ages and 1σ errors). It is possible that the LA-ICP-MS data from the Tower Hill Formation analysis also suffered from Pb-loss and an upper limit error value should be used when determining the maximum age of deposition. Thus the youngest detrital zircon population would be between 513 and 528 Ma, making the maximum age of deposition Early Cambrian. This makes it up to 100 Ma older than the youngest age populations in the eastern MT samples and unlikely to be a formation within the MT. For the Tower Hill Formation to be deposited in the same depositional basin as the remainder of the MT, the basin would have to be present earlier and open for ~100 Ma, an abnormally long time. There is no evidence from the remainder of the MT that a basin would have been present for that length of time. As mentioned previously, there was one grain present in the Tower Hill Formation with an age of 468 Ma. Even if this grain was incorporated, the age of the Tower Hill Formation would still be unlike the remainder the of MT.

The fact that the youngest grain in the Tower Hill Formation is older than those in the other samples in the MT may mean that its depositional age was older than the other samples. Alternatively, the Tower Hill Formation may have a similar depositional age as the rest of the MT, but the source area may have been different so that no young detrital zircons were received.

Correlations among formations

Eastern samples –Kittery, Eliot, & Berwick Formations

It is clear that the Kittery, Eliot, and Berwick Formations correlate with one another from the probability density plots (Figure 6.1). All three samples show similar youngest ages in the Middle/Late Silurian, a peak in the Middle to Late Ordovician, followed by general lows 600-800 Ma and 800-900 Ma, and then input from approximately 1.0-1.8 Ga with scattered Archean grains. These data strongly suggest that the three formations formed as a single sedimentary group.

Hussey et al. (2010) suggests that the Berwick Formation in Maine and New Hampshire is a part of the Central Maine terrane (CMT). The Berwick Formation has been correlated with the Vassalboro and Madrid Formations of the CMT based on detrital zircon work (Wintsch et al., 2007), similarities in lithology and along-strike positioning

(Hussey et al., 2010). However, based on similarities in lithologies, youngest detrital zircon age populations and overall detrital zircon age population distributions between the Kittery, Eliot, and Berwick Formations, it is clear that the portion of the Berwick Formation sampled in MA for this study correlates with the Kittery and Eliot Formation samples. Hence, the Berwick Formation should remain a member of the MT and forms part of a single sedimentary package with the Kittery and Eliot Formations.

Western samples –Oakdale, Worcester, & Paxton Formations

It is also clear that the Oakdale, Worcester, and Paxton Formations correlate with one another from the probability density plots (Figure 6.2). All three samples show similar youngest detrital zircon ages in the Early Silurian, a peak in the Late to Middle Ordovician followed by a general low 800-900 Ma, and then input from approximately 1.0-1.8 Ga with scattered Archean grains. This suggests the Oakdale, Worcester, and Paxton Formations belong to a single depositional sequence of rocks. Slight differences in distribution are expected as there were likely several sources supplying detritus and the three samples lie in different locations stratigraphically.

Correlations between Eastern and Western MT samples

Comparison between the three eastern and the three western MT samples (Figure 6.3) shows that all six samples have very similar LA-ICP-MS age distributions. All have detrital zircon age distributions with peaks in the Late to Middle Ordovician, similar abundances of early Paleozoic and late Neoproterozoic zircons, input from ~ 1.0 to ~1.8 Ga and limited Archean grains. Also the eastern and western samples both have smaller peaks at ~1.0 and ~1.5 Ga. Therefore, it is interpreted that all six samples correlate and belong to a single sequence of rocks.

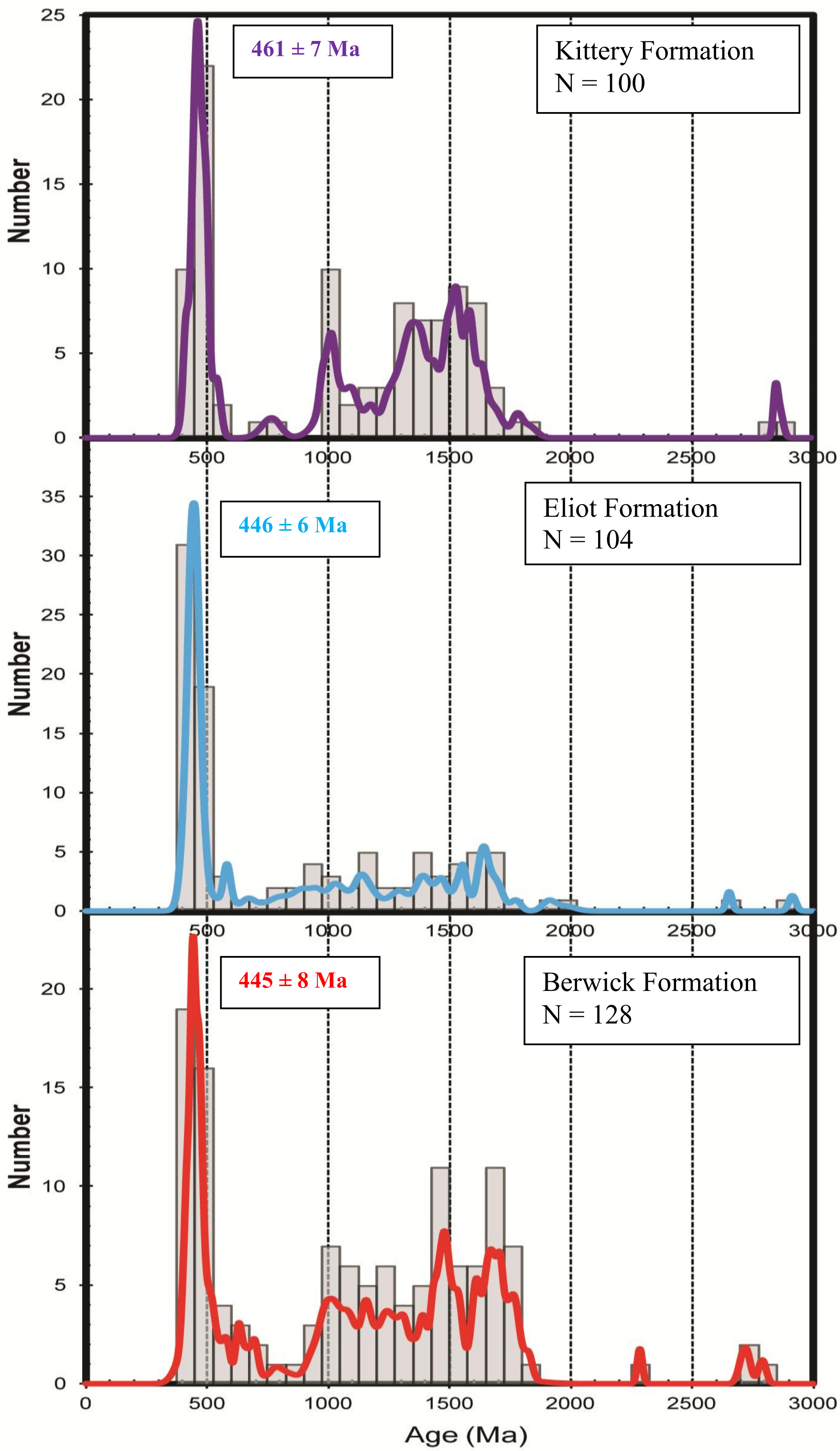

Figure 6.1 Probability density plots for zircon grains for the Kittery (purple), Eliot (light blue), and Berwick (red) Formations. Dates in the boxes represent the age of the most prominent peak.

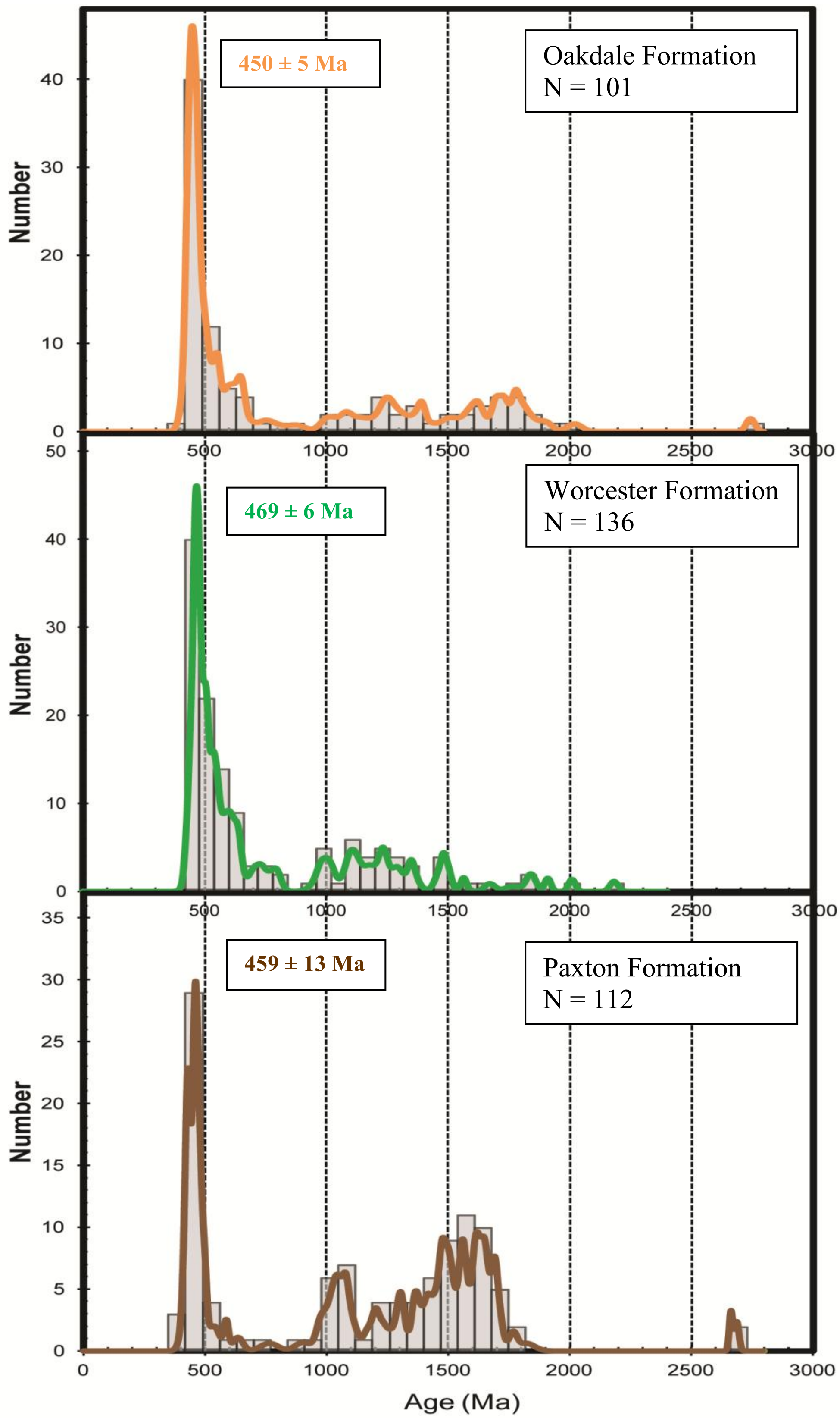

Figure 6.2 Probability density plots for zircon grains for the Oakdale (orange), Worcester (green), and Paxton (brown) Formations. Dates in the boxes represent the age of the most prominent peak.

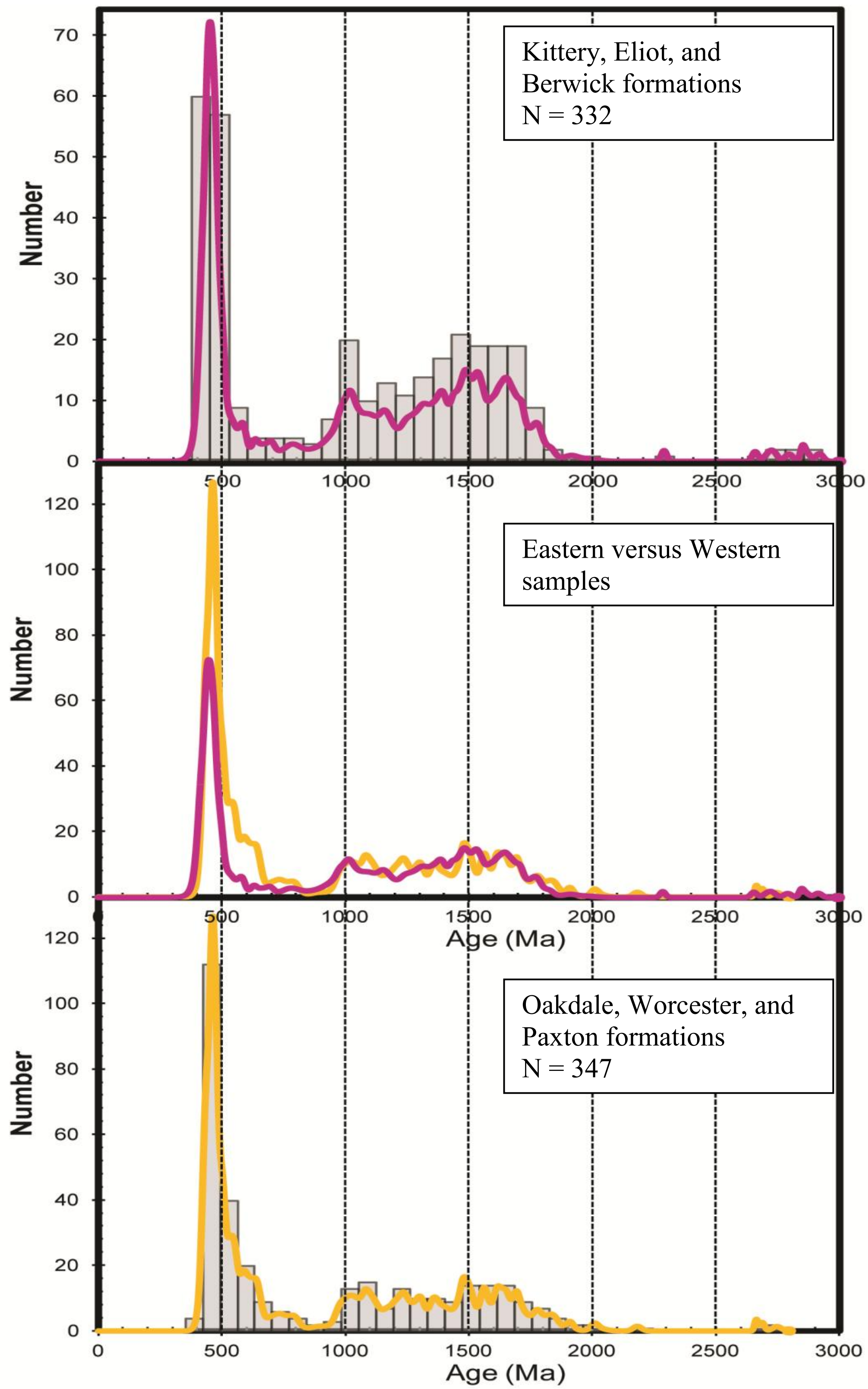

Figure 6.3 Probability density plot for the eastern samples (Kittery, Eliot, and Berwick Formations) shown in pink versus the western samples (Oakdale, Worcester, and Paxton Formations) in bright yellow.

However, there are slight differences between the western and eastern MT samples. The eastern samples have 51% of the zircon grains 1.0-1.8 Ga, whereas the western samples have only 39% of grains in this age range. Thus, the western samples have more Paleozoic and Neoproterozoic grains than the eastern samples. This is especially observed between 500-800 Ma, where the western samples have 22% of their grains and the eastern samples have only 10% in this range. Furthermore, the eastern samples have an especially low point 600-800 Ma and have more Archean grains with seven, versus the three the western samples have.

Correlations with the Tower Hill Formation and the Merrimack terrane

The overall detrital zircon age distribution for the Tower Hill Formation does not resemble the rest of the formations sampled from the MT (Figure 6.4). The Tower Hill Formation has a large peak in the Neoproterozoic at ~644 Ma. This is nearly 200 Ma older than the large peaks in the remainder of the MT samples. The Neoproterozoic peak is followed by input through 1.4 Ga and scattered grains in the Paleoproterozoic and Archean. The Tower Hill Formation has 71% of its grains 600-800 Ma, which contrasts strongly with the low number of grains observed in the other MT samples during this interval. Due to the lack of similarities in the youngest age populations and the overall zircon age distributions between the Tower Hill Formation and the rest of the MT, the Tower Hill Formation should no longer be considered as a part of the MT. If the Tower Hill Formation had the same provenance as the remainder of the MT, it would be expected the zircon age distributions would be similar, which is not observed.

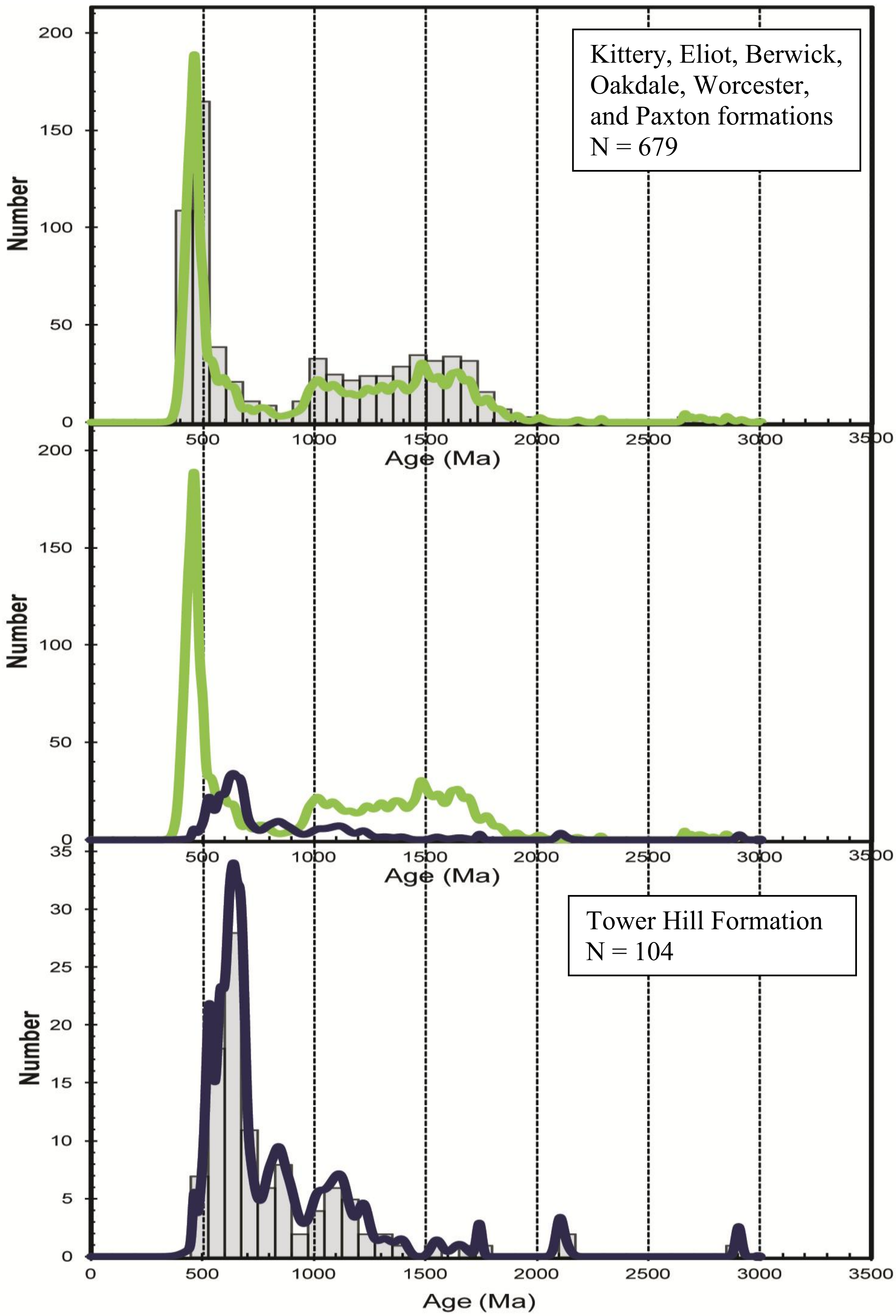

Figure 6.4 Probability density plots of the six MT samples combined (green) versus the Tower Hill Formation (navy blue).

Comparison of the MT results and works by others

Kittery Formation

Based on SHRIMP U-Pb analysis of zircons from the Kittery and Berwick Formations, Wintsch et al. (2007) suggested the Kittery and Eliot Formations were not a part of the same terrane as the Berwick Formation. A comparison of the Kittery Formation data from Wintsch et al. (2007) versus the Kittery Formation data from this study (Figure 6.5) shows that the two different samples do not correlate. The Kittery Formation sample analyzed by Wintsch et al. (2007) lacks the major Ordovician peak observed in this study and has its largest peak near 1.0 Ga. Although there is a small peak at 1.0 Ga in the Kittery Formation sample from this study, it is not as prevalent. It should be noted that although Figure 6.5 shows a peak at ~485 Ma and ~650 Ma for the Wintsch et al. (2007) data, each peak only has one grain at that age.

If the two samples were of the same sequence of rocks it would be expected the major peaks in both would be similar. It is possible that the difference in signatures of the two Kittery Formation samples is the result of stratigraphic position within the Kittery Formation, multiple rock types being mapped as a part of the Kittery Formation and/or the mapping needs revision. The location of the Kittery Formation sampled in this study is in close proximity to the type locality and continuous with the Kittery type locality.

Berwick Formation

Detrital zircons from the Berwick Formation in Maine were also dated by Wintsch et al. (2007) and interpreted as correlative with those from the Hebron Formation in CT. A comparison of the Berwick Formation sample from Wintsch et al. (2007) and the Berwick Formation sample from this study shows similarities and

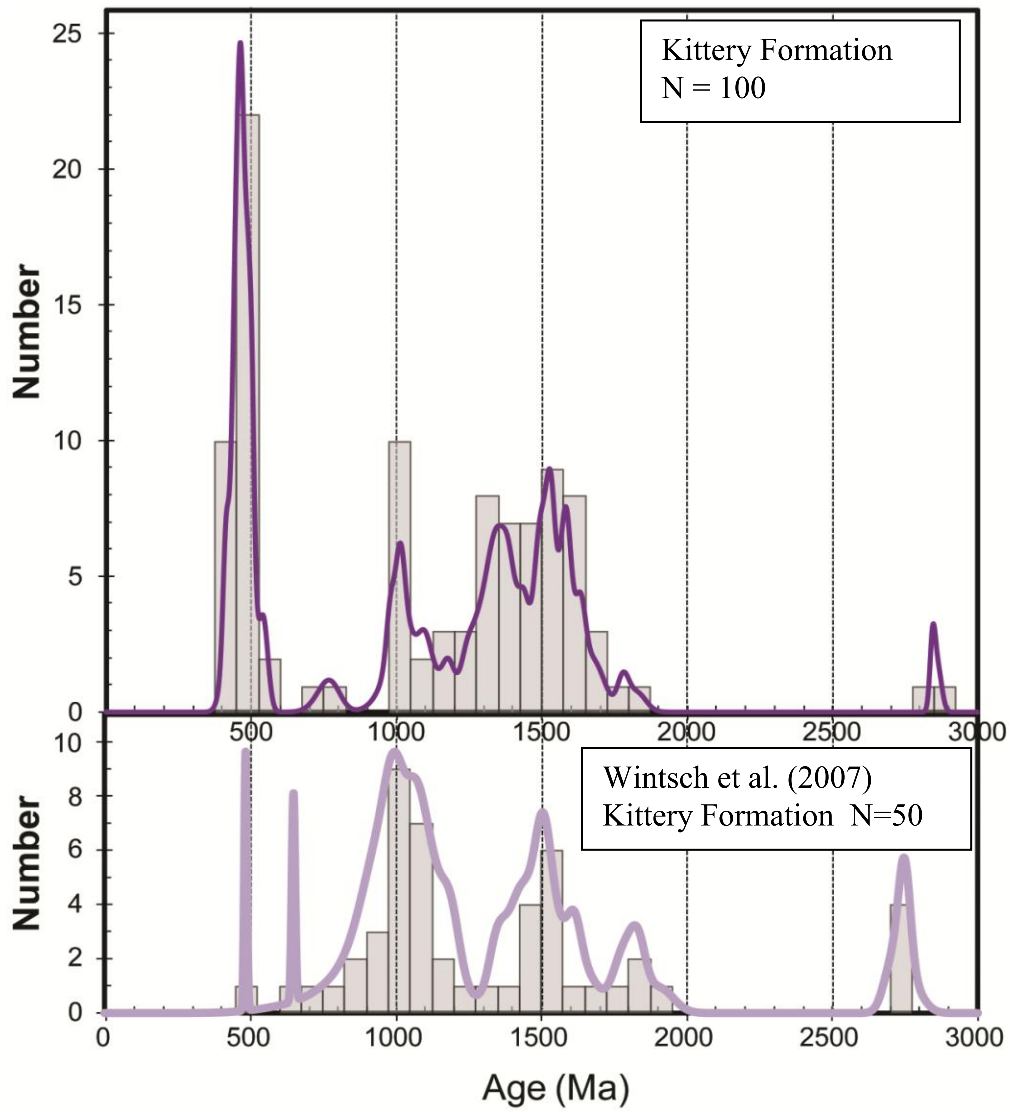

Figure 6.5 Probability density plots for zircon grains for the Kittery (purple) Formation from the study outlined and for the Kittery (light purple) Formation from Wintsch et al. (2007).

differences between these samples (Figure 6.6). Similarities showed both have major Ordovician peaks and smaller peaks around 1.0 and 1.5 Ga. Also, the youngest detrital zircon grain from the Berwick Formation as analyzed by Wintsch et al. (2007) was determined to be 426 Ma. This further supports that the upper error limit value should be used when determining the maximum ages of deposition for the MT samples in this study. When using the upper error limit value for the Berwick Formation from the study, the maximum age of deposition is 420 Ma, very close in age to the Berwick Formation sample from Wintsch et al. (2007). This suggests that both samples are a part of the Berwick Formation.

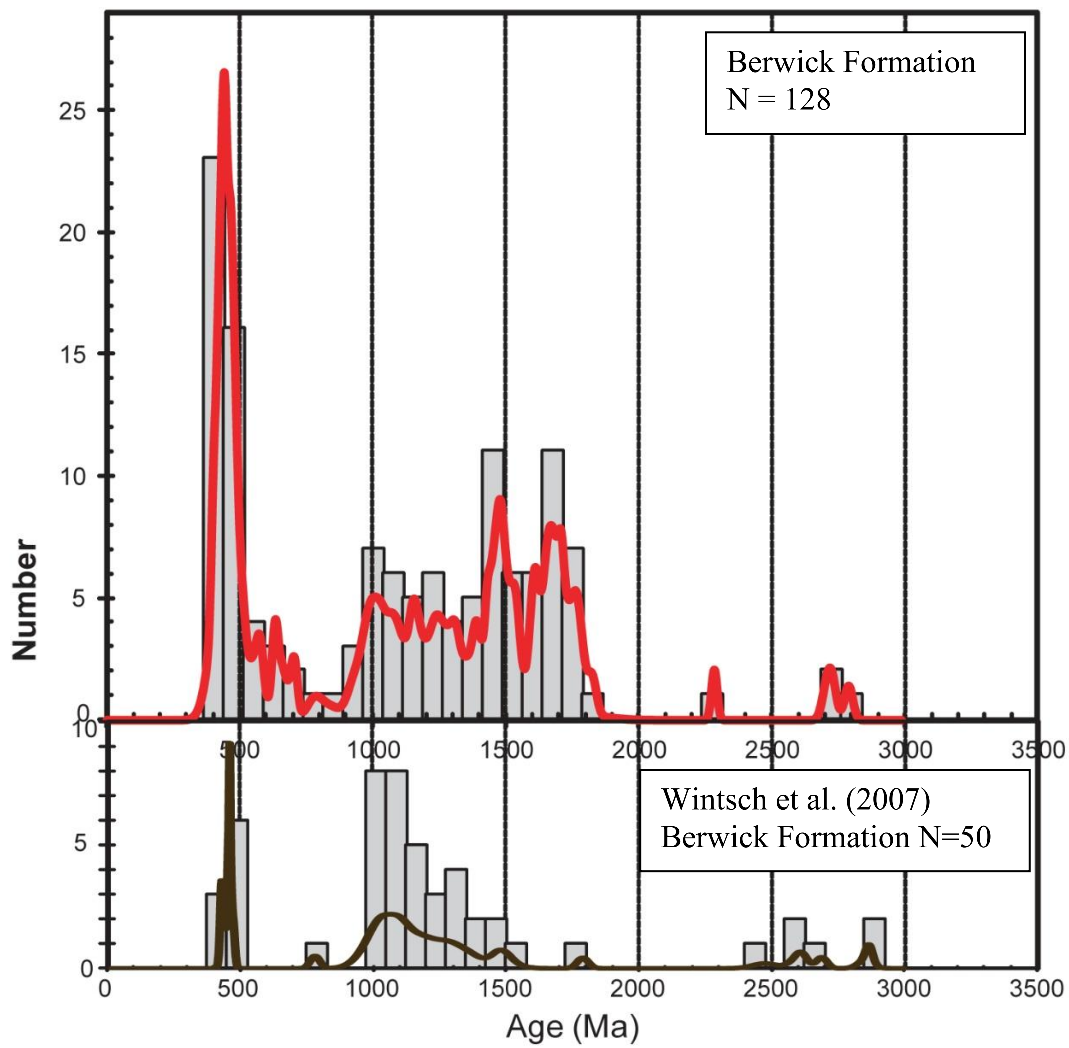

Figure 6.6 Probability density plots for zircon grains for the Berwick (top -red) Formation from the study outlined and for the Berwick (dark brown-bottom) Formation from Wintsch et al. (2007).

However, there are some differences between the two Berwick Formation samples. The sample analyzed by Wintsch et al. (2007) has a much more obvious gap between 600-900 Ma and lacks zircons in the 1.5-1.8 Ga range. The distinction may be due to the differences in sample locations or in the number of grains used in the studies.

Hebron Formation

The Oakdale, Worcester, and Paxton Formations have been correlated with the Hebron Formation in CT (Robinson and Goldsmith, 1991; Wintsch et al., 2007). Figure 6.7 shows a comparison of the three western MT samples from this study combined versus the Hebron Formation samples analyzed by Wintsch et al. (2007). Due to differences in the numbers of grains used for each study, Figure 6.7 is not to scale. However in Figure 6.8 the Hebron Formation is compared with the Oakdale Formation at the same scale as both have a roughly equal number of grains analyzed. Both the Hebron Formation samples and the three MT samples show an Ordovician peak followed by a low 800-900 Ma, significant input 1.0-1.8 Ga and scattered Archean grains. The Hebron Formation and MT samples also have smaller peaks at ~1.48 Ga and shortly after 1.0 Ga. One difference between the Hebron and the MT is the Hebron has more grains 1.0-1.3 Ga. This may be the result of the Hebron having slightly more of an input from that particular source, such as Laurentia as Wintsch et al. (2007) suggested. Also, both the Hebron Formation and MT samples have youngest detrital zircon populations in the Silurian. The similarities between this study and the study of Wintsch et al. (2007) further supports that the Hebron Formation and the Oakdale, Worcester, and Paxton Formations all belong to the MT as they have been previously correlated and mapped (Pease, 1989; Robinson and Goldsmith, 1991).

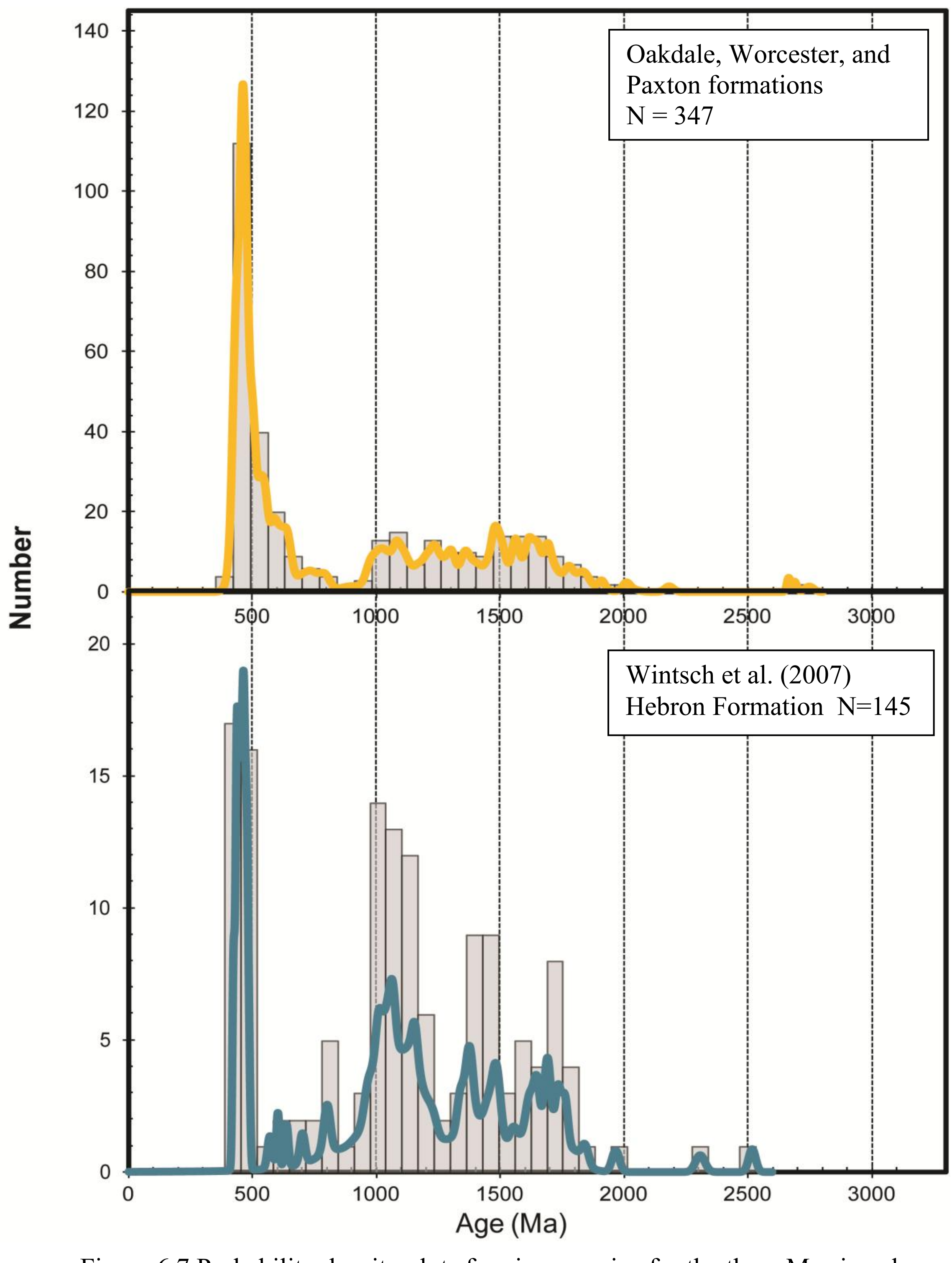

Figure 6.7 Probability density plots for zircon grains for the three Merrimack terrane western samples in MA, the Oakdale, Worcester, and Paxton Formations (bright orange) versus zircon grains from the Hebron Formation from Wintsch et al. (2007) (teal). The two probability density plots are not to scale.

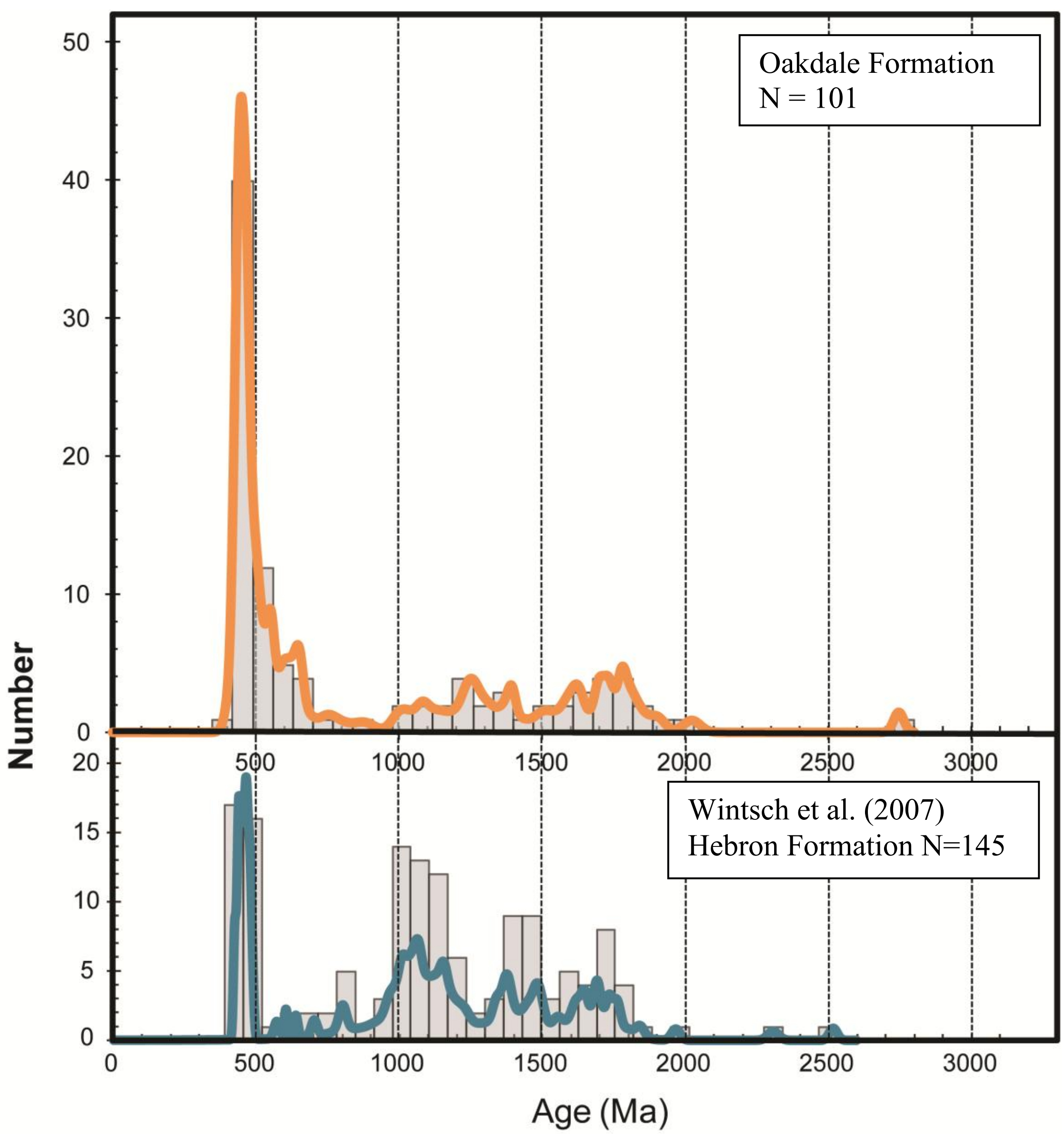

Figure 6.8 Probability density plot for the Oakdale Formation (orange) versus the Hebron Formation from Wintsch et al. (2007) (teal).

Correlations between the MT and adjacent terranes

Although current geologic maps (i.e. Zen et al., 1983) show the MT as a separate terrane from both the Nashoba and Central Maine terranes, comparisons have been provided to further illustrate the MT is not a part of either. Comparisons outlined below include the MT detrital zircon data from this study and detrital zircon studies performed by others in the Nashoba and Central Maine terranes (Loan, 2011; Dorais et al., 2009).

Nashoba terrane

The four formations within the Nashoba terrane analyzed by Loan (2011) showed maximum ages of deposition in the Early Ordovician, making them ~30 million years older than the Silurian MT samples from this study. The Nashoba terrane also has a large peak of detritus at ~540 Ma that is much older than the dominant peak observed in the MT at ~460 Ma (Figure 6.9). If both were a part of a single terrane it would be expected that the dominant peaks of detrital zircons would be similar. Also, the MT has a large population of grains 1.0-1.8 Ga, which is not as prevalent in the Nashoba terrane samples. Based on: (1) the differences between maximum ages of deposition, (2) the overall detrital zircon age distribution, (3) a difference between metamorphic grades across the fault boundary and (4) the presence of a major fault boundary, it is interpreted that the terranes did not form in the same geologic setting.

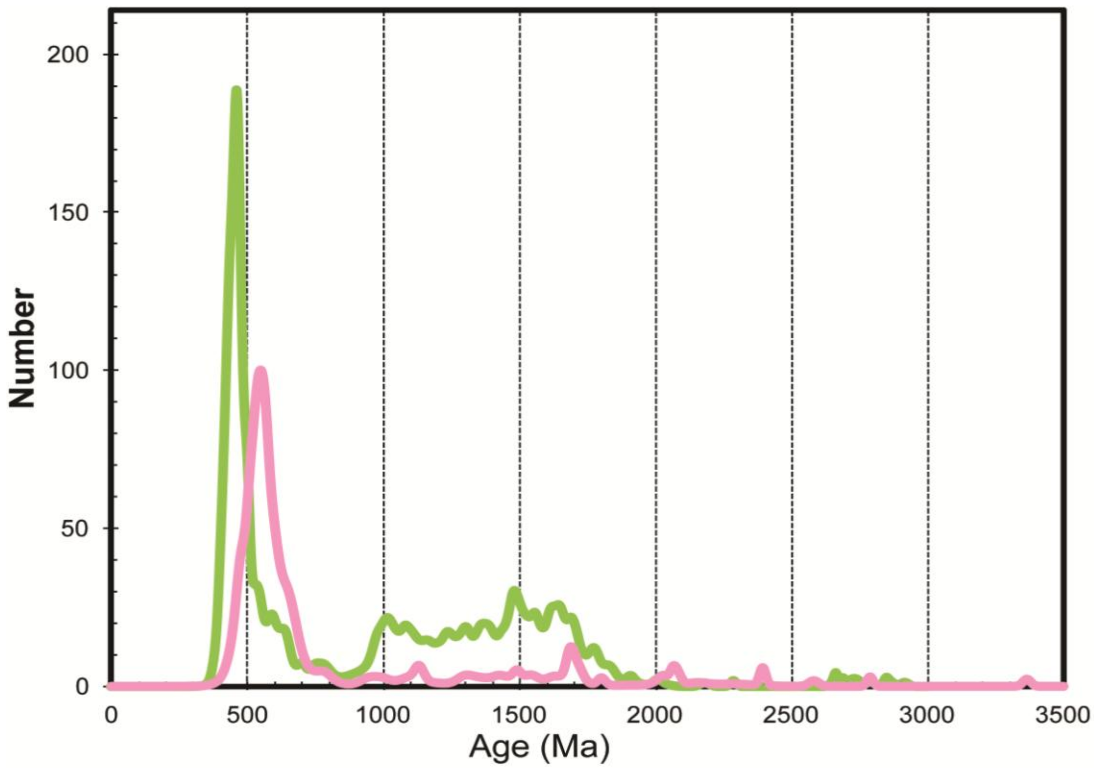

Figure 6.9 Density probability plot of the Nashoba terrane (Loan , 2011) in pink versus the Merrimack terrane (this study) in green.

Central Maine terrane

Unlike the boundary between the Nashoba terrane and the MT, the boundary between the MT and the Central Maine terrane (CMT) is not as clear. The terranes, at least in part, have long been correlated (Hussey et al., 2010). Furthermore, a comparison of the Worcester and Berwick Formations from this study with the Carrabassett Formation of Dorais et al. (2009) from north-central Maine shows many similarities as well as a number of differences (Figure 6.10).

Data from the Carrabassett Formation was compared with the Worcester and Berwick Formations individually due to the smaller number of grains used in the study of the Carrabassett Formation. If all MT samples were used and the probability density plot of the MT and the Carrabassett Formation was to scale, similarities and contrasts between the Carrabassett Formation and the MT would not be obvious. The LA-ICP-MS U-Pb detrital zircon study of the Carrabassett Formation of the CMT by Dorais et al. (2009) indicated a youngest detrital zircon at 412 ± 23 Ma, similar to the eastern samples from this study. All three formations show a low in detritus 800-900 Ma, similar age distributions from 1.0-1.8 Ga, and scattered Archean grains.

The fact that the MT exhibits a large Ordovician peak, not present in the Carrabassett Formation is the most obvious difference in these samples. The Carrabassett Formation has only two grains in the Ordovician and its largest peaks are ~540 and 600 – 660, similar to Ganderia. If the CMT and MT formed in the same geologic setting, the Carrabassett Formation would likely have a much larger Ordovician signal. Therefore the MT and CMT have separate geologic histories and sources as indicated by Bradley and Hanson (2002) and Hussey et al. (2010). This further supports that the Berwick Formation is a part of the MT and not a member of the CMT. This also suggests that the detrital sources for the MT provided more abundant younger zircons than the sources for the Carrabassett Formation.

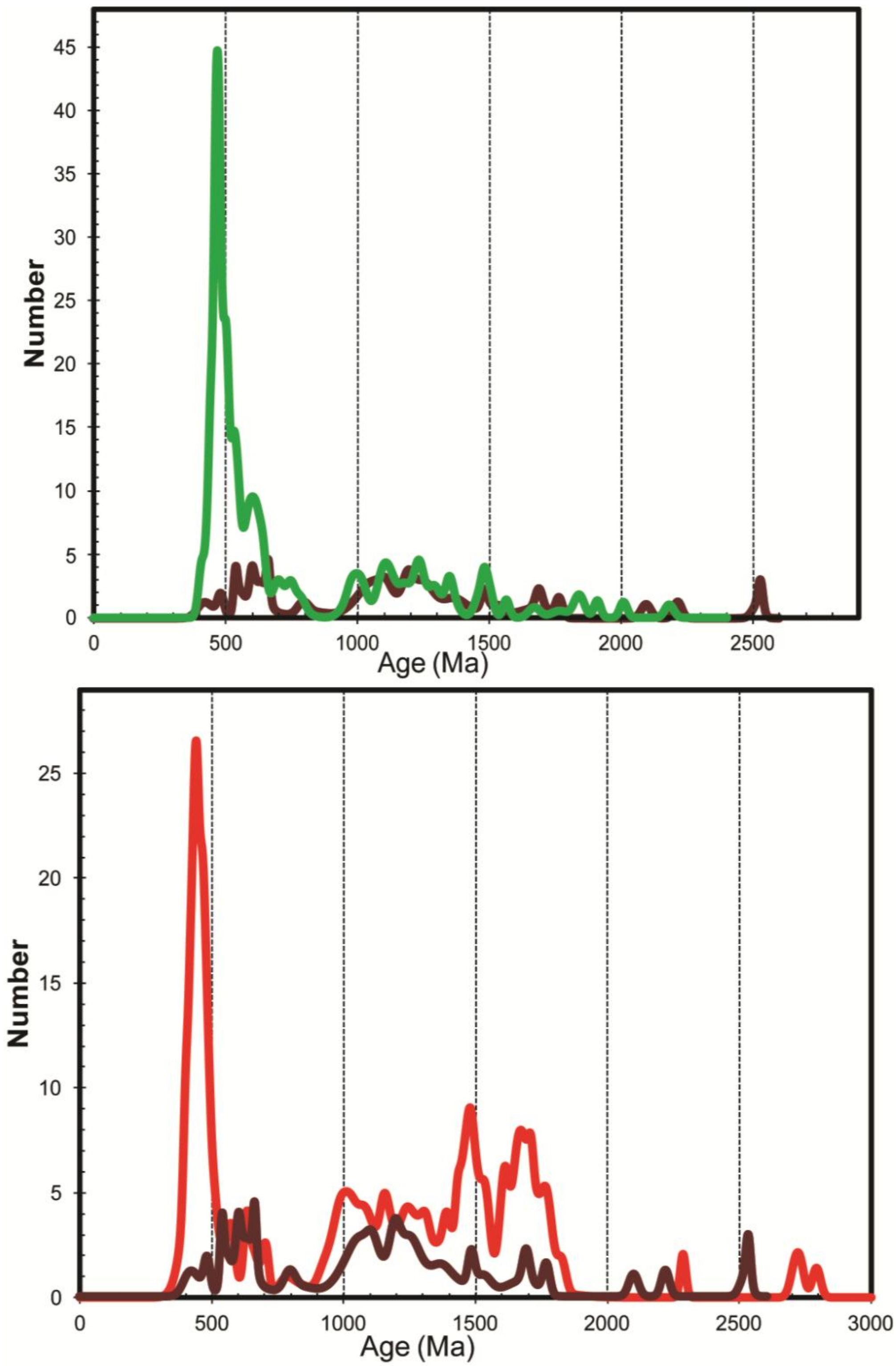

Figure 6.10 Probability Density Plots comparing the Worcester Formation (green) of the MT and the Carabassett Formation (maroon) of the CMT (top) and comparing the Berwick Formation (red) of the MT and the Carabassett Formation (maroon) of the CMT (bottom). Carabassett Formation data from Dorais et al. (2009).

Correlations with the Bucksport Formation and the Fredericton trough

Recent literature has suggested that the MT may be comparable to the Bucksport Formation of the Fredericton belt in Maine and New Brunswick (e.g., Hussey et al., 2010) suggesting that the Fredericton belt, Bucksport Formation and MT form one large sedimentary basin, called the "Merribuckfred" basin. This is based on similarities in lithologies, deformation, metamorphism and suggested similarities in ages of deposition (Hussey et al., 1999; Wintsch et al., 2007; Hussey et al., 2010).

Based on ages of a cross-cutting post-tectonic Pocomoonshine pluton, the Fredericton belt is thought to have been deposited prior to 422.7 ± 3 Ma (West et al., 1992). Correlation of the Fredericton belt with the MT implies that the MT would have been deposited prior to 422 Ma as well, which is observed in the upper age limit of the LA-ICP-MS results for the eastern MT samples and in the youngest detrital zircon age populations for the western MT samples. The similarities in depositional ages further supports that the MT and Fredericton belt may have formed in the same depositional basin.

Although it is likely that both the MT and Fredericton belt formed in similar geologic settings, it also remains possible that they formed in two separate sedimentary basins similar in size, location and source areas. Without detrital zircon work performed in the Fredericton belt it is difficult to prove. If both were instead a part of a single basin the younger detrital zircons in the eastern MT samples could be the result of the basin closing in the north first (Fredericton belt), allowing the MT to continue to receive sediment at a younger age. The younger detritus is likely the result of grains from the Coastal Volcanic Belt that developed from the subduction of the Acadian seaway beneath

Laurentia. To fully investigate if the MT and Fredericton belt formed in two separate basins or as a part of one, further detrital zircon work needs to be done.

Correlations between the Tower Hill Formation and adjacent terranes

Nashoba terrane

The Tower Hill Formation lies directly along the Clinton-Newbury fault zone. This makes it reasonable to assume that if it is not correlative with the MT, then it could be a member of the Nashoba terrane. Figure 6.11 shows that the overall detrital zircon age signatures of the Tower Hill Formation are different from the Nashoba terrane (cf. Loan, 2011). First, the maximum age of deposition in the Nashoba terrane is in the Early Ordovician, whereas for the Tower Hill Formation it is Early Cambrian. Also, the Tower Hill Formation has its largest peak ~100 million years older than the largest peak in the Nashoba terrane. Therefore, the Tower Hill Formation is not correlative with the Nashoba terrane.

Avalon terrane

The youngest detrital zircons in the Avalon terrane were found by Pollock et al. (2009) to be Late Neoproterozoic, close in age to the Early Cambrian Tower Hill Formation. However, Figure 6.11 shows the Tower Hill Formation detrital zircon data from this study and detrital zircon data from the Avalon terrane from Pollock et al. (2009) and Hepburn (personal communication, 2012) do not correlate. Although the most prominent peaks in both are similar in age, the Avalon terrane has zero grains of 800-900 Ma, whereas the Tower Hill Formation has ~11% of its grains within this range, making it unlikely that they had the same provenance.

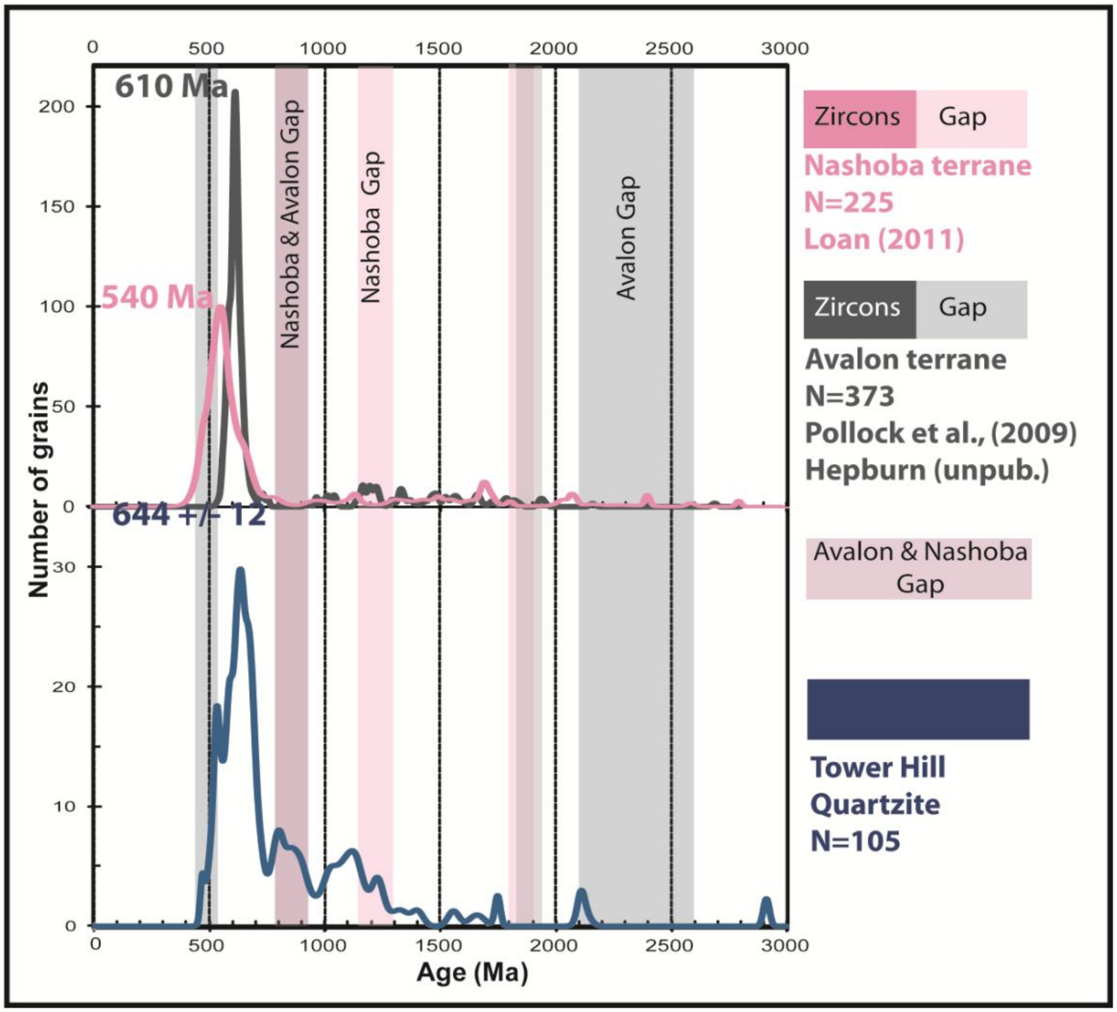

Figure 6.11 Probability density plots comparing both the Nashoba and Avalon terranes to the Tower Hill Formation

Provenance

Merrimack terrane

Provenance of the MT can be determined by comparing its detrital zircon ages with compiled data from various published U/Pb zircon studies done in the northern Appalachians (e.g. Nance et al., 2008) (Figure 6.12). A relationship between the Amazon Craton (Ganderia) and the MT exist. During the Late Proterozoic both Baltica and Eastern Laurentia have a gap in detrital zircons. During this time Ganderia and the MT samples from this study both have significant zircons present. Also, during the Early Proterozoic (2.1-2.4 Ga) a gap in Ganderian detrital zircons is mimicked by the MT samples with only two grains during this time. Although there is a strong case for detritus from Ganderia, Ganderian detritus cannot explain all of the detritus received in the MT samples. For example, between 1.7-1.9 Ga Ganderia exhibits a gap. In contrast, the MT has detritus of this age present. This can be explained by detritus also being received from Laurentia. Detritus received from Laurentia can also explain why the detrital signal of 650-900 Ma in the MT samples has gaps. Ganderia has a steady signal of detritus here, whereas Laurentia does not. This suggests a dual source provenance for the MT from both Ganderia and Laurentia. Detrital zircon data from both Laurentia and Ganderia have been plotted versus the eastern and western MT samples to demonstrate this (Figure 6.13) and will be discussed further below.

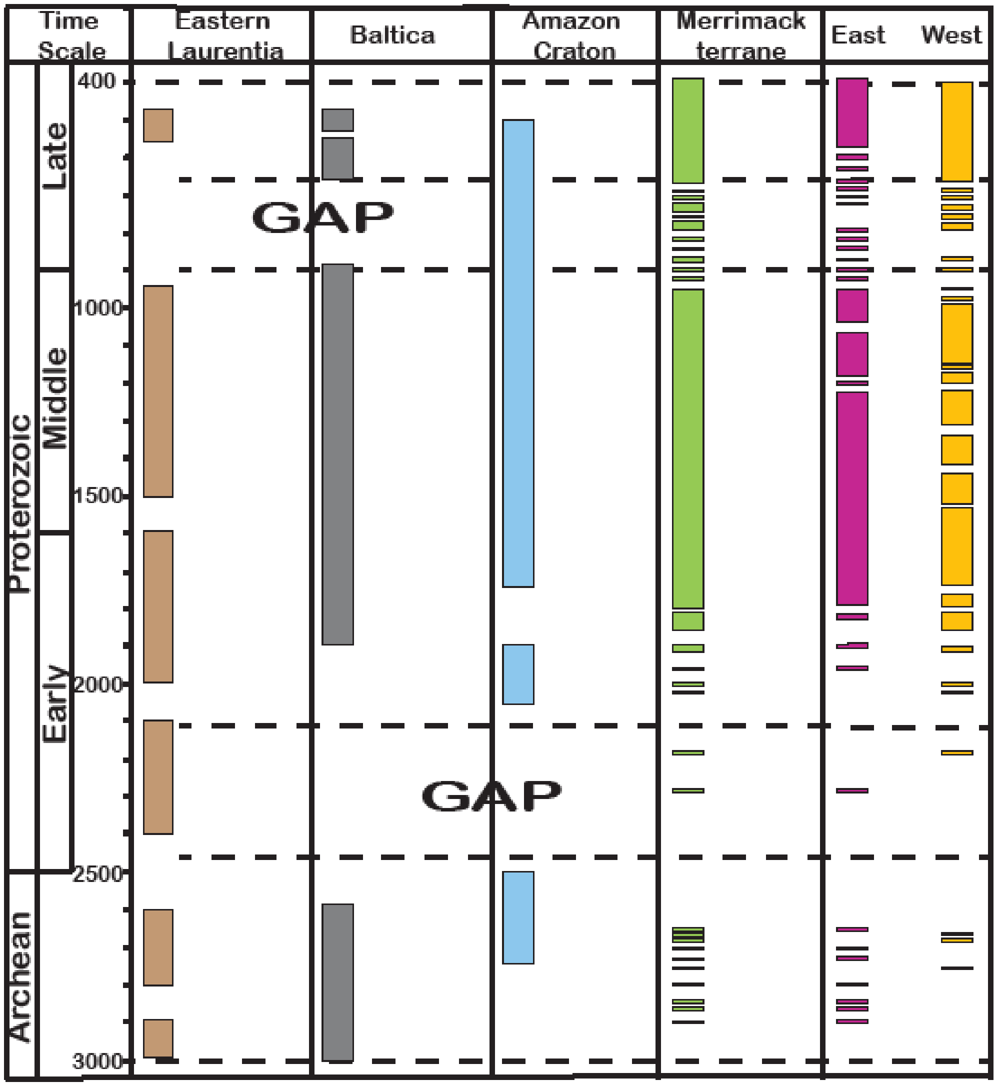

Figure 6.12 Zircon data for cratonic provinces from Laurentia (brown), Baltica (grey), Amazonia (light blue), all MT samples from this study combined (green), eastern MT samples (pink), and western MT samples (orange). The detrital zircon signals demonstrate a dual source provenance for the MT from Laurentia and Ganderia. Small bars representing the MT (all, east and west) represent individual zircon grains or small groups of grains (1-3 grains). Diagram modified from Nance and Murphy (2008).

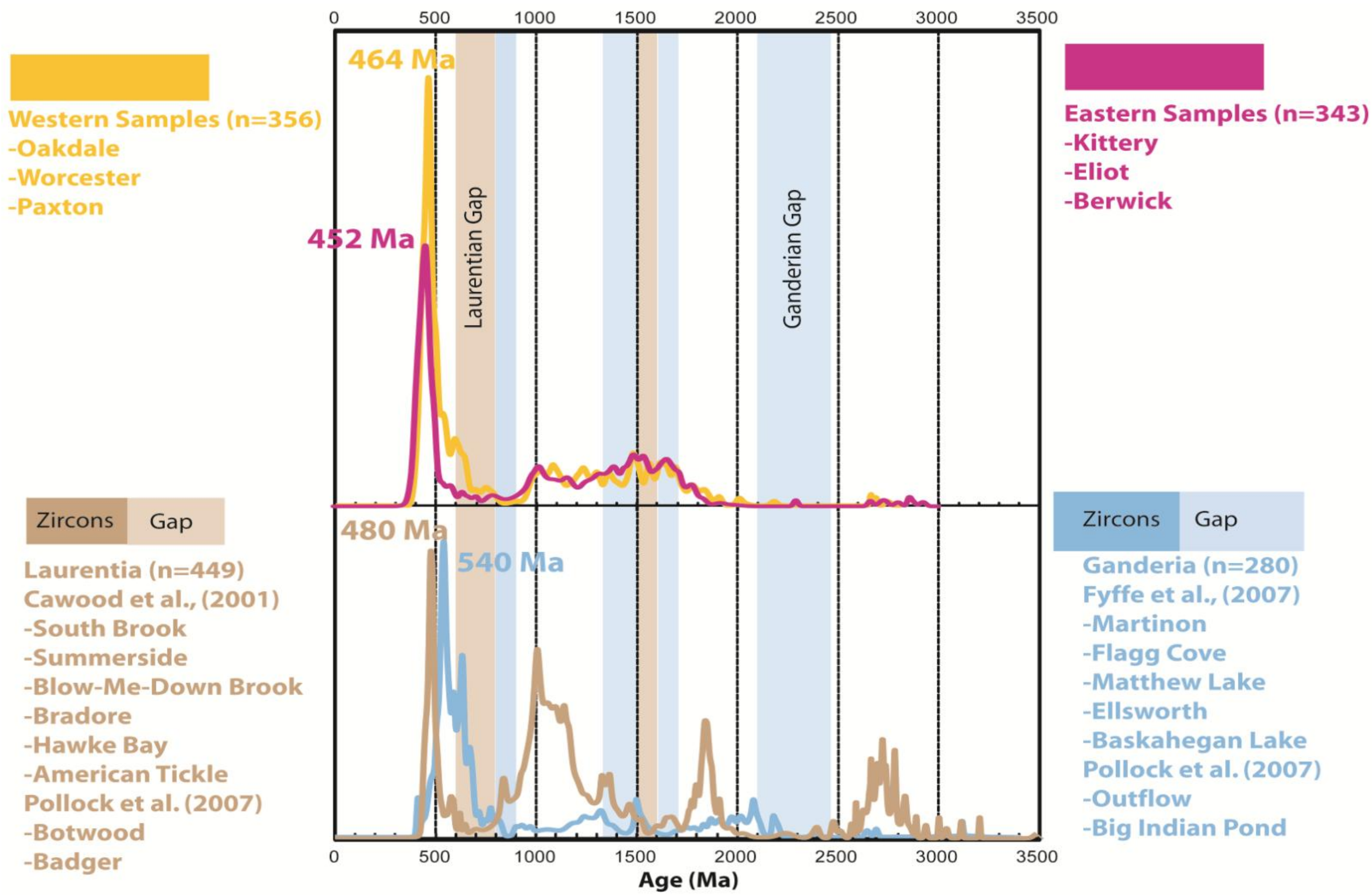

Figure 6.13 Probability density plots of the western and eastern MT samples (top) vs. data from Laurentia and Ganderia (bottom) to show provenance. The light blue (Ganderia) and light brown (Laurentia) shaded areas show where there are gaps in detrital signals in Ganderia and Laurentia.

Comparison with Laurentia

Cawood and Nemchin (2001) dated detrital zircons from rift-related, drift-related, and foreland basins from the Humber zone in Newfoundland, a portion of the east Laurentian margin. These data were combined with the detrital zircons northwest of the Dog Bay Line (Botwood and Badger groups) dated by Pollock et al. (2007) to show a representation of Laurentian detritus in Figure 6.13. This has been compared with the MT to show the similarities and differences in detail.

The comparison of the MT and Laurentia shows a clear overlap in peaks during the Ordovician. During this time in both Laurentia and Ganderia, magmatic activity was widespread as reflected in the Notre Dame Arc, Penobscot Arc, Popelogan-Victoria Arc, Shelburne Falls Arc, and Bronson Hill Arc (Karabinos et al., 1998; van Staal et al., 1998; van Staal et al., 2007; Pollock et al., 2007; van Staal et al., 2009), and detrital input during this time doesn't differentiate Laurentian from Ganderian sources.

However, there are a number of differences between the signatures of Laurentia and the MT. First, a typical Laurentian signature shows a gap in detritus between 600-800 Ma (Cawood and Nemchin, 2001). This is only partly true for the eastern MT samples with 3% of its grains in this range. No gap exists in the western MT samples where 9% of the grains fall within this range. Also, there is a large peak in Laurentia at ~1.0 Ga resulting from the third pulse of the Grenville orogeny (1230-955 Ma) (Gower and Krogh, 2002). There are only small peaks in the MT during this time, being slightly better defined in the eastern samples. Laurentia exhibits sharp peaks at ~1.8 and ~2.7 Ga, and these are noticeably absent in the MT data. If Laurentia were the primary source of detritus for the MT, stronger similarities should be expected in the overall age distributions. Therefore, it is interpreted that Laurentia supplied only partial detritus to the MT, with a slightly greater amount in the eastern MT samples.

Comparison with Ganderia

Data from five formations within Ganderia dated by Fyffe et al. (2009) using U-Pb detrital zircons have been combined with detrital zircons from southeast of the Dog Bay Line in Newfoundland, dated by Pollock et al. (2007). The plot (Figure 6.13) shows the Ganderian detrital zircon signature and provides a clear comparison with data from this study – both similarities and differences.

There are many similarities between the MT and Ganderia. Although the MT data lacks large peaks at ~540 and ~630 Ma when Ganderia experienced magmatism (Fyffe et al., 2009), there are smaller peaks in the MT during this time. The western MT samples have small peaks at ~548 Ma and ~640 Ma that are very similar to the timing of the Ganderian signature. The eastern samples have only minor detritus present at these times. However, igneous rocks with ages between 510-540 Ma are rare in Avalonia and igneous rocks of this age are not known to occur in Laurentia. It appears therefore that detritus in the MT of this age (510 – 540 Ma) was sourced from Ganderia (Pollock et al., 2007). Also, the presence of a smaller peak at ~1.5 Ga in both MT plots and Ganderia, is noticeably absent from the Laurentian data. In addition, Ganderia has a gap from ~800-900 Ma and both MT plots also have a low in detritus during this time.

One difference between Ganderia and the MT is the gap from 1.6-1.7 Ga in Ganderia, which only appears in the western MT samples. Ganderia also has a gap from ~1.0-1.2 Ga while the western and eastern samples of the MT have ~11% of the zircons within this range. Despite these minor differences it is apparent that the primary source of detritus for the MT was Ganderia; much less detritus came from Laurentia.

Tower Hill Formation

Comparison with Ganderia

The youngest detrital zircons for the Tower Hill Formation are similar to the maximum ages of deposition for three of the formations from Ganderia as dated by SHRIMP analysis (Fyffe et al., 2009) suggesting a possible correlation. The maximum ages of deposition for the samples are: Ellsworth Formation, ~507 ± 6 Ma, Calais Formation, ~510 ± 8 Ma, and Baskahegan Lake Formation, ~525 ± 6 Ma.

However, when comparing the overall detrital zircon populations between Ganderia and the Tower Hill Formation (Figure 6.14) it is clear that the Tower Hill Formation did not receive detritus from Ganderia. The largest peaks in both are similar, but the Tower Hill Formation has another smaller peak at 800-900 Ma whereas Ganderia received no detritus of this time. Eleven percent of the grains in the Tower Hill Formation fall within this range and thus cannot be explained by provenance from Ganderia.

Comparison with Laurentia

The opposite is observed when comparing the Tower Hill Formation with Laurentia (Figure 6.14). Laurentia has detritus at 800-900 Ma and can explain the small peak in the Tower Hill Formation. However, where Laurentia exhibits a low during the interval 600-800 Ma, the Tower Hill Formation has its largest peak of material here, making Laurentia also an unlikely source.

The Tower Hill Formation from this study has been compared to various other detrital zircon studies in the Appalachians as well (e.g. Avalon terrane, Nashoba terrane, Baltica, West African Craton, and Meguma). None have proven to be viable options to explain the source of detritus. Therefore correlations and provenance of the Tower Hill Formation remain elusive.

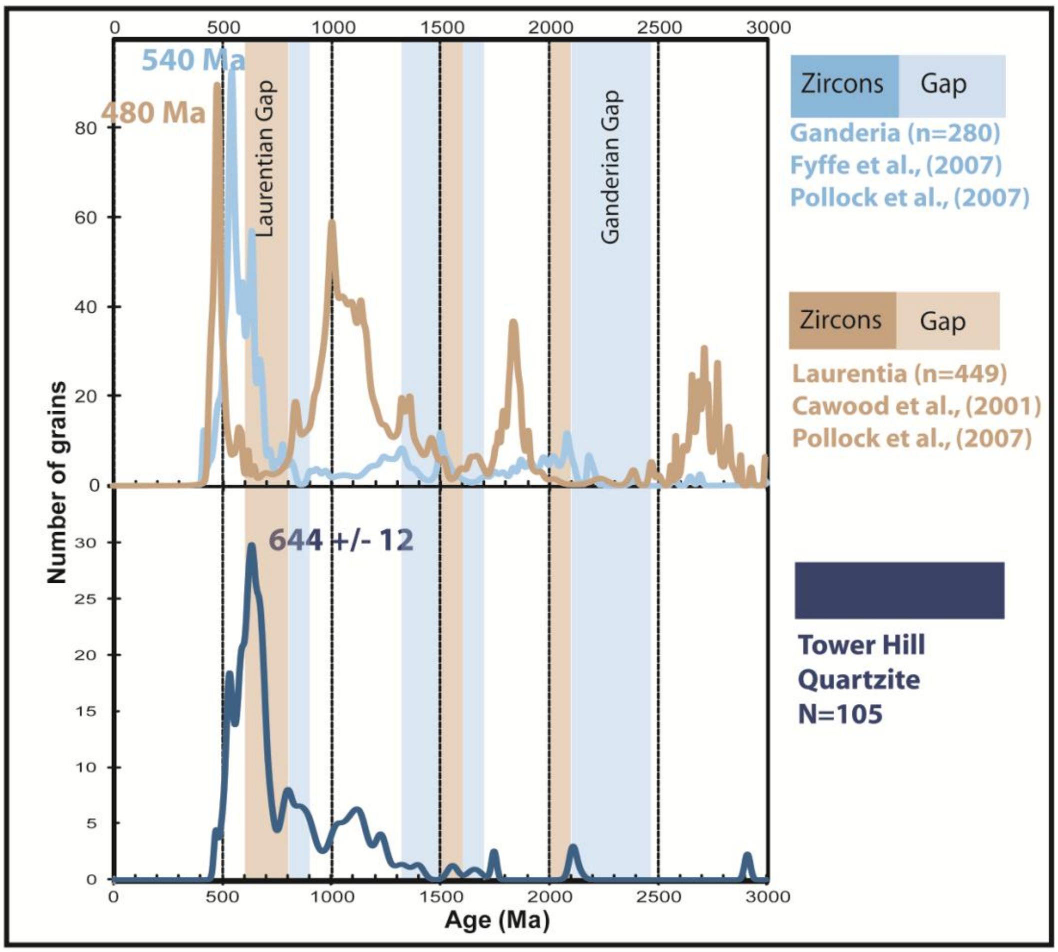

Figure 6.14 Probability density plots comparing both Ganderia and Laurentia to the Tower Hill Quartzite.

Tectonic Reconstruction

The maximum ages of deposition and evidence of a dual source provenance for the MT suggests that it formed in a location that received sediment from both the Laurentian margin and Ganderia. During the Taconic orogeny Laurentia and Ganderia were proximal enough to provide sediment. This is where tectonic interpretations and speculations for the location of the MT begin.

Late Ordovician/Early Silurian

As mentioned previously, the collision of the Popelogan-Victorian Arc (PVA) and the Laurentian margin marked the end of the Taconic orogeny (~460-450 Ma; van Staal et al., 2009; Hatcher 2010). During this time the wide Tetagouche-Exploits (T-E) back-arc basin was present between the PVA on the leading edge and the passive trailing edge of Ganderia (Figure 6.15) (Pollock et al., 2007; van Staal et al., 2009, 2011; Zagorevski et al., 2010). Arc magmatism and Exploits backarc volcanics and intrusions formed during this time as well (van Staal et al., 1998; 2009; Pollock et al., 2007). Approximately ~5 Ma years after the PVA accreted to the Laurentian margin, closure of the T-E back-arc basin began with westward subduction (van Staal et al., 2009) and a variety of depositional basins, including the future site of the MT, were developed. The timing and direction of input in Figure 6.15A is similar to the tectonic reconstruction by Hussey et al. (2010) of the "Merribuckfred" basin, with one major difference being Hussey et al. (2010) considered the Berwick Formation to be a member of the CMT. It should be noted that the T-E basin is found in Newfoundland and New Brunswick and the MT would have been developed in a southern unnamed extension of this basin. Source material to form the MT was received from both sides of the basin including: (1)

the PVA (or southern equivalent) and Laurentia on the west and (2) the passive trailing margin of Ganderia to the east (present day coordinates (Figure 6.15A). The southern equivalent of the PVA is not visible in southern New England and is likely covered by the younger sediments of the MT and CMT. During this time Ganderian detritus was being delivered from both sides of the basin. The PVA is on Ganderian crust and separates the T-E basin from Laurentia, thus making it difficult for detritus from Laurentia to reach the T-E basin and site of deposition for the earlier sediments in the MT. By the beginning of the Early Silurian the trailing edge of Ganderia was accreting to the now extinct arc (Salinic Orogeny) and the western samples of the MT (Oakdale, Worcester and Paxton Formations) stopped receiving sediment.

Middle Silurian through Early Devonian

By the Late/Middle Silurian magmatism associated with the Taconic and Salinic orogenies had ceased and the passive trailing edge of Ganderia was now completely accreted to the Laurentian margin (van Staal et al., 2009). During this time the Acadian seaway between Avalonia and the composite Laurentian margin was closing, resulting in the Coastal Volcanic arc system (van Staal et al., 2009). At this time sediment was still being received and deposited in the younger, eastern MT localities (Figure 6.15B). In addition to the input from the Coastal Volcanic arc, detritus from the west was also being received. This now included an increased input from Laurentia. By this time Laurentia was closer and erosion of the Ganderian arcs would have allowed sediment to travel from Laurentia more readily to the depositional site of the MT. Input to the eastern MT rocks continued until the Late Silurian when they became lithified, deformed and metamorphosed (Hussey et al., 2010). By ~418 and 407 Ma sedimentation in the eastern

MT was complete and the rocks were intruded by the Newburyport Complex (Fargo and Bothner, 1995) and Exeter pluton (Bothner et al., 2009).

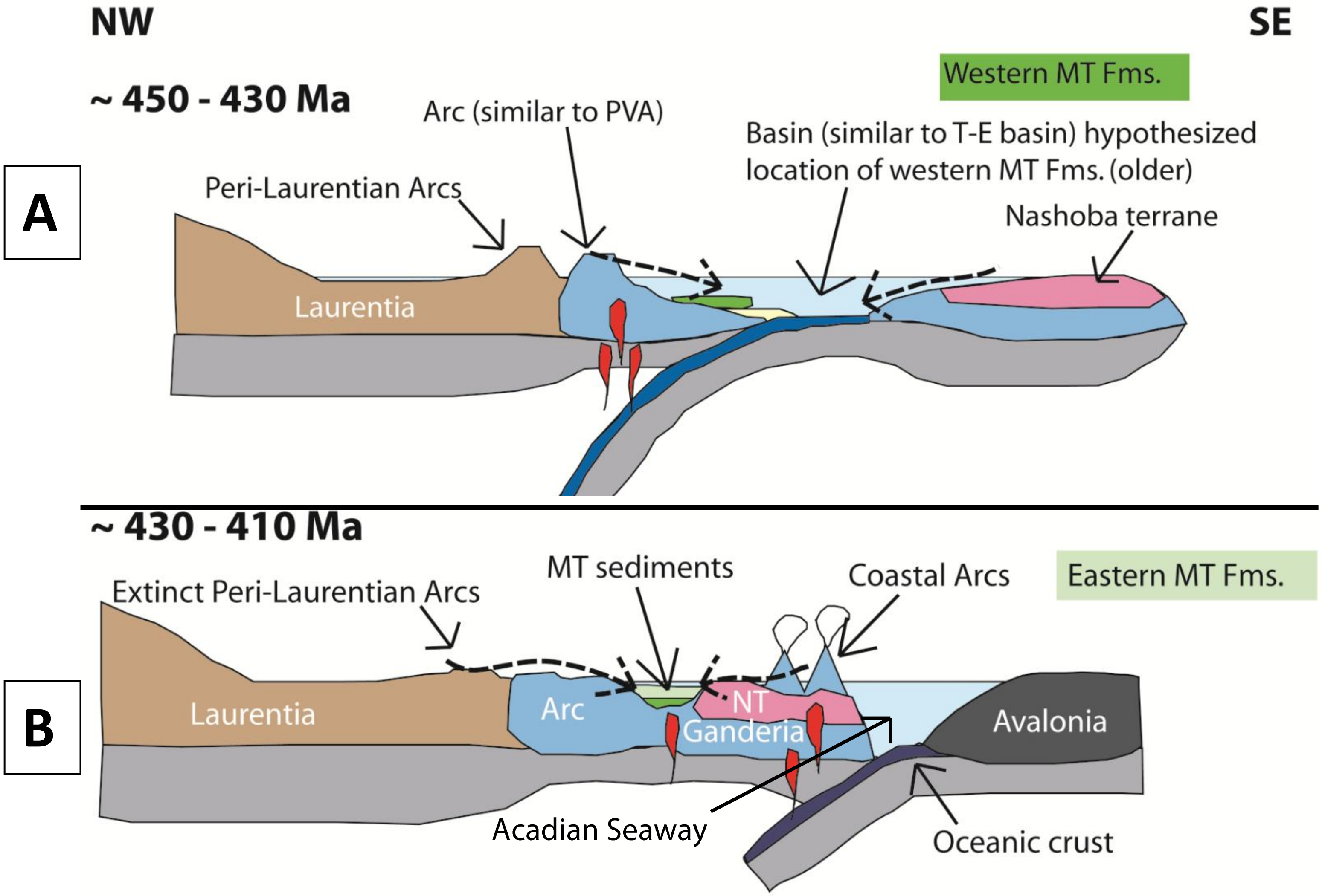

Figure 6.15 Tectonic reconstructions for the MT during the Salinic and Acadian orogenies. A- Sediment primarily from Ganderia and a minor amount from Laurentia is being deposited into a basin - the future site of the older western MT samples. B –the basin is closed, the Acadian seaway is closing and the western MT samples are formed. The eastern MT samples are still receiving sediment from Ganderia with an increased amount from the now proximal Laurentia. Sediment is also being received from the coastal volcanic belt. Modified from van Staal et al. (2009); (2011); Pollock et al. (2007); Hussey et al. (2010).

7.0 Conclusions

1. LA-ICP-MS analysis from this study suggested a maximum depositional age of the eastern samples in the MT to be 411 ± 15 Ma. However, ID-TIMS analysis on the youngest grains in the Kittery Formation indicates a maximum age of deposition to be 432 ± 0.68 Ma, close to the upper error value for the LA-ICP-MS data. Thus, the maximum error value of the LA-ICP-MS analysis was used to determine a maximum depositional age of ~426 Ma for the eastern MT samples (the Kittery, Eliot and Berwick Formations) and were therefore deposited in the Mid-to Late Silurian.
2. The western MT samples (Oakdale, Worcester, and Paxton Formations) have a maximum depositional age of ~438 Ma and were deposited between the Early and Late Silurian.
3. The maximum age of deposition for the Tower Hill Formation is Early Cambrian (~528 Ma).
4. All eastern and western MT samples (Kittery, Eliot, Berwick, Oakdale, Worcester, and Paxton Formations) correlate with one another and belong to a single sequence of rocks (the Merrimack terrane). All have detrital zircon age distributions with significant peaks in the Mid-to Late Ordovician, similar abundances of Early Paleozoic and Late Neoproterozoic zircons, significant input from ~1.0 to ~1.8 Ga sources and limited Archean grains.
5. The Tower Hill Formation has a different overall detrital zircon age distribution and a youngest zircon age population much older than the remainder of the MT.

Therefore, the Tower Hill Formation should no longer be considered to be a part of the MT. Also, the Tower Hill Formation does not correlate with the Nashoba or Avalon terranes. Provenance and correlations of the Tower Hill Formation have yet to be determined.

6. The MT is not correlative with either the Nashoba or Central Maine terranes and should remain a separate terrane from both. Although correlations have been suggested between the MT, the Bucksport Formation and the Fredericton trough, the results from this study cannot prove correlations as more detrital zircon work is needed from the Fredericton trough to do so.
7. The MT exhibits a dual source provenance from both Ganderia and Laurentia with a majority of detritus received from Ganderia. Although the overall input from Laurentia is minor, as the depositional age of the MT decreased, the input of detritus from Laurentia increased (eastern MT samples).

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Appendix A – Locations of Samples

Formation	Sample ID	Coordinates	Location of Sampled Outcrop
Kittery	KSKTI	43°5'12.1"N, 070°46' 06.2" W	Stop 1 of the 1995 NEIGC field trip guide, trip II (Fargo and Bothner, 1995). Located on Michael Succi Drive, Portsmouth, NH, near the National Gypsum Plant.
Eliot	KSELI	43°8'53.9"N, 070°58' 38.9"W	Stop 5, trip A2, NEIGC field trip guide, 1995, p. A2-9 (Fargo and Bothner, 1995). Located at Lee Five Corners, Lee, NH at the intersections of Route 155 and Route 4.
Berwick	KSBWI	43°10’51.3”N, 070°56’51.2”W	Located at the MSPCA/Nevins Farm on Route 28, Methuen, MA near the rear of the property next to a storage facility.
Oakdale	KSOKI	42° 23' 47.5"N, 071° 47' 03.9"W	Stop 2, trip F2, NEIGC field trip guide, 1976, p. 373 (Hepburn, 1976). Located in West Boylston, MA along a set of railroad tracks about 150 meters west of Prescott St.
Tower Hill	KSTHI	42°20'59.1"N, 071°44'23.67"W	Located directly behind the Boylston Fire Station off of Main St., Boylston, MA on Diamond Hill.
Worcester	KSWSI	42°22'14.4"N, 071°44'53.1"W	Stop 1, trip F-2, NEIGC field trip guide, 1976, p. 372 (Hepburn, 1976). Located on the shore of the Wachusett reservoir on the east side of Shalon Point in Boylston, MA.
Paxton	KSPXIII	42°31'12.5"N, 071°46'22.40"W	Located at Barrett Park, located off Chestnut St., Leominster, MA. The outcrop was located along the edge of the parking lot near the information center of the park.

Appendix B – Complete list of zircon analyses

Kittery Fm.	Measured Isotopic Ratios 207Pb /235U	1s error	206Pb /238U	1s error	Rho	207Pb /206Pb	1s error	Calculated Ages (Ma) 207Pb /235U	1s error	206Pb /238U	1s error	207Pb /206Pb	1s error	U-Pb/Pb-Pb conc. %	Conc. age	2s error	Prob. of conc.	Ratio Th/U
mr18a40	1.881	0.089	0.118	0.006	0.532	0.102	0.002	1074	32	717	34	1665	37	43	847	63	0.00	0.405
mr18a56	9.993	0.302	0.371	0.009	0.421	0.177	0.002	2434	28	2035	44	2627	16	77	2345	58	0.00	0.850
mr18a50	9.992	0.277	0.394	0.009	0.394	0.168	0.001	2434	26	2139	40	2542	10	84	2366	52	0.00	0.406
mr18b50	3.468	0.066	0.241	0.004	0.439	0.095	0.001	1520	15	1390	21	1538	11	90	1487	29	0.00	0.171
mr18b48	0.835	0.039	0.076	0.002	0.328	0.066	0.001	617	21	470	14	803	39	59	492	27	0.00	0.258
mr18b43	5.622	0.112	0.319	0.005	0.402	0.114	0.001	1920	17	1784	25	1864	13	96	1887	34	0.00	0.238
mr17b29	2.015	0.094	0.157	0.005	0.308	0.092	0.002	1120	32	939	25	1461	32	64	988	46	0.00	0.709
mr18a25	0.861	0.050	0.079	0.003	0.333	0.077	0.002	631	27	492	18	1115	42	44	516	35	0.00	0.129
mr18a47	3.348	0.107	0.234	0.005	0.361	0.096	0.001	1492	25	1355	28	1549	17	88	1430	45	0.00	0.528
mr17a34	12.230	0.242	0.465	0.010	0.516	0.178	0.002	2622	19	2462	42	2635	14	93	2628	37	0.00	0.638
mr17b19	2.531	0.087	0.196	0.005	0.357	0.087	0.001	1281	25	1153	26	1364	21	85	1214	43	0.00	0.372
mr17b23	3.507	0.077	0.250	0.004	0.384	0.094	0.001	1529	17	1440	22	1511	13	95	1498	32	0.00	0.455
mr17b53	0.644	0.025	0.071	0.002	0.410	0.059	0.001	505	16	441	14	575	39	77	464	25	0.00	0.448
mr17b60	4.580	0.157	0.283	0.006	0.320	0.107	0.001	1746	29	1607	31	1743	22	92	1679	50	0.00	0.496
mr18a19	3.395	0.083	0.245	0.004	0.353	0.093	0.001	1503	19	1412	22	1491	18	95	1464	34	0.00	0.472
mr17a49	2.249	0.097	0.179	0.006	0.409	0.087	0.002	1197	30	1062	34	1349	39	79	1137	55	0.00	1.060
mr17a32	4.507	0.090	0.291	0.005	0.432	0.103	0.001	1732	17	1646	25	1682	14	98	1716	32	0.00	0.929
mr18b45	3.856	0.097	0.264	0.005	0.383	0.100	0.001	1604	20	1510	26	1630	16	93	1573	38	0.00	1.991
mr18a16	4.359	0.075	0.288	0.004	0.447	0.103	0.001	1705	14	1631	22	1684	13	97	1693	28	0.00	0.336
mr18b13	3.495	0.144	0.238	0.008	0.400	0.102	0.001	1526	33	1378	41	1670	17	83	1473	62	0.00	0.185
mr17b20	1.130	0.089	0.099	0.005	0.329	0.078	0.001	768	42	607	30	1158	24	52	639	57	0.00	0.217
mr17a11	4.020	0.121	0.266	0.007	0.447	0.098	0.001	1638	25	1519	37	1585	19	96	1615	48	0.00	0.726
mr18b42	3.263	0.082	0.240	0.004	0.353	0.090	0.001	1472	20	1388	22	1422	18	98	1436	35	0.00	0.647
mr18a36	3.121	0.068	0.235	0.005	0.450	0.088	0.001	1438	17	1360	24	1382	14	98	1421	32	0.00	0.428
mr17b14	3.655	0.110	0.254	0.005	0.343	0.096	0.001	1562	24	1460	27	1541	22	95	1516	42	0.00	0.371
mr17b28	1.439	0.090	0.179	0.008	0.340	0.074	0.002	905	37	1060	41	1050	50	101	964	62	0.00	1.216

Kittery Fm.	Measured Isotopic Ratios 207Pb /235U	1s error	206Pb /238U	1s error	Rho	207Pb /206Pb	1s error	Calculated Ages (Ma) 207Pb /235U	1s error	206Pb /238U	1s error	207Pb /206Pb	1s error	U-Pb/Pb-Pb conc. %	Conc. age	2s error	Prob. of conc.	Ratio Th/U
mr18a30	2.622	0.245	0.176	0.012	0.349	0.104	0.001	1307	69	1046	63	1700	18	61	1129	114	0.00	0.431
mr18b07	4.140	0.119	0.275	0.006	0.355	0.102	0.001	1662	24	1565	28	1660	21	94	1625	43	0.00	0.453
mr18b39	3.963	0.105	0.269	0.005	0.369	0.098	0.001	1627	21	1538	27	1578	15	97	1595	40	0.00	0.692
mr18a35	4.455	0.106	0.289	0.006	0.424	0.101	0.001	1723	20	1634	29	1646	18	99	1704	38	0.00	1.295
mr17a42	2.038	0.059	0.177	0.004	0.396	0.077	0.001	1128	20	1053	22	1132	22	93	1096	36	0.00	0.431
mr18b44	4.518	0.095	0.294	0.005	0.405	0.105	0.001	1734	17	1661	25	1714	13	97	1717	34	0.00	0.369
mr18a24	4.304	0.124	0.282	0.006	0.368	0.103	0.001	1694	24	1601	30	1675	17	96	1662	44	0.00	0.559
mr18a12	4.217	0.107	0.280	0.006	0.410	0.101	0.001	1677	21	1593	29	1642	17	97	1656	40	0.00	0.271
mr18a22	4.453	0.066	0.296	0.004	0.448	0.099	0.001	1722	12	1670	19	1600	10	104	1715	24	0.00	0.128
mr18a54	2.641	0.062	0.215	0.003	0.337	0.083	0.001	1312	17	1253	18	1259	20	99	1283	29	0.00	0.461
mr18a08	3.307	0.159	0.232	0.010	0.441	0.091	0.002	1483	38	1343	52	1440	39	93	1445	73	0.00	0.808
mr17b33	2.682	0.192	0.195	0.010	0.341	0.099	0.003	1323	53	1151	51	1599	49	72	1221	89	0.00	0.392
mr17b57	0.711	0.030	0.080	0.002	0.273	0.063	0.001	545	18	494	11	724	35	68	503	21	0.00	0.235
mr18b10	2.715	0.148	0.204	0.009	0.399	0.090	0.002	1332	41	1195	48	1418	34	84	1275	75	0.00	0.351
mr18b29	1.954	0.053	0.175	0.004	0.398	0.074	0.001	1100	18	1042	21	1050	20	99	1076	32	0.01	0.754
mr17a40	0.775	0.048	0.082	0.004	0.437	0.063	0.001	583	28	506	26	714	32	71	539	46	0.01	0.414
mr18a15	3.831	0.097	0.267	0.006	0.429	0.096	0.001	1599	20	1526	30	1557	17	98	1583	40	0.01	0.466
mr17b21	4.168	0.108	0.281	0.006	0.430	0.099	0.001	1668	21	1595	32	1610	18	99	1653	42	0.01	0.742
mr18b27	3.250	0.121	0.239	0.006	0.338	0.093	0.001	1469	29	1384	31	1493	23	93	1429	50	0.01	0.362
mr18a53	3.109	0.120	0.233	0.006	0.338	0.088	0.001	1435	30	1349	32	1374	22	98	1394	51	0.02	0.193
mr17b09	3.790	0.132	0.264	0.005	0.270	0.097	0.001	1591	28	1513	25	1560	23	97	1544	43	0.02	0.304
mr17b22	3.319	0.105	0.246	0.005	0.300	0.094	0.001	1486	25	1416	24	1501	30	94	1448	40	0.02	0.343
mr18b32	4.557	0.284	0.276	0.015	0.441	0.108	0.002	1741	52	1573	77	1763	31	89	1705	103	0.02	0.928
mr18a23	5.218	1.062	0.231	0.014	0.154	0.197	0.006	1856	173	1339	76	2799	51	48	1359	150	0.02	0.606
mr18b40	2.593	0.098	0.209	0.005	0.333	0.088	0.001	1299	28	1223	28	1381	20	89	1259	46	0.02	0.200
mr17a29	4.102	0.137	0.277	0.006	0.341	0.105	0.001	1655	27	1576	32	1710	24	92	1623	49	0.02	0.988
mr18b30	0.695	0.032	0.079	0.002	0.314	0.058	0.001	536	19	492	14	532	34	93	503	25	0.03	0.719
mr17b17	0.550	0.017	0.067	0.001	0.279	0.055	0.001	445	11	419	7	417	26	101	424	13	0.03	0.793
mr17b37	0.793	0.041	0.087	0.002	0.267	0.063	0.001	593	23	540	14	702	35	77	550	27	0.03	0.315

APPENDIX B

	Measured Isotopic Ratios							Calculated Ages (Ma)										
Kittery Fm.	207Pb /235U	1s error	206Pb /238U	1s error	Rho	207Pb /206Pb	1s error	207Pb /235U	1s error	206Pb /238U	1s error	207Pb /206Pb	1s error	U-Pb/Pb-Pb conc. %	Conc. age	2s error	Prob. of conc.	Ratio Th/U
mr17b42	3.917	0.106	0.273	0.005	0.367	0.099	0.001	1617	22	1557	27	1597	18	97	1596	40	0.03	0.973
mr18b31	2.946	0.066	0.233	0.004	0.404	0.086	0.001	1394	17	1348	22	1342	14	100	1380	32	0.03	0.368
mr18a57	3.104	0.091	0.238	0.005	0.377	0.090	0.001	1434	23	1376	28	1418	21	97	1413	41	0.04	0.531
mr17b13	3.329	0.080	0.251	0.004	0.329	0.091	0.001	1488	19	1441	20	1451	13	99	1467	32	0.04	0.278
mr18b23	2.495	0.151	0.198	0.009	0.389	0.088	0.001	1271	44	1164	50	1375	22	85	1225	79	0.04	0.326
mr17b47	3.796	0.076	0.271	0.005	0.446	0.095	0.001	1592	16	1548	25	1531	13	101	1585	32	0.05	0.068
mr18b18	3.352	0.169	0.243	0.008	0.317	0.098	0.001	1493	39	1402	40	1580	20	89	1446	66	0.05	0.874
mr18b22	3.267	0.166	0.239	0.008	0.339	0.096	0.002	1473	40	1382	43	1548	31	89	1431	69	0.06	0.864
mr18a10	3.920	0.112	0.274	0.006	0.366	0.100	0.001	1618	23	1562	29	1628	22	96	1599	43	0.06	1.057
mr17b50	2.881	0.088	0.228	0.005	0.344	0.085	0.001	1377	23	1325	25	1322	24	100	1354	40	0.06	0.645
mr18a34	3.167	0.088	0.243	0.005	0.333	0.095	0.001	1449	22	1400	23	1526	19	92	1427	37	0.06	0.503
mr18b20	18.985	0.269	0.617	0.009	0.513	0.202	0.001	3041	14	3099	36	2846	9	109	3037	27	0.06	0.320
mr17a48	2.556	0.084	0.211	0.005	0.370	0.082	0.001	1288	24	1235	27	1237	20	100	1266	42	0.07	0.445
mr18a11	3.291	0.083	0.267	0.005	0.406	0.086	0.001	1479	20	1528	28	1329	22	115	1490	37	0.07	0.373
mr17b10	2.767	0.110	0.221	0.006	0.315	0.089	0.001	1347	30	1286	29	1415	25	91	1314	48	0.08	0.882
mr18b34	0.546	0.035	0.064	0.003	0.343	0.057	0.001	442	23	401	17	475	37	84	412	31	0.08	0.783
mr18a58	4.599	0.128	0.301	0.007	0.400	0.100	0.001	1749	23	1694	33	1624	21	104	1736	45	0.09	0.481
mr17a50	2.030	0.099	0.203	0.005	0.275	0.073	0.001	1126	33	1190	29	1012	33	118	1162	49	0.09	0.804
mr17a13	3.631	0.069	0.266	0.004	0.391	0.093	0.001	1556	15	1522	20	1490	15	102	1547	28	0.09	0.456
mr17a17	2.593	0.114	0.211	0.006	0.337	0.084	0.002	1299	32	1234	33	1285	37	96	1266	54	0.09	0.559
mr18b09	3.121	0.073	0.243	0.003	0.279	0.088	0.001	1438	18	1402	17	1385	17	101	1417	28	0.09	0.284
mr18b12	0.542	0.025	0.076	0.003	0.378	0.049	0.001	440	16	470	16	149	48	315	455	27	0.09	0.453
mr18b49	3.915	0.228	0.262	0.016	0.531	0.098	0.001	1617	47	1501	83	1585	14	95	1612	95	0.10	0.120
mr18a14	0.565	0.042	0.065	0.003	0.336	0.055	0.001	455	27	409	20	412	58	99	420	37	0.10	0.814
mr18b51	2.767	0.191	0.214	0.009	0.311	0.087	0.001	1347	51	1250	49	1363	29	92	1291	83	0.10	0.183
mr18b24	1.845	0.071	0.171	0.004	0.329	0.074	0.001	1062	25	1016	24	1047	29	97	1036	40	0.10	0.418
mr18b33	4.196	0.090	0.288	0.005	0.419	0.101	0.001	1673	18	1634	26	1637	16	100	1665	34	0.11	0.410
mr17a24	4.256	0.138	0.288	0.007	0.352	0.103	0.001	1685	27	1630	33	1671	22	98	1665	49	0.11	0.545
mr18b28	2.316	0.067	0.201	0.004	0.321	0.079	0.001	1217	21	1179	20	1178	20	100	1197	33	0.11	0.490

APPENDIX B

	Measured Isotopic Ratios							Calculated Ages (Ma)										
Kittery Fm.	207Pb /235U	1s error	206Pb /238U	1s error	Rho	207Pb /206Pb	1s error	207Pb /235U	1s error	206Pb /238U	1s error	207Pb /206Pb	1s error	U-Pb/Pb-Pb conc. %	Conc. age	2s error	Prob. of conc.	Ratio Th/U
mr18a55	0.623	0.028	0.075	0.002	0.331	0.056	0.001	491	17	463	13	471	42	98	472	24	0.12	0.520
mr17a38	1.751	0.041	0.168	0.003	0.346	0.073	0.001	1028	15	1001	15	1009	16	99	1014	25	0.13	0.521
mr17a22	2.140	0.067	0.191	0.004	0.303	0.076	0.001	1162	22	1125	19	1091	24	103	1140	33	0.13	0.098
mr17a39	1.677	0.075	0.159	0.005	0.358	0.072	0.000	1000	28	953	28	977	13	98	975	47	0.15	0.199
mr18a43	2.038	0.088	0.183	0.004	0.264	0.083	0.002	1128	29	1083	23	1272	37	85	1097	40	0.16	0.453
mr17b12	4.038	0.109	0.282	0.006	0.390	0.098	0.001	1642	22	1601	30	1589	18	101	1631	41	0.16	0.483
mr17b07	3.225	0.121	0.245	0.007	0.374	0.092	0.001	1463	29	1414	36	1475	19	96	1446	53	0.18	0.286
mr17a30	4.164	0.302	0.276	0.011	0.281	0.112	0.002	1667	59	1572	57	1826	32	86	1614	95	0.18	0.980
mr17b52	2.889	0.113	0.230	0.005	0.304	0.090	0.001	1379	30	1335	29	1417	23	94	1356	48	0.21	0.548
mr17a23	0.683	0.062	0.077	0.004	0.284	0.065	0.001	529	38	480	24	781	42	61	490	45	0.21	0.128
mr18a46	2.829	0.129	0.226	0.006	0.293	0.088	0.001	1363	34	1314	32	1375	30	96	1335	53	0.21	0.124
mr18b11	0.463	0.027	0.066	0.002	0.213	0.056	0.001	387	19	410	10	472	35	87	406	19	0.22	0.653
mr17a12	1.663	0.076	0.160	0.004	0.251	0.077	0.001	995	29	956	21	1127	29	85	966	37	0.22	0.320
mr18a44	0.685	0.052	0.079	0.003	0.232	0.061	0.001	530	31	491	17	647	41	76	496	32	0.22	0.707
mr17b41	1.209	0.090	0.123	0.007	0.367	0.069	0.001	805	42	749	39	904	22	83	773	67	0.23	0.098
mr17b49	3.656	0.091	0.269	0.005	0.375	0.094	0.001	1562	20	1533	26	1515	20	101	1553	37	0.27	0.307
mr17a37	18.059	0.420	0.580	0.011	0.402	0.205	0.002	2993	22	2949	44	2863	14	103	2990	45	0.28	0.353
mr17b27	2.852	0.081	0.232	0.004	0.304	0.086	0.001	1369	21	1343	21	1347	20	100	1355	34	0.28	0.452
mr18a33	0.617	0.027	0.076	0.002	0.292	0.058	0.001	488	17	470	12	534	40	88	474	21	0.29	0.077
mr18a13	2.144	0.069	0.203	0.004	0.306	0.076	0.001	1163	22	1190	21	1099	22	108	1177	35	0.30	0.124
mr18a21	0.662	0.051	0.089	0.002	0.177	0.058	0.001	516	31	548	14	530	50	103	544	28	0.30	0.406
mr17a33	0.572	0.032	0.070	0.002	0.224	0.059	0.001	459	20	438	10	564	43	78	441	20	0.31	0.619
mr17b24	2.640	0.182	0.215	0.008	0.269	0.087	0.001	1312	51	1254	42	1366	20	92	1275	74	0.31	0.191
mr17b44	0.643	0.022	0.079	0.002	0.290	0.059	0.001	504	14	490	9	555	31	88	493	17	0.32	0.216
mr17b34	3.426	0.453	0.238	0.026	0.414	0.102	0.004	1510	104	1378	136	1657	68	83	1468	199	0.32	0.395
mr18b41	0.590	0.036	0.072	0.002	0.274	0.059	0.001	471	23	447	14	582	36	77	452	27	0.32	0.454
mr18b52	1.662	0.096	0.174	0.005	0.265	0.073	0.002	994	36	1033	29	1026	44	101	1019	51	0.33	0.799
mr17b30	2.104	0.104	0.188	0.006	0.315	0.079	0.001	1150	34	1113	32	1175	34	95	1129	54	0.34	0.460
mr18b37	0.599	0.026	0.074	0.002	0.275	0.056	0.001	477	16	461	11	472	45	98	465	20	0.36	0.575

Kittery Fm.	Measured Isotopic Ratios 207Pb /235U	1s error	206Pb /238U	1s error	Rho	207Pb /206Pb	1s error	Calculated Ages (Ma) 207Pb /235U	1s error	206Pb /238U	1s error	207Pb /206Pb	1s error	U-Pb/Pb-Pb conc. %	Conc. age	2s error	Prob. of conc.	Ratio Th/U
mr17b43	0.632	0.027	0.078	0.002	0.293	0.057	0.001	497	17	481	12	494	32	97	485	21	0.36	0.519
mr18b17	2.555	0.117	0.215	0.006	0.282	0.084	0.001	1288	34	1254	30	1289	27	97	1268	50	0.38	0.171
mr18b38	1.784	0.077	0.170	0.005	0.324	0.073	0.001	1040	28	1012	26	1002	36	101	1024	44	0.38	1.435
mr17a09	0.637	0.016	0.079	0.001	0.384	0.056	0.000	501	10	492	9	442	15	111	496	16	0.39	0.234
mr17a41	0.628	0.023	0.078	0.001	0.259	0.058	0.001	495	14	483	9	533	25	91	485	17	0.40	0.547
mr18a31	3.964	0.094	0.283	0.006	0.422	0.094	0.001	1627	19	1605	28	1518	21	106	1623	37	0.42	0.376
mr17b18	3.360	0.141	0.255	0.007	0.311	0.093	0.001	1495	33	1463	34	1482	20	99	1480	55	0.42	0.703
mr17b51	2.705	0.106	0.224	0.005	0.307	0.085	0.001	1330	29	1303	28	1307	24	100	1316	47	0.43	0.550
mr17b48	3.922	0.105	0.281	0.006	0.390	0.097	0.001	1618	22	1597	29	1575	16	101	1613	41	0.46	0.828
mr17a31	0.578	0.033	0.072	0.002	0.209	0.056	0.001	463	21	447	10	449	47	100	449	20	0.46	1.006
mr17b08	2.700	0.178	0.221	0.009	0.320	0.086	0.001	1328	49	1287	49	1344	25	96	1307	81	0.47	0.380
mr18a32	2.889	0.115	0.235	0.005	0.264	0.090	0.001	1379	30	1360	26	1435	24	95	1367	44	0.57	0.369
mr17b59	2.836	0.151	0.241	0.007	0.268	0.097	0.002	1365	40	1390	36	1570	46	89	1379	59	0.58	0.080
mr17a20	0.635	0.027	0.082	0.002	0.259	0.059	0.001	499	17	509	11	576	35	88	506	20	0.60	0.830
mr17b31	0.571	0.027	0.072	0.002	0.280	0.057	0.001	458	17	449	11	501	32	90	451	21	0.61	0.646
mr18a29	2.866	0.457	0.224	0.018	0.246	0.090	0.002	1373	120	1305	93	1431	48	91	1326	165	0.61	0.205
mr17a18	1.900	0.176	0.189	0.010	0.300	0.072	0.002	1081	62	1116	57	977	53	114	1100	95	0.61	0.390
mr18a52	3.906	0.094	0.282	0.004	0.324	0.093	0.001	1615	19	1603	22	1497	19	107	1610	34	0.62	0.319
mr17b39	1.827	0.053	0.180	0.004	0.399	0.073	0.001	1055	19	1066	23	1014	15	105	1059	34	0.65	0.259
mr17a14	3.517	0.179	0.264	0.007	0.273	0.098	0.002	1531	40	1510	37	1581	31	95	1519	62	0.65	1.017
mr18a26	1.652	0.163	0.171	0.006	0.184	0.072	0.002	990	62	1019	34	983	48	104	1014	64	0.65	0.417
mr18a20	0.526	0.027	0.070	0.002	0.235	0.055	0.001	429	18	438	10	393	49	111	436	20	0.66	0.376
mr17a21	0.580	0.042	0.077	0.003	0.256	0.060	0.002	464	27	476	17	596	56	80	474	32	0.67	0.695
mr18b14	3.455	0.096	0.263	0.005	0.367	0.091	0.001	1517	22	1505	27	1442	16	104	1513	40	0.68	0.467
mr18b19	0.522	0.033	0.067	0.003	0.308	0.056	0.001	426	22	417	16	452	34	92	420	29	0.68	0.738
mr17b11	3.272	0.101	0.255	0.004	0.272	0.088	0.001	1474	24	1464	22	1388	25	105	1469	37	0.71	0.401
mr17a07	0.645	0.016	0.081	0.001	0.290	0.057	0.001	506	10	502	7	474	22	106	503	13	0.75	0.460
mr18b08	3.876	0.148	0.281	0.006	0.281	0.104	0.001	1609	31	1597	30	1703	26	94	1603	49	0.76	0.263
mr18a09	0.579	0.023	0.074	0.002	0.323	0.055	0.001	464	15	459	12	403	31	114	460	21	0.77	0.063

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Kittery Fm.	Measured Isotopic Ratios 207Pb /235U	1s error	206Pb /238U	1s error	Rho	207Pb /206Pb	1s error	Calculated Ages (Ma) 207Pb /235U	1s error	206Pb /238U	1s error	207Pb /206Pb	1s error	U-Pb/Pb-Pb conc. %	Conc. age	2s error	Prob. of conc.	Ratio Th/U
mr17a19	0.578	0.024	0.075	0.002	0.264	0.053	0.001	463	15	467	10	331	41	141	466	18	0.79	0.472
mr18a41	2.801	0.112	0.232	0.006	0.308	0.083	0.001	1356	30	1347	30	1267	25	106	1351	48	0.79	0.473
mr17a28	0.671	0.051	0.083	0.004	0.329	0.059	0.001	522	31	514	25	552	31	93	516	44	0.81	0.170
mr17b54	1.657	0.093	0.165	0.005	0.283	0.074	0.001	992	36	986	29	1038	39	95	988	51	0.86	0.668
mr18a42	0.563	0.024	0.073	0.002	0.332	0.055	0.001	454	16	456	13	420	44	109	455	22	0.87	0.383
mr17a27	3.251	0.108	0.257	0.006	0.378	0.086	0.001	1469	26	1474	33	1347	31	109	1471	47	0.90	0.598
mr18a45	4.270	0.101	0.300	0.005	0.344	0.095	0.001	1688	20	1690	24	1533	20	110	1688	35	0.93	0.344
mr17a44	0.581	0.023	0.075	0.002	0.307	0.053	0.001	465	15	463	11	339	32	137	464	20	0.93	0.308
mr17b40	0.574	0.050	0.074	0.003	0.253	0.059	0.001	460	32	458	19	573	53	80	458	36	0.93	1.129
mr17b58	0.566	0.047	0.073	0.003	0.257	0.055	0.001	456	30	453	19	425	49	107	454	35	0.94	0.880
mr17b38	1.156	0.139	0.128	0.006	0.187	0.065	0.002	780	65	776	33	774	73	100	776	63	0.95	0.524
mr17a47	3.959	0.146	0.287	0.008	0.357	0.095	0.001	1626	30	1628	38	1526	27	107	1627	54	0.95	0.451
mr17a10	0.552	0.054	0.072	0.002	0.165	0.063	0.001	446	35	449	14	719	46	62	448	27	0.95	0.798
mr18b21	0.630	0.020	0.080	0.002	0.327	0.058	0.001	496	12	497	10	529	27	94	497	18	0.96	0.532
mr18a51	0.697	0.039	0.087	0.002	0.227	0.062	0.001	537	23	536	13	658	36	81	536	25	0.97	0.426
mr17a51	0.581	0.031	0.075	0.002	0.314	0.053	0.001	465	20	464	15	323	39	144	464	27	0.98	0.580
mr17b32	0.508	0.026	0.067	0.002	0.262	0.055	0.001	417	17	416	11	402	43	104	417	20	0.98	0.753
mr17a08	5.117	0.148	0.330	0.006	0.297	0.109	0.001	1839	25	1838	28	1779	19	103	1839	42	0.98	0.329
mr17a43	3.899	0.138	0.284	0.006	0.310	0.095	0.002	1613	29	1614	31	1537	33	105	1614	48	0.99	0.657

	Measured Isotopic Ratios							Calculated Ages										
Eliot Fm.	207Pb /235U	1s error	206Pb /238U	1s error	Rho	207Pb /206Pb	1s error	207Pb /235U	1s error	206Pb /238U	1s error	207Pb /206Pb	1s error	U-Pb/Pb-Pb con. %	Con. age	2s error	Prob. of con.	Ratio Th/U
mr10b106	0.912	0.031	0.069	0.003	0.570	0.073	0.001	658	17	432	16	1010	19	43	503	31	0.000	0.617
mr10b89	1.560	0.078	0.085	0.004	0.439	0.110	0.002	954	31	525	22	1798	35	29	535	44	0.000	1.071
mr09b53	1.890	0.138	0.076	0.002	0.179	0.133	0.005	1077	48	472	12	2143	65	22	466	24	0.000	0.575
mr10b115	0.979	0.055	0.071	0.003	0.421	0.076	0.001	693	28	440	20	1082	33	41	468	40	0.000	0.426
mr10b55	2.180	0.100	0.147	0.008	0.554	0.087	0.001	1175	32	885	42	1365	25	65	1082	66	0.000	0.134
mr10b68	2.152	0.072	0.161	0.004	0.356	0.087	0.001	1166	23	965	21	1352	30	71	1035	38	0.000	0.532
mr09b44	0.676	0.028	0.064	0.002	0.397	0.069	0.001	524	17	399	13	899	38	44	426	24	0.000	0.521
mr09b45	0.698	0.021	0.073	0.002	0.502	0.061	0.001	537	12	451	13	652	20	69	495	22	0.000	0.258
mr10b112	4.841	0.180	0.271	0.008	0.414	0.107	0.001	1792	31	1545	42	1752	14	88	1712	62	0.000	0.741
mr10b82	4.190	0.281	0.218	0.014	0.480	0.127	0.003	1672	55	1272	74	2062	40	62	1526	115	0.000	0.108
mr09b34	3.222	0.126	0.213	0.008	0.499	0.101	0.001	1462	30	1244	44	1642	22	76	1416	61	0.000	0.479
mr11a08	1.764	0.103	0.133	0.006	0.365	0.093	0.001	1032	38	802	32	1497	29	54	864	59	0.000	0.388
mr09b64	2.675	0.129	0.186	0.008	0.436	0.093	0.003	1322	36	1099	42	1486	52	74	1225	68	0.000	0.411
mr10b40	2.998	0.090	0.216	0.006	0.427	0.092	0.001	1407	23	1263	29	1465	18	86	1359	44	0.000	0.312
mr10b111	4.727	0.318	0.243	0.017	0.529	0.111	0.001	1772	56	1401	90	1811	17	77	1716	117	0.000	0.243
mr10b85	2.766	0.223	0.168	0.008	0.301	0.119	0.002	1346	60	1003	45	1941	30	52	1061	86	0.000	0.574
mr09b22	0.642	0.019	0.072	0.002	0.369	0.056	0.001	504	11	445	9	449	38	99	463	17	0.000	0.080
mr10b61	0.684	0.030	0.070	0.002	0.274	0.067	0.001	529	18	438	10	836	31	52	451	20	0.000	0.633
mr10b81	0.960	0.053	0.089	0.004	0.439	0.069	0.001	683	27	551	25	898	30	61	600	46	0.000	0.617
mr10b08	0.821	0.043	0.080	0.002	0.229	0.067	0.002	609	24	495	11	840	53	59	506	22	0.000	0.818
mr10b30	3.341	0.118	0.231	0.006	0.368	0.099	0.001	1491	28	1340	31	1608	19	83	1423	50	0.000	0.546
mr09b23	12.450	0.313	0.464	0.010	0.447	0.179	0.001	2639	24	2457	46	2643	14	93	2629	48	0.000	0.517
mr09b63	3.067	0.099	0.221	0.007	0.472	0.093	0.001	1425	25	1285	36	1496	11	86	1394	49	0.000	0.275
mr10b101	0.957	0.044	0.094	0.003	0.402	0.061	0.001	682	23	577	21	623	27	93	615	37	0.000	0.655
mr11a07	1.983	0.098	0.160	0.004	0.274	0.087	0.001	1110	33	957	24	1369	27	70	993	45	0.000	0.877
mr10b84	3.530	0.094	0.247	0.006	0.452	0.093	0.001	1534	21	1421	31	1494	18	95	1510	41	0.000	0.301
mr10b60	0.647	0.025	0.072	0.002	0.307	0.059	0.001	507	15	447	10	580	22	77	459	19	0.000	0.529
mr10b39	0.632	0.020	0.072	0.002	0.354	0.058	0.001	497	12	448	10	523	28	86	463	18	0.000	0.834
mr10a20	3.847	0.209	0.243	0.009	0.344	0.093	0.001	1603	44	1403	47	1497	25	94	1500	78	0.000	0.517

APPENDIX B

Eliot Fm.	Measured Isotopic Ratios 207Pb /235U	1s error	206Pb /238U	1s error	Rho	207Pb /206Pb	1s error	Calculated Ages 207Pb /235U	1s error	206Pb /238U	1s error	207Pb /206Pb	1s error	U-Pb/Pb-Pb con. %	Con. age	2s error	Prob. of con.	Ratio Th/U
mr10b97	3.843	0.178	0.248	0.009	0.403	0.093	0.001	1602	37	1428	48	1495	14	95	1540	71	0.000	0.324
mr09b58	3.039	0.085	0.226	0.006	0.443	0.087	0.001	1417	21	1316	30	1360	25	97	1392	42	0.000	0.735
mr10b21	3.585	0.113	0.249	0.006	0.376	0.095	0.001	1546	25	1435	30	1528	13	94	1504	46	0.000	0.590
mr10b80	1.870	0.057	0.166	0.003	0.317	0.077	0.001	1070	20	990	18	1120	22	88	1020	31	0.000	0.011
mr10b32	0.660	0.037	0.069	0.005	0.578	0.062	0.001	515	23	432	27	676	26	64	487	44	0.000	1.057
mr10b29	4.049	0.111	0.270	0.006	0.414	0.108	0.004	1644	22	1540	31	1760	67	87	1617	43	0.000	0.696
mr10b70	3.094	0.135	0.220	0.010	0.501	0.092	0.001	1431	34	1281	51	1471	14	87	1407	67	0.001	0.324
mr09b98	4.005	0.165	0.258	0.010	0.480	0.102	0.001	1635	33	1481	52	1652	18	90	1612	67	0.001	1.100
mr09b51	0.588	0.023	0.067	0.002	0.331	0.058	0.001	470	15	420	11	526	28	80	432	20	0.001	0.446
mr10a14	5.614	0.303	0.303	0.015	0.450	0.105	0.001	1918	46	1706	73	1709	14	100	1880	93	0.001	0.294
mr09b31	6.426	0.168	0.348	0.008	0.423	0.123	0.001	2036	23	1926	37	1995	17	97	2018	46	0.001	0.259
mr10b131	1.550	0.176	0.118	0.012	0.462	0.090	0.001	950	70	717	71	1420	22	50	808	127	0.002	0.160
mr10b73	0.646	0.029	0.072	0.002	0.243	0.063	0.001	506	18	450	9	695	32	65	457	18	0.002	0.829
mr10b69	1.917	0.068	0.169	0.004	0.299	0.076	0.001	1087	24	1007	20	1085	23	93	1034	35	0.002	0.219
mr10a13	6.484	0.829	0.287	0.021	0.281	0.153	0.002	2044	112	1625	103	2382	20	68	1739	188	0.003	0.142
mr10b62	0.667	0.026	0.075	0.002	0.332	0.060	0.001	519	16	469	12	589	31	80	482	22	0.003	0.407
mr10b88	0.760	0.082	0.069	0.006	0.402	0.073	0.001	574	47	430	36	1027	26	42	461	69	0.003	0.484
mr09b19	3.638	0.105	0.257	0.005	0.337	0.097	0.001	1558	23	1475	26	1571	24	94	1521	40	0.003	0.192
mr10b99	1.172	0.111	0.102	0.006	0.322	0.076	0.001	787	52	626	36	1093	25	57	657	69	0.004	0.186
mr09b18	3.743	0.076	0.265	0.005	0.438	0.097	0.001	1581	16	1516	24	1566	15	97	1568	32	0.004	0.274
mr10b37	0.649	0.032	0.072	0.002	0.290	0.062	0.001	508	20	449	12	662	23	68	460	23	0.004	0.087
mr11a17	0.648	0.048	0.067	0.005	0.534	0.061	0.001	507	30	420	32	639	30	66	468	55	0.004	0.524
mr10a09	3.392	0.197	0.232	0.009	0.334	0.089	0.001	1503	46	1347	47	1405	16	96	1420	78	0.004	0.381
mr09b74	2.555	0.090	0.205	0.005	0.331	0.082	0.001	1288	26	1202	26	1257	26	96	1242	43	0.004	0.222
mr09b84	0.653	0.029	0.074	0.002	0.298	0.060	0.001	510	18	458	12	586	32	78	469	22	0.005	1.140
mr10b58	3.910	0.158	0.263	0.006	0.300	0.108	0.002	1616	33	1507	33	1759	28	86	1557	54	0.006	1.016
mr10b54	2.594	0.194	0.190	0.011	0.400	0.092	0.001	1299	55	1119	62	1460	18	77	1214	101	0.006	0.279
mr10b74	3.528	0.077	0.256	0.005	0.412	0.093	0.001	1533	17	1471	24	1496	11	98	1517	33	0.006	0.115
mr09b33	14.537	0.266	0.522	0.007	0.380	0.191	0.001	2785	17	2706	31	2752	11	98	2775	34	0.006	0.137

APPENDIX B

	Measured Isotopic Ratios							Calculated Ages										
Eliot Fm.	207Pb /235U	1s error	206Pb /238U	1s error	Rho	207Pb /206Pb	1s error	207Pb /235U	1s error	206Pb /238U	1s error	207Pb /206Pb	1s error	U-Pb/Pb-Pb con. %	Con. age	2s error	Prob. of con.	Ratio Th/U
mr09b83	3.755	0.153	0.257	0.007	0.337	0.099	0.002	1583	33	1474	36	1602	31	92	1533	57	0.006	0.747
mr10b103	4.281	0.239	0.271	0.008	0.261	0.109	0.001	1690	46	1543	40	1784	25	86	1595	70	0.007	0.606
mr09b72	3.257	0.138	0.236	0.007	0.332	0.089	0.002	1471	33	1364	35	1405	35	97	1417	56	0.007	0.445
mr09b28	2.251	0.048	0.195	0.003	0.347	0.076	0.001	1197	15	1150	16	1094	18	105	1174	25	0.007	0.585
mr10c10	3.436	0.132	0.243	0.009	0.492	0.095	0.001	1513	30	1401	48	1521	15	92	1498	60	0.007	0.549
mr10b17	13.379	0.330	0.499	0.009	0.351	0.189	0.001	2707	23	2610	37	2734	12	95	2688	45	0.008	0.124
mr09b54	3.017	0.098	0.230	0.004	0.297	0.092	0.001	1412	25	1335	23	1457	19	92	1368	39	0.008	0.367
mr10b96	1.853	0.111	0.159	0.006	0.312	0.075	0.001	1064	39	949	33	1073	22	88	987	59	0.008	0.795
mr09b73	4.533	0.101	0.296	0.005	0.417	0.103	0.001	1737	18	1669	27	1678	16	100	1723	36	0.008	0.691
mr10b65	0.666	0.028	0.076	0.002	0.294	0.062	0.001	518	17	472	11	690	34	68	482	21	0.009	0.576
mr10b49	0.682	0.034	0.076	0.002	0.328	0.062	0.001	528	20	473	15	682	34	69	487	27	0.009	0.756
mr09b82	4.325	0.151	0.283	0.006	0.314	0.102	0.001	1698	29	1608	31	1664	25	97	1656	49	0.011	1.033
mr10a11	0.643	0.035	0.072	0.003	0.345	0.053	0.001	504	22	448	16	338	26	133	463	30	0.012	0.778
mr10b12	3.547	0.198	0.244	0.009	0.330	0.099	0.001	1538	44	1405	47	1609	20	87	1470	76	0.013	0.224
mr10b72	0.539	0.026	0.063	0.002	0.271	0.063	0.001	438	17	394	10	694	26	57	401	19	0.014	0.935
mr10b63	0.617	0.035	0.069	0.003	0.354	0.062	0.001	488	22	432	17	658	30	66	448	31	0.014	0.232
mr09b10	0.758	0.038	0.083	0.004	0.510	0.059	0.001	573	22	516	26	580	31	89	552	41	0.017	0.016
mr10b27	3.177	0.151	0.232	0.008	0.384	0.092	0.001	1452	37	1345	44	1463	18	92	1411	68	0.020	0.688
mr09b100	0.598	0.037	0.068	0.004	0.469	0.056	0.001	476	23	422	23	462	40	91	448	40	0.024	0.440
mr09b40	0.591	0.019	0.071	0.001	0.314	0.057	0.001	471	12	443	9	481	25	92	450	16	0.024	0.730
mr11a20	4.034	0.150	0.273	0.008	0.376	0.104	0.001	1641	30	1555	38	1692	13	92	1612	56	0.027	0.654
mr09b25	15.517	0.358	0.533	0.012	0.472	0.196	0.002	2848	22	2754	49	2793	15	99	2848	44	0.028	0.457
mr09b75	0.580	0.024	0.069	0.002	0.316	0.056	0.001	464	15	430	11	471	29	91	438	20	0.030	0.668
mr10b117	1.090	0.171	0.091	0.014	0.475	0.080	0.001	748	83	563	81	1204	22	47	631	146	0.032	0.100
mr10b34	4.990	0.334	0.292	0.017	0.430	0.116	0.002	1818	57	1653	84	1895	25	87	1781	112	0.035	1.386
~~mr10b59~~	~~0.436~~	~~0.050~~	~~0.072~~	~~0.006~~	~~0.349~~	~~0.041~~	~~0.001~~	~~367~~	~~35~~	~~448~~	~~35~~	~~-270~~	~~64~~	~~-166~~	~~406~~	~~56~~	~~0.041~~	~~0.490~~
mr10b38	1.701	0.060	0.160	0.003	0.297	0.073	0.001	1009	23	958	19	1009	28	95	976	33	0.041	0.407
mr09b48	11.233	0.367	0.515	0.018	0.535	0.151	0.002	2543	30	2678	77	2353	21	114	2532	61	0.041	0.367
mr09b14	0.577	0.029	0.068	0.002	0.263	0.059	0.001	463	19	424	11	554	52	77	431	21	0.047	0.349

APPENDIX B

	Measured Isotopic Ratios							Calculated Ages										
Eliot Fm.	207Pb /235U	1s error	206Pb /238U	1s error	Rho	207Pb /206Pb	1s error	207Pb /235U	1s error	206Pb /238U	1s error	207Pb /206Pb	1s error	U-Pb/Pb-Pb con. %	Con. age	2s error	Prob. of con.	Ratio Th/U
mr10b102	3.901	0.297	0.256	0.012	0.308	0.101	0.001	1614	61	1469	62	1642	24	89	1534	103	0.049	0.819
mr09b49	0.576	0.016	0.071	0.001	0.333	0.055	0.001	462	10	441	8	418	22	105	447	14	0.051	0.465
mr10b98	2.130	0.132	0.180	0.006	0.267	0.078	0.001	1158	43	1067	33	1143	25	93	1093	59	0.052	0.326
mr10b13	3.469	0.116	0.254	0.006	0.352	0.095	0.001	1520	26	1458	31	1523	20	96	1495	47	0.057	0.578
mr09b70	1.756	0.058	0.165	0.004	0.329	0.073	0.001	1029	21	983	20	1013	23	97	1003	34	0.058	0.386
mr09b29	2.004	0.093	0.177	0.006	0.348	0.076	0.001	1117	31	1051	31	1094	37	96	1082	52	0.068	0.551
~~mr10b43~~	~~1.475~~	~~0.374~~	~~0.098~~	~~0.011~~	~~0.213~~	~~0.127~~	~~0.004~~	~~920~~	~~154~~	~~605~~	~~63~~	~~2053~~	~~59~~	~~29~~	~~615~~	~~124~~	~~0.072~~	~~0.257~~
mr10b64	2.016	0.079	0.180	0.004	0.307	0.079	0.001	1121	26	1068	24	1178	30	91	1089	41	0.076	0.474
mr10a12	0.591	0.112	0.056	0.010	0.469	0.061	0.001	472	71	349	60	629	27	55	382	114	0.081	0.273
mr11a11	3.669	0.122	0.263	0.007	0.423	0.096	0.001	1565	27	1503	38	1555	11	97	1550	51	0.086	0.414
mr11a09	3.764	0.213	0.259	0.012	0.411	0.101	0.001	1585	45	1483	62	1647	13	90	1557	87	0.088	0.881
mr10b09	2.868	0.110	0.227	0.005	0.285	0.088	0.001	1373	29	1317	26	1385	24	95	1340	44	0.089	0.305
mr10c17	2.834	0.181	0.218	0.009	0.312	0.092	0.001	1365	48	1270	46	1466	23	87	1311	77	0.089	0.399
mr10b78	4.309	0.112	0.291	0.006	0.376	0.100	0.001	1695	21	1649	28	1630	16	101	1681	40	0.104	0.959
mr09b21	0.595	0.024	0.072	0.002	0.297	0.059	0.001	474	15	449	10	565	31	79	455	19	0.114	0.695
mr10b52	2.137	0.062	0.191	0.003	0.282	0.077	0.001	1161	20	1126	17	1129	22	100	1139	29	0.119	0.250
mr09b81	4.182	0.111	0.287	0.006	0.389	0.102	0.001	1671	22	1626	30	1656	17	98	1658	41	0.122	0.595
mr10b107	0.838	0.122	0.083	0.009	0.356	0.064	0.001	618	67	512	51	739	26	69	538	95	0.130	0.091
mr10b23	4.774	0.443	0.290	0.015	0.280	0.121	0.003	1780	78	1641	75	1970	44	83	1700	126	0.135	1.109
mr09b13	0.613	0.033	0.073	0.002	0.222	0.061	0.001	486	21	455	10	648	39	70	459	20	0.147	0.691
mr09b38	0.821	0.029	0.095	0.002	0.362	0.060	0.001	609	16	583	14	591	34	99	593	25	0.149	0.748
mr09b20	17.648	0.458	0.568	0.014	0.468	0.211	0.002	2971	25	2899	57	2914	15	99	2972	50	0.153	0.475
mr10b07	0.858	0.052	0.095	0.004	0.329	0.063	0.001	629	29	586	23	708	28	83	599	41	0.162	0.331
~~mr10b41~~	~~1.857~~	~~0.551~~	~~0.125~~	~~0.021~~	~~0.285~~	~~0.092~~	~~0.002~~	~~1066~~	~~196~~	~~757~~	~~121~~	~~1466~~	~~34~~	~~52~~	~~788~~	~~236~~	~~0.162~~	~~0.258~~
mr09b79	0.561	0.016	0.075	0.001	0.304	0.048	0.001	452	11	468	8	76	34	613	463	15	0.163	0.676
mr09b52	1.565	0.062	0.153	0.004	0.325	0.071	0.001	957	24	919	22	955	27	96	934	38	0.165	0.820
mr10b10	0.582	0.032	0.070	0.002	0.306	0.058	0.001	466	20	437	14	542	22	81	444	26	0.165	0.009
mr09b50	0.611	0.041	0.072	0.003	0.261	0.062	0.001	484	26	448	15	683	47	66	454	29	0.168	0.838
mr10b22	0.712	0.040	0.094	0.002	0.213	0.063	0.001	546	24	579	13	695	36	83	572	25	0.178	0.703

	Measured Isotopic Ratios							Calculated Ages										
Eliot Fm.	207Pb /235U	1s error	206Pb /238U	1s error	Rho	207Pb /206Pb	1s error	207Pb /235U	1s error	206Pb /238U	1s error	207Pb /206Pb	1s error	U-Pb/Pb-Pb con. %	Con. age	2s error	Prob. of con.	Ratio Th/U
mr09b68	0.631	0.049	0.073	0.004	0.373	0.060	0.001	497	31	453	26	595	47	76	468	46	0.178	0.608
mr10b100	1.326	0.235	0.116	0.012	0.291	0.084	0.001	857	103	709	69	1297	28	55	737	131	0.178	0.322
mr10b125	0.600	0.047	0.070	0.004	0.379	0.059	0.001	477	30	437	25	551	37	79	451	45	0.193	0.280
mr10c13	3.057	0.197	0.233	0.010	0.348	0.092	0.001	1422	49	1349	55	1470	20	92	1389	86	0.220	0.755
mr11a13	4.151	0.335	0.274	0.017	0.388	0.105	0.001	1664	66	1562	87	1709	22	91	1633	125	0.237	1.005
mr10b83	0.531	0.037	0.065	0.003	0.358	0.056	0.001	432	24	403	19	461	24	87	412	35	0.244	0.309
mr09b12	4.123	0.099	0.288	0.004	0.304	0.100	0.001	1659	20	1631	21	1629	17	100	1646	33	0.246	0.348
mr10b33	0.583	0.018	0.073	0.001	0.263	0.056	0.001	466	11	453	7	465	21	97	455	13	0.250	0.606
mr10a22	0.589	0.062	0.068	0.003	0.187	0.060	0.001	470	40	425	16	610	38	70	428	32	0.262	0.534
mr10b126	0.564	0.034	0.069	0.003	0.385	0.056	0.001	454	22	428	19	459	27	93	438	34	0.269	0.297
mr10b122	0.434	0.024	0.061	0.002	0.301	0.052	0.001	366	17	384	12	307	25	125	379	22	0.287	0.365
mr11a18	0.898	0.261	0.080	0.012	0.259	0.100	0.002	651	139	495	72	1615	30	31	509	140	0.292	0.361
mr10b20	0.605	0.071	0.069	0.010	0.593	0.056	0.001	480	45	433	58	469	43	92	470	88	0.320	0.648
mr10b108	0.535	0.037	0.066	0.003	0.275	0.054	0.001	435	24	411	15	374	37	110	416	29	0.339	0.661
mr09b76	0.642	0.033	0.078	0.002	0.256	0.057	0.001	504	20	484	12	504	27	96	488	23	0.347	0.123
mr09b08	1.397	0.072	0.142	0.006	0.415	0.069	0.001	888	31	854	34	903	32	95	874	55	0.347	0.457
mr10c18	4.103	0.338	0.276	0.017	0.373	0.104	0.001	1655	67	1573	86	1693	22	93	1628	125	0.349	0.463
mr10b110	0.742	0.198	0.073	0.010	0.264	0.070	0.001	563	116	452	62	921	37	49	464	120	0.355	0.352
mr10b48	3.435	0.171	0.256	0.009	0.339	0.097	0.001	1512	39	1468	44	1567	17	94	1493	68	0.355	0.305
mr10c19	1.766	0.170	0.163	0.006	0.182	0.086	0.002	1033	62	972	32	1334	41	73	981	61	0.358	0.827
mr09b59	0.609	0.018	0.076	0.001	0.328	0.054	0.001	483	11	473	9	366	31	129	476	16	0.368	0.180
mr09b24	14.378	0.272	0.530	0.011	0.532	0.180	0.001	2775	18	2740	45	2654	12	103	2777	35	0.368	0.693
mr09b96	3.531	0.090	0.264	0.006	0.415	0.095	0.001	1534	20	1510	28	1538	16	98	1528	38	0.372	0.108
mr10a16	1.268	0.186	0.124	0.009	0.248	0.068	0.001	832	83	755	52	858	31	88	770	98	0.387	0.307
mr11a23	2.568	0.168	0.213	0.008	0.293	0.088	0.002	1292	48	1245	43	1388	39	90	1264	74	0.397	0.395
mr10b71	1.721	0.086	0.165	0.006	0.361	0.074	0.001	1016	32	986	33	1031	32	96	1001	54	0.402	1.302
mr10b127	0.651	0.094	0.074	0.006	0.285	0.063	0.001	509	58	461	37	698	33	66	470	69	0.420	0.448
mr10b14	0.547	0.024	0.073	0.001	0.171	0.058	0.001	443	16	456	7	520	32	88	454	13	0.426	0.784
mr10a10	2.920	0.353	0.225	0.012	0.222	0.092	0.001	1387	91	1308	64	1466	30	89	1328	116	0.435	0.587

APPENDIX B

Eliot Fm.	Measured Isotopic Ratios 207Pb /235U	1s error	206Pb /238U	1s error	Rho	207Pb /206Pb	1s error	Calculated Ages 207Pb /235U	1s error	206Pb /238U	1s error	207Pb /206Pb	1s error	U-Pb/Pb-Pb con. %	Con. age	2s error	Prob. of con.	Ratio Th/U
mr10b45	0.610	0.025	0.076	0.001	0.221	0.057	0.001	484	16	471	8	479	30	98	473	16	0.437	0.245
mr11a22	0.580	0.038	0.071	0.003	0.281	0.059	0.001	464	24	445	16	552	33	81	449	30	0.439	0.296
mr10a19	0.612	0.058	0.073	0.003	0.212	0.057	0.001	485	37	456	18	490	41	93	459	34	0.448	0.323
mr10a15	2.774	0.673	0.205	0.020	0.203	0.098	0.002	1349	181	1202	108	1583	40	76	1227	204	0.464	0.662
mr10b53	0.550	0.039	0.075	0.002	0.202	0.054	0.001	445	25	464	13	391	33	119	461	24	0.469	0.497
mr11a21	0.517	0.038	0.071	0.002	0.214	0.058	0.001	423	26	442	14	546	36	81	439	26	0.472	0.248
mr10c08	1.411	0.149	0.157	0.005	0.160	0.089	0.002	893	63	939	29	1408	49	67	932	56	0.478	0.492
mr10b137	4.430	0.698	0.282	0.038	0.427	0.108	0.001	1718	130	1600	191	1773	21	90	1692	255	0.510	0.629
mr09b07	0.497	0.027	0.068	0.002	0.207	0.057	0.001	410	18	421	9	493	37	85	420	17	0.529	0.506
~~mr10b28~~	~~3.606~~	~~0.534~~	~~0.254~~	~~0.025~~	~~0.335~~	~~0.100~~	~~0.001~~	~~1551~~	~~118~~	~~1461~~	~~130~~	~~1630~~	~~23~~	~~90~~	~~1510~~	~~205~~	~~0.531~~	~~0.794~~
mr09b69	0.542	0.041	0.068	0.003	0.287	0.057	0.001	440	27	423	18	484	35	88	427	33	0.551	0.737
mr10b19	2.332	0.090	0.212	0.004	0.227	0.084	0.001	1222	27	1240	20	1299	26	95	1234	35	0.556	0.746
mr09b11	0.513	0.019	0.069	0.002	0.304	0.052	0.001	421	12	428	9	302	34	142	426	17	0.573	0.392
mr11a14	0.746	0.134	0.085	0.008	0.250	0.067	0.001	566	78	523	45	851	40	61	530	86	0.596	0.569
mr10a23	0.548	0.063	0.068	0.003	0.215	0.057	0.001	444	42	422	20	477	34	88	425	39	0.605	0.598
mr10b75	1.752	0.069	0.170	0.004	0.290	0.074	0.001	1028	25	1013	21	1041	27	97	1019	37	0.608	0.796
mr10b132	4.024	0.235	0.283	0.011	0.330	0.100	0.001	1639	47	1609	55	1623	17	99	1627	83	0.611	1.019
mr10b116	3.793	0.297	0.273	0.009	0.217	0.102	0.002	1591	63	1557	47	1668	34	93	1567	83	0.623	0.560
mr09b99	0.565	0.082	0.077	0.005	0.208	0.053	0.001	455	53	481	28	334	64	144	477	53	0.627	0.643
mr10b120	0.504	0.050	0.069	0.003	0.202	0.062	0.001	414	34	430	17	671	41	64	428	32	0.642	0.164
mr10c07	0.534	0.059	0.067	0.004	0.257	0.057	0.001	434	39	416	23	493	35	84	420	44	0.657	0.557
mr09b95	2.177	0.209	0.194	0.009	0.232	0.089	0.001	1174	67	1142	47	1415	27	81	1150	85	0.661	0.280
mr09b93	0.604	0.055	0.075	0.003	0.243	0.065	0.001	480	35	464	20	762	43	61	467	37	0.666	0.166
mr10b42	0.645	0.205	0.072	0.011	0.241	0.063	0.001	505	127	450	67	693	49	65	457	129	0.670	0.499
mr11a12	0.484	0.032	0.063	0.002	0.287	0.058	0.001	401	22	393	14	536	22	73	395	27	0.721	0.373
mr09b42	1.388	0.074	0.145	0.004	0.262	0.071	0.001	884	32	872	23	960	27	91	875	41	0.726	0.595
mr10b135	0.510	0.038	0.066	0.004	0.389	0.054	0.001	418	26	409	23	355	29	115	413	41	0.729	0.390
mr10b24	0.556	0.024	0.071	0.002	0.276	0.056	0.001	449	15	444	10	445	26	100	445	19	0.735	0.117
mr10b130	3.412	0.185	0.260	0.007	0.259	0.103	0.001	1507	42	1491	37	1672	20	89	1497	63	0.736	0.766

	Measured Isotopic Ratios							Calculated Ages										
Eliot Fm.	207Pb /235U	1s error	206Pb /238U	1s error	Rho	207Pb /206Pb	1s error	207Pb /235U	1s error	206Pb /238U	1s error	207Pb /206Pb	1s error	U-Pb/Pb-Pb con. %	Con. age	2s error	Prob. of con.	Ratio Th/U
mr10b128	2.001	0.694	0.173	0.036	0.299	0.088	0.001	1116	235	1028	197	1384	28	74	1058	349	0.737	0.121
mr10a21	1.788	0.144	0.172	0.007	0.248	0.069	0.001	1041	53	1024	38	904	39	113	1029	68	0.760	0.692
mr09b43	1.176	0.149	0.134	0.007	0.203	0.075	0.002	790	69	811	39	1071	42	76	807	73	0.763	0.816
mr10b11	0.524	0.029	0.070	0.001	0.165	0.057	0.001	428	19	433	8	488	33	89	433	15	0.794	0.645
mr10b121	0.489	0.045	0.066	0.003	0.285	0.054	0.001	404	31	412	21	372	30	111	410	39	0.798	0.353
mr09b30	5.013	0.207	0.324	0.009	0.322	0.117	0.002	1822	35	1811	42	1908	26	95	1817	62	0.809	0.027
mr09b39	1.688	0.067	0.170	0.005	0.375	0.068	0.001	1004	25	1011	28	876	36	115	1007	44	0.813	0.695
mr09b65	0.613	0.029	0.079	0.002	0.234	0.057	0.001	486	18	490	10	506	35	97	489	19	0.822	0.308
mr10c11	0.498	0.032	0.065	0.002	0.242	0.058	0.003	410	22	405	12	547	110	74	406	23	0.822	0.332
mr10b18	0.540	0.046	0.069	0.003	0.226	0.056	0.001	438	30	432	16	452	42	95	433	31	0.829	0.911
mr10b118	0.516	0.048	0.067	0.003	0.235	0.060	0.001	423	32	416	18	590	27	71	417	33	0.836	0.238
~~mr10c09~~	~~0.439~~	~~0.214~~	~~0.054~~	~~0.015~~	~~0.279~~	~~0.079~~	~~0.001~~	~~369~~	~~151~~	~~337~~	~~89~~	~~1164~~	~~24~~	~~29~~	~~343~~	~~171~~	~~0.836~~	~~0.244~~
mr09b61	0.563	0.054	0.072	0.003	0.206	0.059	0.001	453	35	446	17	572	54	78	447	33	0.838	0.304
mr10b50	1.421	0.314	0.154	0.011	0.158	0.079	0.001	898	132	924	60	1168	35	79	920	114	0.847	0.253
mr09b60	1.237	0.105	0.137	0.009	0.372	0.067	0.001	818	48	828	49	851	43	97	823	80	0.849	0.367
mr09b32	1.398	0.150	0.150	0.006	0.185	0.077	0.002	888	64	901	33	1134	39	79	899	63	0.850	0.336
mr09b35	0.557	0.029	0.072	0.002	0.224	0.056	0.001	449	19	446	10	454	39	98	446	19	0.851	0.405
mr10b119	0.529	0.065	0.068	0.004	0.227	0.063	0.001	431	43	423	23	723	37	59	424	44	0.851	0.528
mr09b80	0.537	0.034	0.069	0.002	0.241	0.056	0.001	437	23	432	13	468	38	92	433	25	0.855	0.218
~~mr10b44~~	~~1.129~~	~~1.279~~	~~0.106~~	~~0.082~~	~~0.340~~	~~0.085~~	~~0.001~~	~~767~~	~~610~~	~~650~~	~~476~~	~~1309~~	~~26~~	~~50~~	~~682~~	~~880~~	~~0.857~~	~~0.108~~
mr10b31	0.499	0.022	0.065	0.002	0.286	0.053	0.001	411	15	408	10	314	35	130	409	19	0.862	0.690
mr11a19	0.541	0.116	0.072	0.007	0.239	0.057	0.001	439	76	451	44	478	49	94	448	84	0.882	0.651
mr09b09	0.574	0.024	0.074	0.001	0.230	0.058	0.001	460	16	463	9	520	34	89	462	17	0.899	0.293
mr10b79	0.570	0.168	0.071	0.006	0.148	0.062	0.001	458	109	444	38	668	35	66	445	74	0.900	0.317
mr09b41	0.922	0.054	0.109	0.004	0.346	0.057	0.002	664	28	667	26	502	58	133	666	44	0.901	0.896
mr10b109	1.383	0.522	0.142	0.023	0.211	0.083	0.001	882	222	857	128	1271	31	67	862	240	0.917	0.156
mr09b94	0.508	0.084	0.068	0.005	0.211	0.059	0.002	417	56	423	28	580	56	73	422	54	0.917	0.756
mr09b97	1.756	0.201	0.172	0.008	0.214	0.082	0.002	1029	74	1023	46	1237	41	83	1025	85	0.938	0.727
mr10c14	0.494	0.054	0.065	0.003	0.202	0.064	0.001	407	36	405	17	749	35	54	405	33	0.947	0.835

APPENDIX B

Eliot Fm.	Measured Isotopic Ratios 207Pb /235U	1s error	206Pb /238U	1s error	Rho	207Pb /206Pb	1s error	Calculated Ages 207Pb /235U	1s error	206Pb /238U	1s error	207Pb /206Pb	1s error	U-Pb/Pb-Pb con. %	Con. age	2s error	Prob. of con.	Ratio Th/U
mr09b62	1.206	0.152	0.132	0.006	0.176	0.082	0.002	803	70	799	33	1257	46	64	800	64	0.957	0.332
mr09b55	0.562	0.044	0.073	0.003	0.221	0.061	0.001	453	29	455	15	631	50	72	454	29	0.957	0.810
mr10b51	0.560	0.086	0.072	0.003	0.157	0.056	0.001	452	56	450	21	432	41	104	450	41	0.971	0.377
mr11a10	0.332	0.081	0.047	0.006	0.275	0.064	0.001	291	62	293	38	737	27	40	293	72	0.973	0.207
mr10b136	0.553	0.181	0.071	0.014	0.309	0.056	0.001	447	119	445	87	447	41	100	445	159	0.986	0.128
mr10b129	0.496	0.064	0.065	0.004	0.254	0.065	0.002	409	43	409	26	787	60	52	409	49	0.990	0.770
mr10c12	0.547	0.045	0.071	0.003	0.261	0.058	0.001	443	29	442	18	547	29	81	443	34	0.993	0.424

	Measured Isotopic Ratios							Calculated Ages										
Berwick Fm.	207Pb /235U	1s error	206Pb /238U	1s error	Rho	207Pb /206Pb	1s error	207Pb /235U	1s error	206Pb /238U	1s error	207Pb /206Pb	1s error	U-Pb/Pb-Pb con. %	Con. age	2s error	Prob. of con.	Ratio Th/U
mr05a16	9.547	0.348	0.352	0.012	0.475	0.180	0.001	2392	34	1944	58	2649	13	73	2332	70	0.00	0.521
mr05a11	3.627	0.051	0.256	0.003	0.439	0.093	0.001	1555	11	1468	16	1497	12	98	1536	22	0.00	0.565
mr05a114	2.358	0.093	0.178	0.005	0.324	0.083	0.002	1230	28	1058	25	1263	37	84	1116	45	0.00	0.527
~~mr09a20~~	~~1.280~~	~~0.108~~	~~0.188~~	~~0.007~~	~~0.230~~	~~0.051~~	~~0.001~~	~~837~~	~~48~~	~~1110~~	~~40~~	~~229~~	~~35~~	~~485~~	~~984~~	~~64~~	~~0.00~~	~~0.590~~
mr05a12	4.152	0.129	0.261	0.007	0.406	0.102	0.001	1665	25	1497	34	1656	20	90	1611	49	0.00	0.490
mr05a120	3.630	0.151	0.235	0.006	0.305	0.101	0.003	1556	33	1358	31	1636	46	83	1433	54	0.00	0.438
mr04b32	9.834	1.295	0.261	0.009	0.129	0.198	0.025	2419	121	1493	45	2812	206	53	1498	91	0.00	0.376
mr04b80	0.841	0.031	0.086	0.002	0.361	0.063	0.001	620	17	529	13	702	36	75	555	25	0.00	0.492
mr05a90	3.583	0.087	0.248	0.006	0.470	0.098	0.001	1546	19	1426	29	1591	21	90	1525	38	0.00	0.864
mr04b93	2.048	0.057	0.174	0.004	0.426	0.078	0.001	1132	19	1032	22	1153	18	90	1094	35	0.00	0.480
mr04b48	2.987	0.088	0.220	0.006	0.472	0.087	0.001	1404	22	1282	32	1365	25	94	1379	44	0.00	0.781
mr05a14	4.224	0.083	0.279	0.005	0.456	0.101	0.001	1679	16	1586	25	1651	12	96	1664	32	0.00	0.527
mr05a25	2.459	0.078	0.195	0.005	0.406	0.085	0.001	1260	23	1150	27	1322	20	87	1216	42	0.00	0.863
mr05a20	2.782	0.060	0.217	0.004	0.471	0.085	0.001	1351	16	1266	23	1327	17	95	1334	32	0.00	0.446
mr05a24	1.722	0.084	0.146	0.006	0.396	0.076	0.001	1017	31	880	32	1090	36	81	942	54	0.00	1.668
mr04b13	5.587	0.109	0.327	0.005	0.427	0.114	0.001	1914	17	1822	27	1862	14	98	1899	33	0.00	0.530
mr05a27	4.049	0.098	0.273	0.005	0.356	0.101	0.001	1644	20	1554	24	1647	15	94	1610	36	0.00	0.069
mr04b46	4.898	0.237	0.286	0.009	0.321	0.128	0.002	1802	41	1622	45	2069	28	78	1713	72	0.00	1.076
mr04b64	1.940	0.066	0.168	0.005	0.419	0.075	0.001	1095	23	999	27	1073	28	93	1056	42	0.00	0.970
mr05a32	11.294	0.365	0.444	0.013	0.453	0.177	0.002	2548	30	2368	58	2624	21	90	2538	61	0.00	1.021
mr04b78	4.078	0.091	0.273	0.006	0.502	0.101	0.001	1650	18	1557	31	1638	12	95	1643	37	0.00	0.327
mr05a83	4.139	0.103	0.276	0.005	0.371	0.103	0.001	1662	20	1573	26	1676	13	94	1631	38	0.00	0.617
mr05a66	1.398	0.091	0.121	0.010	0.661	0.079	0.001	888	39	738	60	1163	30	63	889	77	0.00	0.381
mr09a30	4.618	0.163	0.287	0.007	0.357	0.107	0.001	1753	29	1626	36	1748	15	93	1705	54	0.00	0.510
mr04b92	2.127	0.084	0.178	0.004	0.277	0.078	0.001	1158	27	1057	21	1136	28	93	1087	38	0.00	0.584
mr09a40	3.829	0.126	0.259	0.007	0.400	0.094	0.001	1599	26	1487	35	1507	13	99	1564	50	0.00	0.768
mr04b89	0.599	0.018	0.070	0.002	0.404	0.056	0.001	476	11	438	10	463	21	95	453	18	0.00	0.552
mr04b30	2.293	0.061	0.193	0.004	0.375	0.078	0.001	1210	19	1138	21	1151	20	99	1178	33	0.00	0.417
mr04b25	4.616	0.680	0.216	0.007	0.107	0.136	0.016	1752	123	1260	36	2176	206	58	1268	72	0.00	0.279

	Measured Isotopic Ratios							Calculated Ages										
Berwick Fm.	207Pb /235U	1s error	206Pb /238U	1s error	Rho	207Pb /206Pb	1s error	207Pb /235U	1s error	206Pb /238U	1s error	207Pb /206Pb	1s error	U-Pb/Pb-Pb con. %	Con. age	2s error	Prob. of con.	Ratio Th/U
mr04b91	5.237	0.117	0.316	0.007	0.485	0.111	0.001	1859	19	1772	33	1819	11	97	1853	38	0.00	0.108
mr04b38	4.301	0.116	0.283	0.006	0.418	0.102	0.001	1694	22	1604	32	1656	13	97	1673	43	0.00	0.685
mr05a52	0.544	0.021	0.078	0.002	0.258	0.054	0.001	441	14	483	9	386	29	125	472	17	0.00	0.881
mr04b85	0.593	0.020	0.070	0.002	0.483	0.055	0.001	473	12	435	13	414	25	105	456	22	0.00	0.525
mr05a94	3.906	0.101	0.268	0.006	0.433	0.101	0.002	1615	21	1532	31	1644	33	93	1597	41	0.00	0.086
mr05a21	3.886	0.127	0.266	0.005	0.279	0.102	0.001	1611	26	1522	25	1659	19	92	1559	41	0.00	0.284
mr04b41	1.941	0.106	0.162	0.009	0.493	0.076	0.001	1095	37	970	48	1098	21	88	1061	72	0.00	0.175
mr04b90	4.141	0.125	0.276	0.006	0.376	0.102	0.001	1662	25	1571	32	1652	18	95	1632	46	0.00	0.986
mr05a26	2.727	0.106	0.213	0.005	0.281	0.087	0.001	1336	29	1244	25	1365	29	91	1277	43	0.01	0.396
mr04b15	3.268	0.081	0.244	0.004	0.364	0.092	0.001	1473	19	1407	23	1474	15	95	1447	35	0.01	0.525
mr09a12	3.988	0.159	0.267	0.007	0.309	0.098	0.001	1632	32	1525	33	1590	20	96	1577	54	0.01	0.410
mr04b74	1.856	0.060	0.168	0.003	0.305	0.076	0.001	1066	21	1002	18	1090	27	92	1025	32	0.01	1.100
mr05a10	2.831	0.122	0.215	0.008	0.417	0.089	0.001	1364	32	1257	41	1402	15	90	1328	61	0.01	0.391
mr05a125	1.352	0.161	0.178	0.007	0.175	0.072	0.002	868	70	1054	41	998	59	106	1005	73	0.01	0.415
mr04b21	1.142	0.090	0.107	0.006	0.383	0.069	0.001	773	43	653	38	907	22	72	694	68	0.01	0.327
mr05a58	4.051	0.092	0.278	0.005	0.396	0.100	0.001	1645	18	1582	25	1629	14	97	1627	35	0.01	0.648
mr05a86	3.203	0.069	0.244	0.004	0.368	0.093	0.001	1458	17	1406	20	1479	12	95	1438	30	0.01	0.361
mr04b20	1.796	0.049	0.167	0.003	0.382	0.073	0.001	1044	18	993	19	1002	16	99	1021	31	0.01	0.470
mr05a22	2.835	0.084	0.223	0.005	0.413	0.086	0.001	1365	22	1297	29	1338	14	97	1344	42	0.02	0.582
mr04b61	0.908	0.064	0.093	0.004	0.331	0.070	0.001	656	34	571	25	937	31	61	593	47	0.02	0.240
mr04b31	0.621	0.032	0.071	0.002	0.232	0.060	0.002	491	20	442	10	609	80	73	448	19	0.02	0.669
mr09a21	3.173	0.105	0.239	0.005	0.306	0.089	0.001	1451	25	1379	25	1399	15	99	1412	41	0.02	0.394
mr04b86	0.651	0.027	0.075	0.002	0.359	0.058	0.001	509	17	468	14	514	32	91	481	25	0.02	0.425
mr05a88	1.271	0.088	0.120	0.007	0.421	0.071	0.001	833	39	731	40	968	25	75	779	68	0.02	0.208
mr09a33	3.762	0.154	0.297	0.007	0.292	0.092	0.002	1585	33	1679	35	1474	31	114	1624	54	0.02	0.803
mr05a77	3.339	0.085	0.249	0.005	0.409	0.093	0.001	1490	20	1431	27	1489	13	96	1474	38	0.02	0.446
mr05a137	2.571	0.207	0.192	0.014	0.449	0.095	0.001	1293	59	1131	75	1520	14	74	1238	114	0.02	0.441
mr05a72	0.572	0.022	0.068	0.002	0.312	0.058	0.001	459	14	427	10	522	35	82	435	18	0.03	0.979
mr04b50	2.397	0.176	0.189	0.007	0.237	0.087	0.006	1242	53	1114	36	1367	133	81	1142	66	0.03	0.402

Berwick Fm.	Measured Isotopic Ratios 207Pb /235U	1s error	206Pb /238U	1s error	Rho	207Pb /206Pb	1s error	Calculated Ages 207Pb /235U	1s error	206Pb /238U	1s error	207Pb /206Pb	1s error	U-Pb/Pb-Pb con. %	Con. age	2s error	Prob. of con.	Ratio Th/U
mr05a82	2.991	0.064	0.235	0.005	0.452	0.089	0.001	1405	16	1359	24	1397	12	97	1396	32	0.03	0.437
mr04b81	3.356	0.102	0.249	0.006	0.374	0.094	0.001	1494	24	1432	29	1503	15	95	1472	43	0.04	0.669
mr05a50	2.936	0.101	0.229	0.005	0.287	0.088	0.001	1391	26	1330	24	1390	22	96	1355	40	0.04	0.579
mr05a17	12.225	0.287	0.484	0.010	0.440	0.166	0.002	2622	22	2544	43	2520	17	101	2618	44	0.04	0.423
mr04b35	0.641	0.023	0.076	0.002	0.342	0.057	0.001	503	14	474	11	494	22	96	483	21	0.05	0.474
mr05a141	3.304	0.123	0.245	0.007	0.375	0.095	0.001	1482	29	1412	35	1525	20	93	1456	53	0.06	0.632
mr04b28	0.649	0.027	0.076	0.002	0.317	0.061	0.001	508	17	475	12	648	37	73	484	22	0.06	0.755
mr04b14	0.604	0.033	0.070	0.002	0.327	0.060	0.001	479	21	439	15	606	33	72	449	28	0.06	0.833
mr04b83	3.907	0.141	0.272	0.006	0.304	0.102	0.001	1615	29	1550	30	1667	21	93	1583	49	0.06	0.952
mr04b24	2.294	0.064	0.199	0.003	0.303	0.081	0.001	1210	20	1170	18	1231	25	95	1187	31	0.07	0.380
mr04b12	0.571	0.029	0.068	0.002	0.339	0.057	0.001	458	19	425	14	485	27	88	434	26	0.09	0.715
mr04b79	0.603	0.034	0.084	0.003	0.268	0.053	0.001	479	22	517	15	341	35	152	506	27	0.09	0.663
mr05a116	0.783	0.056	0.086	0.006	0.489	0.057	0.001	587	32	531	35	495	37	107	564	58	0.10	0.475
mr05a15	5.324	0.121	0.328	0.006	0.388	0.112	0.001	1873	19	1828	28	1826	16	100	1862	37	0.10	0.293
mr04b73	0.484	0.032	0.070	0.002	0.260	0.053	0.001	401	22	438	15	327	41	134	428	27	0.10	0.623
mr04b29	0.530	0.016	0.066	0.001	0.314	0.055	0.001	432	11	414	8	398	22	104	419	14	0.11	0.689
mr05a117	3.816	0.166	0.266	0.010	0.421	0.096	0.001	1596	35	1521	50	1540	15	99	1578	68	0.11	0.307
mr05a46	0.510	0.019	0.071	0.001	0.268	0.054	0.001	419	13	440	9	358	24	123	435	16	0.11	0.465
mr05a40	2.067	0.068	0.200	0.004	0.278	0.079	0.001	1138	22	1177	20	1163	25	101	1161	33	0.12	0.595
mr05a51	2.002	0.079	0.180	0.005	0.358	0.076	0.001	1116	27	1068	28	1099	25	97	1093	45	0.12	0.566
mr04b68	2.027	0.098	0.180	0.004	0.242	0.079	0.001	1125	33	1069	23	1171	34	91	1084	42	0.12	0.624
mr05a115	4.458	0.223	0.289	0.012	0.402	0.102	0.001	1723	41	1637	58	1666	16	98	1701	80	0.12	0.524
mr09a09	4.555	0.364	0.285	0.014	0.312	0.105	0.001	1741	66	1616	71	1716	22	94	1680	114	0.13	1.037
mr05a30	2.425	0.124	0.202	0.006	0.285	0.087	0.001	1250	37	1189	32	1355	17	88	1212	55	0.14	0.284
mr04b23	2.117	0.080	0.188	0.005	0.325	0.081	0.001	1154	26	1110	25	1229	32	90	1130	42	0.14	0.295
mr05a61	3.520	0.078	0.275	0.005	0.409	0.091	0.001	1532	17	1567	25	1452	14	108	1539	33	0.14	0.211
mr05a92	3.204	0.114	0.243	0.009	0.500	0.095	0.001	1458	28	1401	45	1531	24	92	1452	55	0.14	0.927
mr09a25	4.702	0.158	0.305	0.006	0.310	0.103	0.001	1768	28	1716	31	1688	16	102	1745	48	0.15	0.665
mr05a38	4.321	0.160	0.290	0.006	0.293	0.109	0.001	1697	31	1644	31	1785	25	92	1671	50	0.15	0.997

Berwick Fm.	Measured Isotopic Ratios 207Pb /235U	1s error	206Pb /238U	1s error	Rho	207Pb /206Pb	1s error	Calculated Ages 207Pb /235U	1s error	206Pb /238U	1s error	207Pb /206Pb	1s error	U-Pb/Pb-Pb con. %	Con. age	2s error	Prob. of con.	Ratio Th/U
mr04b60	3.396	0.121	0.253	0.007	0.382	0.092	0.001	1503	28	1453	36	1475	17	99	1487	52	0.16	0.362
mr05a106	0.641	0.031	0.076	0.003	0.357	0.057	0.000	503	19	474	16	483	16	98	484	28	0.16	0.241
mr04b63	1.025	0.028	0.114	0.002	0.375	0.063	0.001	716	14	695	14	697	25	100	705	23	0.17	0.427
mr05a37	0.597	0.038	0.071	0.002	0.238	0.055	0.001	476	24	442	13	424	39	104	447	25	0.17	0.919
mr05a43	3.443	0.171	0.253	0.006	0.227	0.095	0.005	1514	39	1455	29	1535	107	95	1473	52	0.18	0.297
mr05a48	4.754	0.226	0.305	0.007	0.242	0.108	0.006	1777	40	1714	35	1769	101	97	1738	59	0.18	0.875
mr04b39	1.779	0.065	0.168	0.004	0.334	0.072	0.001	1038	24	1002	23	987	23	101	1018	38	0.18	0.342
mr04b72	2.632	0.121	0.215	0.007	0.350	0.085	0.001	1310	34	1257	37	1312	26	96	1286	58	0.19	0.805
mr04b08	4.160	0.120	0.287	0.006	0.340	0.094	0.001	1666	24	1628	28	1517	21	107	1652	42	0.20	0.352
mr04b58	3.530	0.098	0.262	0.005	0.343	0.092	0.001	1534	22	1499	26	1462	15	102	1520	39	0.20	0.344
mr04b53	2.050	0.079	0.185	0.005	0.342	0.074	0.001	1132	26	1093	27	1050	23	104	1112	44	0.20	1.003
mr05a140	3.947	0.131	0.278	0.007	0.371	0.102	0.001	1623	27	1579	34	1669	17	95	1609	50	0.20	0.300
mr04b40	0.603	0.030	0.073	0.002	0.318	0.058	0.001	479	19	454	14	517	33	88	461	25	0.21	0.646
mr05a144	2.107	0.105	0.186	0.006	0.344	0.082	0.001	1151	34	1102	35	1247	21	88	1126	57	0.22	0.417
mr05a79	1.699	0.079	0.177	0.005	0.283	0.073	0.001	1008	30	1049	26	1009	29	104	1032	44	0.22	0.605
mr04b84	4.432	0.194	0.295	0.008	0.293	0.107	0.001	1718	36	1665	38	1756	23	95	1692	60	0.23	0.913
mr04b11	3.447	0.091	0.258	0.006	0.410	0.090	0.000	1515	21	1482	29	1431	10	104	1507	39	0.23	0.076
mr05a76	3.550	0.068	0.264	0.005	0.507	0.093	0.001	1538	15	1512	26	1478	12	102	1537	30	0.23	0.347
mr04b18	2.552	0.088	0.215	0.004	0.292	0.083	0.001	1287	25	1254	23	1275	19	98	1268	39	0.25	0.303
mr05a104	4.506	0.242	0.295	0.011	0.349	0.104	0.001	1732	45	1666	55	1704	18	98	1708	81	0.25	0.491
mr09a38	0.391	0.099	0.067	0.005	0.151	0.058	0.002	335	72	417	31	544	67	77	407	59	0.25	0.548
mr05a126	3.472	0.388	0.243	0.018	0.332	0.108	0.001	1521	88	1400	93	1760	16	80	1460	152	0.26	0.999
mr04b33	1.610	0.105	0.154	0.005	0.250	0.074	0.001	974	41	926	28	1030	19	90	938	52	0.27	1.095
mr09a32	4.255	0.183	0.289	0.008	0.304	0.103	0.001	1685	35	1639	38	1670	23	98	1663	60	0.29	0.301
mr05a103	4.170	0.265	0.309	0.011	0.287	0.100	0.002	1668	52	1734	55	1629	36	106	1697	85	0.30	2.027
mr04b09	1.688	0.073	0.163	0.004	0.265	0.076	0.001	1004	28	973	21	1102	26	88	983	37	0.30	0.787
mr05a56	2.971	0.088	0.237	0.005	0.347	0.093	0.001	1400	23	1372	25	1497	27	92	1389	39	0.30	0.652
mr05a63	0.565	0.017	0.071	0.001	0.294	0.056	0.001	455	11	443	8	464	28	95	446	14	0.32	0.868
mr04b34	0.731	0.040	0.094	0.002	0.230	0.056	0.001	557	24	581	14	437	30	133	576	26	0.32	0.727

Berwick	Measured Isotopic Ratios							Calculated Ages										Ratio
Fm.	207Pb /235U	1s error	206Pb /238U	1s error	Rho	207Pb /206Pb	1s error	207Pb /235U	1s error	206Pb /238U	1s error	207Pb /206Pb	1s error	U-Pb/Pb-Pb con. %	Con. age	2s error	Prob. of con.	Th/U
mr05a123	4.237	0.160	0.289	0.010	0.456	0.099	0.001	1681	31	1637	50	1609	17	102	1675	61	0.32	0.595
mr09a13	3.161	0.145	0.244	0.006	0.263	0.091	0.001	1448	35	1408	30	1448	19	97	1424	52	0.33	0.029
mr09a18	1.537	0.131	0.167	0.005	0.164	0.079	0.002	945	52	997	26	1164	41	86	989	49	0.33	0.491
mr05a13	1.686	0.065	0.164	0.004	0.286	0.073	0.001	1003	25	978	20	1003	30	97	987	35	0.35	0.323
mr09a34	0.473	0.020	0.065	0.002	0.313	0.052	0.001	393	13	406	10	288	54	141	402	18	0.35	0.273
mr04b22	9.897	0.163	0.462	0.006	0.412	0.145	0.001	2425	15	2449	28	2285	11	107	2427	30	0.36	0.995
mr05a107	3.247	0.294	0.239	0.019	0.438	0.088	0.001	1469	70	1384	99	1387	14	100	1448	136	0.36	0.378
mr05a42	2.130	0.055	0.193	0.004	0.385	0.078	0.001	1158	18	1139	21	1152	16	99	1151	32	0.36	0.077
mr05a108	0.559	0.047	0.077	0.003	0.260	0.056	0.004	451	31	478	20	444	177	108	471	37	0.41	0.811
mr04b82	1.454	0.055	0.148	0.004	0.349	0.065	0.001	912	23	890	22	779	28	114	900	37	0.41	0.681
mr09a22	2.679	0.534	0.203	0.029	0.362	0.089	0.001	1323	147	1189	157	1397	18	85	1256	258	0.44	0.080
~~mr09a23~~	~~10.365~~	~~2.721~~	~~0.407~~	~~0.078~~	~~0.365~~	~~0.170~~	~~0.002~~	~~2468~~	~~243~~	~~2200~~	~~357~~	~~2558~~	~~15~~	~~86~~	~~2394~~	~~483~~	~~0.44~~	~~0.554~~
mr04b95	1.445	0.065	0.147	0.006	0.468	0.070	0.001	908	27	883	35	923	24	96	901	52	0.45	0.354
mr09a35	0.549	0.094	0.063	0.006	0.282	0.061	0.001	444	62	396	37	648	46	61	405	71	0.45	0.328
mr05a87	0.583	0.018	0.074	0.001	0.329	0.056	0.001	466	11	458	9	436	21	105	460	16	0.45	0.620
mr05a129	4.115	0.175	0.286	0.009	0.362	0.104	0.001	1657	35	1623	44	1695	18	96	1646	64	0.45	1.187
mr05a41	2.284	0.149	0.199	0.009	0.342	0.084	0.001	1207	46	1167	48	1286	23	91	1188	78	0.46	0.178
mr04b75	0.608	0.025	0.076	0.002	0.247	0.057	0.001	483	16	471	9	486	26	97	473	18	0.46	0.507
mr05a78	0.940	0.050	0.114	0.004	0.333	0.064	0.001	673	26	693	24	742	45	93	685	40	0.48	0.605
mr05a139	0.567	0.033	0.071	0.003	0.342	0.058	0.001	456	21	441	17	531	27	83	446	30	0.49	0.537
mr05a138	3.166	0.201	0.244	0.010	0.312	0.096	0.001	1449	49	1409	50	1548	23	91	1429	81	0.49	1.167
mr05a71	4.668	0.073	0.312	0.004	0.427	0.105	0.001	1761	13	1749	21	1709	10	102	1759	26	0.50	0.129
mr05a62	0.879	0.029	0.103	0.002	0.301	0.061	0.001	641	16	629	12	626	22	101	633	22	0.50	0.127
mr04b51	13.868	0.409	0.522	0.014	0.457	0.186	0.002	2741	28	2706	60	2708	18	100	2740	56	0.51	1.773
mr05a57	0.595	0.022	0.075	0.001	0.261	0.056	0.001	474	14	465	9	461	27	101	467	16	0.54	0.672
mr04b67	2.785	0.112	0.229	0.006	0.323	0.085	0.001	1352	30	1330	31	1312	23	101	1341	50	0.55	0.487
mr05a33	3.352	0.114	0.257	0.006	0.360	0.093	0.001	1493	27	1473	32	1494	17	99	1486	48	0.55	1.014
mr05a124	0.535	0.106	0.077	0.007	0.219	0.055	0.001	435	70	478	40	417	42	115	469	75	0.55	0.275
mr09a31	2.945	0.165	0.236	0.007	0.259	0.091	0.001	1394	43	1365	36	1438	26	95	1376	62	0.55	0.467

	Measured Isotopic Ratios							Calculated Ages										
Berwick Fm.	207Pb /235U	1s error	206Pb /238U	1s error	Rho	207Pb /206Pb	1s error	207Pb /235U	1s error	206Pb /238U	1s error	207Pb /206Pb	1s error	U-Pb/Pb-Pb con. %	Con. age	2s error	Prob. of con.	Ratio Th/U
mr05a68	4.115	0.068	0.291	0.004	0.418	0.099	0.001	1657	14	1646	20	1614	12	102	1655	26	0.56	0.402
mr05a89	1.873	0.046	0.179	0.003	0.345	0.075	0.001	1071	16	1061	16	1071	22	99	1066	27	0.56	0.272
mr09a19	0.536	0.043	0.067	0.003	0.266	0.056	0.001	436	29	420	17	450	28	93	423	33	0.59	0.327
mr05a69	0.892	0.042	0.108	0.003	0.257	0.066	0.001	648	22	660	15	801	35	82	657	28	0.59	0.394
mr05a70	0.582	0.045	0.078	0.004	0.292	0.054	0.001	466	29	481	21	356	47	135	477	38	0.60	0.789
mr05a47	0.513	0.066	0.064	0.006	0.357	0.055	0.001	421	44	398	35	412	23	97	406	64	0.63	0.566
mr05a36	3.832	0.120	0.279	0.005	0.286	0.101	0.001	1599	25	1585	25	1650	18	96	1592	40	0.63	0.820
mr04b57	1.923	0.064	0.182	0.004	0.333	0.075	0.001	1089	22	1077	22	1070	25	101	1083	36	0.63	0.386
mr04b49	3.195	0.077	0.251	0.006	0.460	0.085	0.001	1456	19	1444	29	1312	17	110	1454	37	0.64	0.325
mr05a31	1.832	0.104	0.174	0.009	0.460	0.076	0.002	1057	37	1036	50	1101	42	94	1052	71	0.65	0.571
mr05a135	1.854	0.090	0.183	0.005	0.279	0.079	0.001	1065	32	1081	27	1161	27	93	1075	47	0.65	0.344
mr05a91	0.673	0.079	0.088	0.005	0.221	0.058	0.001	523	48	545	27	517	42	105	540	51	0.66	0.757
mr05a147	1.692	0.431	0.155	0.023	0.286	0.082	0.001	1005	163	927	126	1237	25	75	950	228	0.66	0.209
mr04b10	0.552	0.028	0.070	0.002	0.224	0.058	0.001	446	18	438	10	548	25	80	439	18	0.67	0.965
~~mr04b19~~	~~0.566~~	~~0.035~~	~~0.075~~	~~0.003~~	~~0.287~~	~~0.051~~	~~0.001~~	~~455~~	~~23~~	~~465~~	~~16~~	~~240~~	~~42~~	~~194~~	~~462~~	~~29~~	~~0.67~~	~~0.208~~
mr04b94	0.573	0.027	0.073	0.002	0.328	0.056	0.001	460	18	453	14	458	30	99	455	25	0.68	0.659
mr05a53	3.551	0.082	0.268	0.005	0.383	0.093	0.001	1539	18	1529	24	1490	16	103	1536	34	0.69	0.310
mr05a60	13.999	0.431	0.527	0.015	0.461	0.188	0.002	2750	29	2727	63	2729	16	100	2750	58	0.69	0.615
mr05a93	14.782	0.348	0.540	0.012	0.460	0.196	0.002	2801	22	2784	49	2791	16	100	2801	45	0.69	1.198
mr05a39	1.664	0.065	0.169	0.005	0.377	0.072	0.001	995	25	1006	28	981	32	103	1000	43	0.70	0.287
mr05a136	4.709	0.382	0.309	0.018	0.368	0.109	0.001	1769	68	1733	91	1777	17	98	1759	127	0.70	0.410
mr09a10	0.528	0.039	0.067	0.003	0.272	0.054	0.001	430	26	420	17	383	30	110	422	31	0.70	0.523
mr05a109	3.336	0.213	0.256	0.010	0.306	0.093	0.001	1490	50	1467	51	1480	21	99	1479	82	0.71	0.249
mr05a119	0.623	0.078	0.076	0.004	0.210	0.065	0.001	492	49	474	24	783	45	61	476	46	0.72	0.486
mr09a24	2.329	0.186	0.204	0.009	0.289	0.080	0.001	1221	57	1198	51	1204	36	100	1208	86	0.72	0.379
mr09a08	2.745	0.204	0.235	0.007	0.199	0.105	0.003	1341	55	1362	36	1714	53	79	1356	66	0.73	0.313
mr05a81	1.661	0.056	0.165	0.004	0.322	0.073	0.001	994	21	986	20	1010	25	98	990	33	0.74	0.318
mr05a67	0.607	0.049	0.076	0.003	0.207	0.056	0.001	482	31	471	15	452	46	104	472	29	0.74	0.600
mr05a146	0.530	0.033	0.070	0.002	0.265	0.055	0.001	432	22	439	14	418	42	105	437	26	0.74	0.369

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Berwick Fm.	Measured Isotopic Ratios 207Pb /235U	1s error	206Pb /238U	1s error	Rho	207Pb /206Pb	1s error	Calculated Ages 207Pb /235U	1s error	206Pb /238U	1s error	207Pb /206Pb	1s error	U-Pb/Pb-Pb con. %	Con. age	2s error	Prob. of con.	Ratio Th/U
mr04b62	0.748	0.052	0.090	0.005	0.377	0.057	0.001	567	30	556	28	478	39	116	561	48	0.75	0.609
mr05a59	4.154	0.097	0.293	0.005	0.380	0.098	0.001	1665	19	1657	26	1595	15	104	1663	36	0.76	0.999
mr05a133	0.518	0.094	0.065	0.006	0.263	0.055	0.001	424	63	405	37	417	45	97	408	71	0.76	0.551
mr05a73	4.582	0.185	0.308	0.010	0.395	0.106	0.001	1746	34	1732	49	1732	16	100	1743	64	0.77	0.735
mr05a118	0.519	0.058	0.066	0.003	0.233	0.059	0.001	425	39	414	21	568	30	73	416	40	0.79	0.807
mr05a128	2.332	0.177	0.211	0.008	0.243	0.088	0.002	1222	54	1236	42	1380	35	90	1231	73	0.81	1.003
mr04b59	0.523	0.027	0.069	0.002	0.300	0.056	0.001	427	18	432	13	452	42	95	430	23	0.82	1.233
mr09a15	0.604	0.116	0.074	0.006	0.214	0.063	0.001	480	73	463	37	709	44	65	465	70	0.82	0.713
mr05a113	0.562	0.042	0.072	0.003	0.267	0.057	0.001	453	27	446	17	494	29	90	448	32	0.82	0.586
mr09a14	4.593	0.223	0.314	0.009	0.287	0.107	0.002	1748	41	1758	43	1754	30	100	1753	67	0.84	0.610
mr05a127	1.146	0.200	0.124	0.015	0.357	0.068	0.001	775	94	756	89	873	23	87	764	151	0.85	0.184
mr05a134	4.178	0.371	0.299	0.017	0.315	0.101	0.001	1670	73	1685	83	1643	16	103	1676	125	0.86	0.198
mr09a39	0.489	0.024	0.064	0.002	0.258	0.054	0.001	404	16	402	10	359	25	112	402	18	0.86	0.989
mr05a145	3.569	0.158	0.269	0.007	0.314	0.099	0.001	1543	35	1536	38	1609	18	95	1540	59	0.87	0.239
mr05a49	3.058	0.093	0.246	0.004	0.246	0.090	0.002	1422	23	1418	19	1420	41	100	1420	33	0.87	0.612
mr05a23	1.594	0.174	0.164	0.008	0.222	0.071	0.001	968	68	978	44	965	37	101	976	81	0.88	1.396
mr09a11	0.498	0.094	0.067	0.005	0.210	0.054	0.001	411	64	419	32	373	39	112	418	62	0.89	1.280
mr05a130	0.540	0.034	0.071	0.003	0.323	0.056	0.001	438	23	439	17	470	26	93	439	31	0.96	0.207
mr05a110	0.652	0.048	0.082	0.003	0.230	0.059	0.001	510	29	511	17	575	41	89	510	31	0.98	0.778
mr05a80	1.643	0.059	0.166	0.004	0.307	0.071	0.001	987	23	988	20	964	27	102	987	34	0.98	0.359
mr09a29	1.849	0.247	0.180	0.011	0.238	0.075	0.003	1063	88	1065	62	1079	79	99	1065	112	0.98	12.698
mr04b96	0.861	0.035	0.103	0.003	0.301	0.060	0.001	631	19	631	15	588	43	107	631	26	0.99	0.435
mr05a105	1.289	0.163	0.139	0.008	0.229	0.067	0.001	841	72	840	46	838	40	100	840	84	0.99	0.472

APPENDIX B

Oakdale Fm.	Measured Isotopic Ratios 207Pb /235U	1s error	206Pb /238U	1s error	Rho	207Pb /206Pb	1s error	Calculated Ages 207Pb /235U	1s error	206Pb /238U	1s error	207Pb /206Pb	1s error	U-Pb/Pb-Pb con. %	Con. age	2s error	Prob. of Con.	Ratio Th/U
mr16b60	5.470	0.230	0.234	0.008	0.413	0.161	0.001	1896	36	1353	42	2465	15	55	1555	75	0.00	0.342
mr16b93	0.693	0.023	0.068	0.002	0.426	0.062	0.001	535	14	426	12	664	34	64	459	22	0.00	0.475
mr16b84	1.137	0.040	0.102	0.004	0.534	0.070	0.001	771	19	627	22	938	29	67	715	36	0.00	0.172
mr16c18	0.838	0.062	0.149	0.007	0.310	0.055	0.002	618	34	896	39	416	80	215	715	56	0.00	1.144
mr16a13	0.884	0.029	0.089	0.003	0.552	0.065	0.001	643	16	548	19	766	25	71	612	30	0.00	0.116
mr16b14	1.855	0.060	0.155	0.004	0.408	0.076	0.001	1065	21	931	23	1108	29	84	999	38	0.00	0.169
mr16b51	2.477	0.076	0.192	0.005	0.392	0.086	0.001	1265	22	1134	25	1332	18	85	1206	40	0.00	0.174
mr16b92	0.828	0.032	0.085	0.004	0.579	0.063	0.001	613	18	526	22	705	27	75	590	34	0.00	0.241
mr16b82	1.874	0.048	0.165	0.003	0.363	0.078	0.001	1072	17	984	17	1146	21	86	1025	29	0.00	1.093
mr12c31	4.342	0.488	0.203	0.016	0.344	0.150	0.002	1701	93	1190	84	2350	26	51	1285	160	0.00	0.236
mr16b69	3.406	0.161	0.224	0.008	0.388	0.100	0.001	1506	37	1305	43	1630	23	80	1416	69	0.00	0.505
mr16b44	4.882	0.120	0.297	0.006	0.407	0.107	0.001	1799	21	1675	30	1745	18	96	1768	40	0.00	0.675
mr16a10	0.676	0.022	0.074	0.002	0.410	0.059	0.001	524	13	463	12	571	30	81	486	21	0.00	0.195
mr16b73	3.319	0.087	0.237	0.005	0.429	0.094	0.001	1486	20	1373	28	1511	23	91	1455	40	0.00	0.594
mr16a22	0.687	0.036	0.071	0.003	0.429	0.063	0.001	531	21	440	19	713	32	62	471	34	0.00	0.124
mr16a32	0.505	0.018	0.075	0.002	0.301	0.047	0.001	415	12	467	10	71	34	655	448	17	0.00	0.166
mr16b62	1.028	0.050	0.099	0.003	0.309	0.076	0.001	718	25	609	18	1085	23	56	632	33	0.00	0.291
mr16b41	2.788	0.095	0.210	0.005	0.382	0.092	0.001	1352	25	1228	29	1458	16	84	1298	46	0.00	0.491
mr16a23	0.486	0.026	0.078	0.003	0.346	0.049	0.001	402	18	482	17	136	37	354	442	28	0.00	0.369
mr16a28	14.712	0.302	0.509	0.010	0.456	0.195	0.002	2797	20	2654	41	2785	14	95	2794	39	0.00	0.482
mr16a39	0.375	0.031	0.067	0.003	0.250	0.048	0.001	323	23	419	17	79	52	527	387	29	0.00	1.203
mr16b70	3.145	0.133	0.223	0.007	0.375	0.099	0.001	1444	33	1296	37	1605	24	81	1378	59	0.00	0.395
mr16b101	0.739	0.048	0.073	0.003	0.342	0.071	0.002	562	28	455	19	966	46	47	477	37	0.00	0.883
mr16b94	0.647	0.031	0.070	0.002	0.276	0.064	0.001	507	19	436	11	736	37	59	447	21	0.00	0.201
mr16a07	0.747	0.047	0.075	0.002	0.258	0.078	0.001	566	27	467	15	1146	35	41	479	28	0.00	0.764
mr12c17	1.264	0.070	0.117	0.005	0.369	0.073	0.001	830	31	713	28	1018	24	70	753	49	0.00	0.047
mr16b27	1.051	0.048	0.105	0.003	0.322	0.070	0.001	730	24	643	18	927	42	69	666	33	0.00	0.400
mr16b83	4.023	0.099	0.270	0.006	0.473	0.100	0.001	1639	20	1542	32	1617	15	95	1626	40	0.00	0.290
mr12c20	2.762	0.081	0.215	0.004	0.353	0.088	0.001	1345	22	1257	24	1385	20	91	1304	38	0.00	0.235

APPENDIX B

Oakdale	Measured Isotopic Ratios							Calculated Ages										Ratio
Oakdale Fm.	207Pb /235U	1s error	206Pb /238U	1s error	Rho	207Pb /206Pb	1s error	207Pb /235U	1s error	206Pb /238U	1s error	207Pb /206Pb	1s error	U-Pb/Pb-Pb con. %	Con. age	2s error	Prob. of Con.	Ratio Th/U
mr16c09	3.713	0.208	0.314	0.010	0.285	0.099	0.002	1574	45	1759	49	1611	39	109	1646	72	0.00	1.018
mr16b07	0.759	0.038	0.081	0.003	0.361	0.065	0.002	574	22	499	17	776	54	64	521	32	0.00	0.350
mr16b39	2.348	0.064	0.196	0.004	0.363	0.081	0.001	1227	20	1152	21	1232	21	94	1192	34	0.00	0.501
mr16b49	3.790	0.148	0.254	0.008	0.427	0.100	0.002	1591	31	1457	43	1625	33	90	1555	61	0.00	1.004
mr16c24	3.391	0.205	0.295	0.007	0.190	0.101	0.002	1502	47	1666	34	1649	38	101	1608	58	0.00	0.212
mr12c23	3.782	0.159	0.253	0.008	0.395	0.103	0.002	1589	34	1453	43	1673	34	87	1542	64	0.00	0.971
mr16b85	4.156	0.103	0.277	0.007	0.487	0.099	0.001	1665	20	1574	34	1607	15	98	1656	40	0.00	0.164
mr16b47	2.849	0.073	0.222	0.005	0.437	0.085	0.001	1369	19	1294	26	1320	20	98	1349	37	0.00	0.556
mr16a14	2.761	0.202	0.195	0.012	0.422	0.097	0.001	1345	55	1149	65	1569	19	73	1262	104	0.00	0.371
mr16b13	1.898	0.048	0.172	0.003	0.358	0.073	0.001	1080	17	1023	17	1020	21	100	1051	29	0.00	0.100
mr16b99	0.632	0.022	0.073	0.002	0.398	0.055	0.001	497	14	455	12	396	32	115	471	21	0.00	0.097
mr12c34	0.630	0.021	0.073	0.001	0.299	0.059	0.001	496	13	456	9	560	28	82	465	17	0.00	0.103
mr16b102	0.725	0.055	0.073	0.005	0.465	0.058	0.001	554	32	457	31	547	54	84	497	56	0.00	0.333
mr16b75	4.152	0.163	0.272	0.007	0.335	0.105	0.002	1665	32	1550	36	1709	28	91	1614	57	0.00	0.212
mr16b34	0.725	0.051	0.075	0.003	0.297	0.065	0.002	554	30	465	19	774	57	60	481	36	0.00	0.977
mr16b65	0.887	0.033	0.096	0.003	0.386	0.062	0.001	645	18	591	16	669	29	88	612	29	0.00	0.548
mr16b19	2.331	0.109	0.188	0.007	0.408	0.081	0.001	1222	33	1112	39	1227	33	91	1177	61	0.01	0.515
mr16b63	0.555	0.022	0.065	0.002	0.305	0.058	0.001	449	14	408	10	522	38	78	417	18	0.01	0.828
mr16b21	1.072	0.054	0.108	0.004	0.411	0.066	0.001	740	26	663	26	813	46	82	698	45	0.01	0.532
mr16b42	0.675	0.036	0.074	0.003	0.346	0.068	0.002	523	22	463	16	864	53	54	479	30	0.01	0.872
mr16b29	0.738	0.025	0.084	0.002	0.375	0.061	0.001	561	14	521	13	639	30	81	536	22	0.01	0.127
mr16b31	0.667	0.020	0.078	0.002	0.396	0.058	0.001	519	12	485	11	522	29	93	499	20	0.01	0.670
mr16a37	1.821	0.071	0.163	0.006	0.476	0.072	0.001	1053	26	976	34	991	21	98	1032	49	0.01	0.443
mr16b76	0.580	0.025	0.068	0.002	0.371	0.056	0.001	464	16	425	13	449	35	95	438	23	0.02	0.131
mr16b120	0.476	0.038	0.074	0.003	0.234	0.052	0.001	395	26	461	17	292	46	158	444	31	0.02	0.297
mr16b71	0.609	0.021	0.072	0.001	0.293	0.060	0.001	483	13	450	9	592	29	76	457	17	0.02	0.391
mr16b32	2.899	0.217	0.210	0.013	0.398	0.092	0.001	1382	57	1226	67	1475	15	83	1317	105	0.02	0.030
mr16b96	3.711	0.195	0.255	0.009	0.322	0.104	0.001	1574	42	1462	44	1695	18	86	1518	72	0.03	0.681
mr16b89	3.201	0.084	0.243	0.005	0.404	0.093	0.001	1457	20	1400	27	1484	17	94	1440	38	0.03	0.379

Oakdale Fm.	Measured Isotopic Ratios 207Pb /235U	1s error	206Pb /238U	1s error	Rho	207Pb /206Pb	1s error	Calculated Ages 207Pb /235U	1s error	206Pb /238U	1s error	207Pb /206Pb	1s error	U-Pb/Pb-Pb con. %	Con. age	2s error	Prob. of Con.	Ratio Th/U
mr12c11	0.630	0.033	0.073	0.002	0.282	0.061	0.001	496	20	452	13	630	38	72	460	24	0.03	0.347
mr12c12	0.454	0.036	0.070	0.002	0.187	0.056	0.001	380	25	434	12	456	50	95	425	24	0.04	0.417
mr12c10	2.125	0.076	0.186	0.005	0.362	0.079	0.001	1157	25	1098	26	1171	24	94	1129	43	0.04	0.366
mr16b80	0.542	0.017	0.067	0.002	0.419	0.054	0.001	440	11	416	11	382	28	109	427	18	0.04	0.464
mr16b08	2.026	0.112	0.175	0.007	0.370	0.082	0.001	1124	38	1038	39	1255	27	83	1081	65	0.05	0.254
mr16b09	14.489	0.427	0.514	0.015	0.498	0.190	0.002	2782	28	2674	64	2745	18	97	2786	56	0.05	0.385
mr16b59	0.804	0.036	0.090	0.003	0.362	0.061	0.001	599	20	557	17	631	25	88	572	31	0.05	0.507
mr12c14	0.614	0.026	0.073	0.002	0.310	0.057	0.001	486	16	454	11	491	39	92	462	21	0.06	0.303
mr16b22	0.668	0.068	0.070	0.005	0.333	0.063	0.002	519	41	439	29	720	60	61	456	54	0.06	0.511
mr16a18	0.614	0.036	0.072	0.003	0.335	0.060	0.001	486	23	445	17	587	28	76	456	31	0.08	0.732
mr16b121	0.487	0.041	0.073	0.002	0.184	0.056	0.001	403	28	452	13	468	33	96	444	26	0.08	0.072
mr16b40	0.738	0.037	0.084	0.003	0.382	0.060	0.002	561	21	523	19	616	55	85	538	34	0.09	0.788
mr16b58	2.612	0.182	0.206	0.007	0.244	0.093	0.001	1304	51	1209	37	1496	29	81	1235	68	0.09	0.286
mr16b72	0.582	0.019	0.072	0.001	0.307	0.057	0.001	466	12	446	8	488	25	91	451	16	0.10	0.415
~~mr12c40~~	0.703	0.080	0.074	0.003	0.161	0.068	0.003	541	48	461	16	877	79	53	465	32	0.11	0.279
mr16b81	0.669	0.025	0.080	0.002	0.329	0.058	0.001	520	15	495	12	536	28	92	503	22	0.13	0.373
mr16b91	0.771	0.055	0.086	0.004	0.344	0.064	0.001	581	31	531	25	757	29	70	546	45	0.13	0.149
mr16b112	0.449	0.053	0.069	0.003	0.186	0.056	0.001	376	37	432	19	439	50	98	423	35	0.14	0.320
mr16c08	0.539	0.079	0.084	0.005	0.214	0.055	0.001	438	52	517	31	418	55	124	499	58	0.14	0.525
mr16c21	2.599	0.131	0.211	0.009	0.402	0.088	0.001	1300	37	1234	45	1375	21	90	1277	68	0.15	0.421
mr16b66	0.848	0.036	0.096	0.002	0.274	0.065	0.001	624	20	594	13	779	31	76	601	25	0.15	0.851
mr16a12	0.544	0.029	0.076	0.003	0.357	0.056	0.001	441	19	470	17	457	31	103	457	29	0.16	0.280
mr16b37	2.156	0.092	0.190	0.006	0.364	0.082	0.001	1167	30	1122	32	1234	25	91	1146	51	0.19	0.641
mr16b116	0.607	0.032	0.073	0.003	0.375	0.057	0.001	482	20	454	17	474	34	96	464	31	0.20	0.586
mr16a27	4.519	0.095	0.302	0.006	0.444	0.104	0.001	1734	17	1702	28	1694	15	100	1730	34	0.21	0.665
mr12c07	4.454	0.146	0.315	0.006	0.312	0.098	0.001	1722	27	1766	32	1592	22	111	1739	47	0.21	0.086
mr12c38	0.482	0.037	0.069	0.002	0.218	0.054	0.001	399	25	430	14	366	56	118	425	26	0.22	0.735
mr16b111	0.541	0.033	0.075	0.002	0.200	0.059	0.001	439	22	465	11	578	34	80	461	21	0.26	0.123
mr16b100	0.577	0.031	0.071	0.002	0.284	0.059	0.001	463	20	440	13	560	39	79	445	24	0.26	0.222

APPENDIX B

Oakdale Fm.	Measured Isotopic Ratios 207Pb /235U	1s error	206Pb /238U	1s error	Rho	207Pb /206Pb	1s error	Calculated Ages 207Pb /235U	1s error	206Pb /238U	1s error	207Pb /206Pb	1s error	U-Pb/Pb-Pb con. %	Con. age	2s error	Prob. of Con.	Ratio Th/U
mr16b10	0.836	0.057	0.094	0.003	0.251	0.066	0.001	617	31	581	19	791	47	73	587	36	0.27	0.197
mr16a40	0.593	0.031	0.073	0.002	0.248	0.065	0.001	473	20	453	11	787	32	58	456	21	0.32	0.481
mr12c13	1.921	0.069	0.179	0.004	0.326	0.076	0.001	1089	24	1062	23	1083	21	98	1074	38	0.33	0.471
mr16c19	3.043	0.225	0.259	0.011	0.279	0.095	0.002	1418	56	1483	55	1532	43	97	1451	87	0.33	0.767
mr16a30	0.540	0.052	0.076	0.002	0.140	0.061	0.002	438	34	471	12	657	52	72	469	24	0.34	0.261
mr16b79	0.550	0.021	0.069	0.002	0.378	0.055	0.001	445	14	432	12	432	36	100	437	21	0.35	0.233
mr16b17	0.619	0.027	0.076	0.002	0.237	0.055	0.001	489	17	473	9	415	41	114	475	18	0.35	0.153
mr16b30	2.142	0.095	0.192	0.005	0.266	0.077	0.001	1162	31	1132	24	1129	27	100	1142	43	0.38	0.497
mr12c44	0.543	0.048	0.066	0.002	0.198	0.065	0.002	441	31	413	14	765	50	54	416	27	0.39	0.429
mr16c12	0.494	0.049	0.070	0.003	0.198	0.059	0.001	408	33	436	17	576	47	76	432	32	0.41	0.496
mr16b53	0.566	0.027	0.071	0.002	0.306	0.056	0.001	455	18	440	13	467	39	94	444	23	0.42	0.391
mr16c23	0.786	0.049	0.100	0.004	0.332	0.056	0.001	589	28	613	24	463	35	132	603	42	0.42	0.029
mr16b115	0.522	0.041	0.072	0.003	0.234	0.054	0.001	427	27	448	16	356	37	126	444	30	0.44	0.161
mr16b50	4.809	0.233	0.311	0.012	0.411	0.112	0.002	1787	41	1745	61	1826	39	96	1778	79	0.47	1.233
mr16b95	0.553	0.020	0.073	0.002	0.326	0.052	0.001	447	13	457	11	305	36	150	453	19	0.49	0.204
mr16a19	0.621	0.024	0.081	0.002	0.329	0.053	0.001	491	15	501	12	344	26	146	498	21	0.50	0.107
mr16b48	6.118	0.223	0.355	0.011	0.431	0.116	0.002	1993	32	1960	53	1903	27	103	1989	63	0.50	0.753
mr12c18	0.678	0.037	0.082	0.003	0.304	0.055	0.001	526	22	510	16	429	44	119	515	30	0.51	0.516
mr16b23	0.515	0.031	0.065	0.003	0.354	0.055	0.001	422	21	409	17	392	49	104	413	30	0.54	0.312
mr16c10	4.054	0.262	0.283	0.012	0.337	0.106	0.001	1645	53	1605	62	1723	25	93	1629	93	0.54	0.731
mr12c41	5.033	0.235	0.334	0.011	0.350	0.108	0.002	1825	40	1857	53	1772	40	105	1834	72	0.55	1.235
mr16b38	0.577	0.029	0.076	0.002	0.229	0.058	0.001	463	18	473	10	543	41	87	471	20	0.58	0.415
mr16b123	0.954	0.293	0.097	0.017	0.282	0.092	0.001	680	152	594	98	1459	26	41	611	186	0.59	0.350
mr16b122	2.221	0.133	0.198	0.007	0.285	0.085	0.001	1188	42	1162	36	1311	24	89	1172	62	0.59	0.228
mr16b24	0.553	0.024	0.070	0.002	0.303	0.054	0.001	447	16	438	11	390	36	112	441	21	0.60	0.094
mr16b124	2.237	0.194	0.197	0.010	0.292	0.082	0.001	1193	61	1158	54	1257	28	92	1172	92	0.62	0.646
mr12c27	0.565	0.032	0.071	0.002	0.278	0.060	0.001	455	21	445	13	619	45	72	447	25	0.64	0.662
mr12c19	0.587	0.050	0.073	0.004	0.287	0.062	0.002	469	32	454	21	667	61	68	458	40	0.66	1.336
mr16b125	0.522	0.041	0.070	0.003	0.282	0.054	0.001	427	27	439	19	370	36	118	435	34	0.67	0.241

APPENDIX B

Oakdale Fm.	Measured Isotopic Ratios 207Pb /235U	1s error	206Pb /238U	1s error	Rho	207Pb /206Pb	1s error	Calculated Ages 207Pb /235U	1s error	206Pb /238U	1s error	207Pb /206Pb	1s error	U-Pb/Pb-Pb con. %	Con. age	2s error	Prob. of Con.	Ratio Th/U
mr16b33	1.122	0.094	0.122	0.005	0.243	0.067	0.001	764	45	745	29	834	40	89	749	53	0.68	0.570
mr16c25	3.088	0.177	0.252	0.009	0.304	0.097	0.002	1430	44	1451	45	1560	35	93	1439	72	0.69	0.588
mr16b90	1.451	0.069	0.154	0.004	0.260	0.068	0.001	910	29	922	21	878	37	105	919	38	0.70	0.203
mr16b109	2.256	0.195	0.200	0.010	0.303	0.090	0.001	1199	61	1174	56	1425	29	82	1185	95	0.72	0.192
mr16a08	4.932	0.197	0.320	0.010	0.387	0.109	0.001	1808	34	1791	48	1778	14	101	1804	64	0.72	0.296
mr16b55	0.516	0.023	0.067	0.002	0.308	0.051	0.001	422	15	417	11	255	42	163	418	20	0.73	0.831
mr16b103	0.595	0.028	0.075	0.002	0.331	0.055	0.001	474	18	468	14	393	40	119	470	25	0.73	0.851
mr16b74	0.816	0.046	0.100	0.003	0.220	0.063	0.001	606	26	614	15	703	41	87	613	28	0.75	1.100
mr12c21	2.306	0.137	0.210	0.006	0.255	0.079	0.001	1214	42	1229	34	1177	30	104	1224	59	0.75	0.337
mr12c08	1.377	0.066	0.144	0.005	0.340	0.065	0.001	879	28	869	27	790	38	110	874	45	0.76	0.306
mr16a11	0.601	0.056	0.079	0.002	0.140	0.066	0.002	478	35	488	12	805	52	61	487	24	0.78	0.307
mr16b119	0.473	0.020	0.062	0.003	0.489	0.047	0.001	393	14	389	16	61	43	637	392	25	0.78	0.530
mr16c20	1.396	0.116	0.150	0.007	0.287	0.075	0.002	887	49	899	40	1078	43	83	895	70	0.83	0.592
mr16b64	0.597	0.063	0.075	0.003	0.191	0.068	0.002	476	40	467	18	881	46	53	468	35	0.83	0.159
mr12c37	0.546	0.019	0.071	0.002	0.306	0.054	0.001	442	13	440	9	381	34	115	440	17	0.85	0.715
mr12c28	6.756	0.300	0.383	0.011	0.337	0.125	0.002	2080	39	2090	53	2022	30	103	2083	72	0.85	0.996
mr16b110	4.116	0.194	0.291	0.008	0.305	0.110	0.002	1657	38	1649	42	1794	31	92	1654	65	0.86	0.719
mr12c43	0.583	0.052	0.074	0.003	0.235	0.061	0.001	467	34	461	19	622	50	74	462	36	0.86	0.487
mr16a38	0.715	0.034	0.088	0.003	0.360	0.054	0.001	548	20	544	18	375	37	145	546	31	0.86	0.482
mr16a21	4.600	0.137	0.311	0.006	0.344	0.106	0.001	1749	25	1744	31	1734	15	101	1747	45	0.87	0.338
mr16b12	0.594	0.053	0.075	0.003	0.225	0.057	0.001	474	34	468	18	474	50	99	469	35	0.87	0.601
mr16a34	2.197	0.171	0.203	0.006	0.175	0.081	0.002	1180	54	1189	30	1222	44	97	1187	55	0.87	0.372
mr16b54	0.897	0.040	0.106	0.003	0.277	0.062	0.001	650	21	647	15	661	33	98	648	27	0.88	0.253
mr16b28	0.728	0.047	0.089	0.003	0.267	0.062	0.001	555	28	551	18	686	44	80	552	34	0.89	0.479
mr16c17	0.537	0.151	0.072	0.009	0.226	0.058	0.001	436	100	450	55	533	53	84	448	104	0.89	0.581
mr12c29	0.857	0.054	0.102	0.003	0.228	0.058	0.001	629	30	624	17	513	44	122	625	32	0.89	0.815
mr16a31	0.523	0.028	0.068	0.002	0.209	0.058	0.001	427	18	425	9	546	26	78	425	17	0.90	0.440
mr16c14	3.619	0.325	0.275	0.011	0.228	0.112	0.002	1554	71	1564	57	1835	33	85	1560	98	0.90	0.507
mr12c32	0.524	0.047	0.068	0.004	0.293	0.053	0.001	428	31	424	21	349	44	121	425	40	0.90	0.326

Oakdale Fm.	Measured Isotopic Ratios 207Pb /235U	1s error	206Pb /238U	1s error	Rho	207Pb /206Pb	1s error	Calculated Ages 207Pb /235U	1s error	206Pb /238U	1s error	207Pb /206Pb	1s error	U-Pb/Pb-Pb con. %	Con. age	2s error	Prob. of Con.	Ratio Th/U
mr16b11	1.655	0.076	0.166	0.004	0.292	0.072	0.001	992	29	988	24	997	28	99	989	42	0.90	0.738
mr16c07	4.049	0.147	0.291	0.009	0.426	0.100	0.001	1644	30	1649	45	1619	26	102	1645	57	0.91	0.302
mr12c39	0.577	0.020	0.074	0.002	0.314	0.056	0.001	463	13	461	10	455	31	101	462	18	0.91	0.056
mr16a17	0.617	0.112	0.077	0.003	0.118	0.056	0.001	488	71	480	20	469	42	102	481	39	0.91	0.316
mr12c42	0.590	0.037	0.075	0.002	0.218	0.065	0.002	471	24	468	12	779	51	60	469	24	0.91	0.130
mr16b113	0.898	0.036	0.106	0.003	0.368	0.063	0.001	651	19	649	18	698	21	93	650	31	0.92	0.242
mr16b61	0.584	0.030	0.075	0.002	0.297	0.057	0.001	467	19	465	14	482	37	97	466	25	0.92	0.220
mr16b43	4.735	0.130	0.316	0.008	0.482	0.100	0.001	1773	23	1770	41	1625	18	109	1773	46	0.93	0.349
mr16b18	0.727	0.040	0.090	0.002	0.190	0.059	0.001	555	23	553	11	584	34	95	553	21	0.93	0.769
mr12c24	3.964	0.169	0.286	0.008	0.315	0.102	0.002	1627	35	1623	39	1655	28	98	1625	59	0.93	0.728
mr16b86	0.558	0.026	0.072	0.002	0.254	0.056	0.001	450	17	449	10	472	34	95	449	19	0.94	0.196
mr12c33	1.722	0.079	0.171	0.004	0.271	0.074	0.001	1017	29	1019	23	1031	32	99	1018	41	0.94	0.903
mr16b114	0.645	0.097	0.081	0.006	0.226	0.065	0.001	505	60	501	33	777	34	64	502	63	0.95	0.023
mr16b52	0.901	0.029	0.107	0.002	0.355	0.058	0.001	652	15	653	14	542	33	121	653	24	0.95	0.004
mr16a20	0.656	0.027	0.082	0.002	0.354	0.058	0.001	512	17	511	15	532	38	96	511	26	0.95	0.761
mr16a29	0.585	0.062	0.075	0.004	0.266	0.061	0.001	468	40	465	25	626	32	74	466	47	0.95	0.162
mr12c30	0.563	0.030	0.073	0.002	0.273	0.054	0.001	454	19	455	13	384	35	119	455	23	0.95	0.174
mr16a33	0.522	0.033	0.068	0.002	0.237	0.058	0.001	426	22	427	12	536	27	80	427	23	0.97	1.322
mr16b20	0.959	0.047	0.112	0.004	0.390	0.058	0.001	683	24	682	24	530	56	129	683	41	0.97	0.576
mr16c13	2.720	0.139	0.230	0.008	0.354	0.086	0.001	1334	38	1336	44	1344	27	99	1335	66	0.97	0.981
mr16c11	4.740	0.173	0.317	0.010	0.419	0.105	0.001	1774	31	1773	47	1710	19	104	1774	59	0.98	0.694
mr16a24	0.536	0.018	0.070	0.001	0.290	0.055	0.001	436	12	436	8	392	24	111	436	16	0.99	0.708
mr12c09	2.273	0.099	0.205	0.005	0.287	0.083	0.001	1204	31	1204	27	1274	27	95	1204	46	0.99	0.636
mr16c22	4.261	0.254	0.299	0.011	0.296	0.110	0.001	1686	49	1687	52	1791	24	94	1686	81	0.99	0.553
mr16a09	3.211	0.063	0.254	0.004	0.409	0.089	0.001	1460	15	1460	21	1394	14	105	1460	29	1.00	0.499

APPENDIX B

Tower Hill Fm.	Measured Isotopic Ratios 207Pb /235U	1s error	206Pb /238U	1s error	Rho	207Pb /206Pb	1s error	Calculated Ages 207Pb /235U	1s error	206Pb /238U	1s error	207Pb /206Pb	1s error	U-Pb/Pb-Pb Conc. %	Conc. Age	2s error	Prob. of conc.	Ratio Th/U
mr12a23	4.374	0.127	0.240	0.007	0.479	0.120	0.002	1707	24	1384	35	1950	24	71	1622	49	0.00	0.942
mr11c85	9.976	0.246	0.379	0.009	0.501	0.174	0.001	2433	23	2071	44	2600	11	80	2418	46	0.00	0.478
mr12b62	11.487	0.250	0.420	0.009	0.487	0.155	0.001	2564	20	2259	40	2402	12	94	2554	41	0.00	0.012
mr11c24	5.020	0.119	0.282	0.005	0.397	0.122	0.001	1823	20	1599	27	1986	12	81	1747	39	0.00	0.172
mr12b31	2.091	0.064	0.161	0.005	0.469	0.074	0.001	1146	21	964	26	1041	22	93	1076	41	0.00	0.106
mr12b12	1.661	0.062	0.136	0.004	0.364	0.071	0.001	994	24	822	21	945	31	87	879	38	0.00	0.522
mr11c28	3.518	0.182	0.216	0.009	0.405	0.112	0.001	1531	41	1258	48	1825	13	69	1402	78	0.00	0.270
mr12a60	8.156	0.282	0.366	0.010	0.388	0.128	0.001	2248	31	2009	46	2077	15	97	2187	62	0.00	0.140
mr12b57	7.533	0.285	0.352	0.009	0.353	0.128	0.001	2177	34	1946	45	2065	16	94	2095	65	0.00	0.209
mr11b31	6.113	0.119	0.336	0.006	0.454	0.125	0.001	1992	17	1867	29	2031	12	92	1978	34	0.00	0.277
mr11c07	3.960	0.096	0.262	0.005	0.414	0.100	0.001	1626	20	1500	27	1626	12	92	1591	38	0.00	0.197
mr12a22	6.006	0.269	0.303	0.013	0.488	0.130	0.001	1977	39	1708	66	2097	12	81	1945	79	0.00	0.193
mr11c17	3.997	0.092	0.264	0.006	0.464	0.099	0.001	1634	19	1512	29	1603	17	94	1613	37	0.00	0.588
mr11c19	0.881	0.028	0.092	0.003	0.509	0.062	0.001	641	15	565	17	674	22	84	612	28	0.00	0.356
mr12a41	6.773	0.161	0.350	0.008	0.454	0.130	0.001	2082	21	1935	36	2097	12	92	2066	42	0.00	0.292
mr12b43	4.554	0.146	0.280	0.006	0.352	0.093	0.001	1741	27	1591	32	1484	18	107	1679	49	0.00	0.082
mr12b29	5.953	0.253	0.315	0.008	0.314	0.114	0.001	1969	37	1765	41	1865	19	95	1869	66	0.00	0.559
mr11c20	6.326	0.136	0.343	0.006	0.428	0.124	0.001	2022	19	1902	30	2020	8	94	2003	37	0.00	0.265
mr11c78	0.995	0.023	0.105	0.002	0.418	0.062	0.000	701	12	646	12	682	17	95	673	20	0.00	0.574
mr12b46	2.158	0.098	0.171	0.005	0.332	0.074	0.001	1168	31	1020	28	1043	25	98	1073	50	0.00	0.723
mr11b27	1.211	0.099	0.099	0.007	0.418	0.080	0.002	806	45	608	40	1190	38	51	664	74	0.00	1.139
mr11c84	10.003	0.391	0.414	0.010	0.321	0.165	0.001	2435	36	2233	47	2509	12	89	2362	68	0.00	0.476
mr11c12	6.687	0.202	0.346	0.009	0.454	0.131	0.001	2071	27	1914	45	2109	19	91	2053	54	0.00	0.528
mr12a29	5.089	0.268	0.284	0.011	0.382	0.114	0.001	1834	45	1613	57	1868	19	86	1753	86	0.00	0.267
mr11c21	1.158	0.066	0.107	0.003	0.247	0.073	0.001	781	31	654	18	1015	38	64	672	34	0.00	0.836
mr12b49	4.005	0.224	0.249	0.008	0.277	0.110	0.002	1635	45	1435	40	1807	28	79	1502	70	0.00	0.416
mr11c75	6.636	0.284	0.336	0.011	0.400	0.135	0.001	2064	38	1868	55	2166	15	86	2015	74	0.00	0.284
mr12a06	6.548	0.171	0.347	0.008	0.463	0.128	0.001	2052	23	1921	40	2076	9	93	2040	46	0.00	0.173
mr11b18	2.430	0.046	0.203	0.003	0.441	0.081	0.000	1251	14	1189	18	1213	12	98	1234	26	0.00	0.277

APPENDIX B

Tower Hill Fm.	Measured Isotopic Ratios 207Pb /235U	1s error	206Pb /238U	1s error	Rho	207Pb /206Pb	1s error	Calculated Ages 207Pb /235U	1s error	206Pb /238U	1s error	207Pb /206Pb	1s error	U-Pb/Pb-Pb Conc. %	Conc. Age	2s error	Prob. of conc.	Ratio Th/U
mr12a39	11.176	0.233	0.455	0.009	0.448	0.162	0.002	2538	19	2418	38	2482	17	97	2532	39	0.00	0.441
mr11c32	5.325	0.183	0.309	0.008	0.354	0.123	0.001	1873	29	1738	37	2000	15	87	1824	55	0.00	0.357
mr12a24	7.211	0.165	0.370	0.007	0.416	0.131	0.001	2138	20	2031	33	2112	12	96	2121	40	0.00	0.121
mr12a25	7.379	0.158	0.376	0.007	0.428	0.131	0.001	2158	19	2057	32	2114	11	97	2145	38	0.00	0.229
mr11b22	1.243	0.038	0.147	0.003	0.319	0.061	0.001	820	17	887	16	637	31	139	855	27	0.00	0.303
mr11b47	0.715	0.033	0.101	0.002	0.261	0.052	0.001	548	20	619	14	285	39	217	596	25	0.00	0.525
mr12b50	2.760	0.154	0.200	0.009	0.387	0.087	0.001	1345	41	1175	46	1358	28	87	1264	75	0.00	0.209
mr11b30	3.685	0.145	0.249	0.008	0.408	0.096	0.001	1568	31	1432	41	1539	29	93	1525	60	0.00	0.400
mr11c11	5.416	0.121	0.321	0.006	0.426	0.114	0.001	1887	19	1795	30	1871	15	96	1871	38	0.00	0.747
mr12a28	0.998	0.040	0.103	0.003	0.304	0.066	0.001	703	20	631	15	808	29	78	649	27	0.00	0.357
mr11c14	0.877	0.022	0.097	0.002	0.407	0.061	0.000	639	12	596	12	635	17	94	616	20	0.00	0.177
mr12b10	2.315	0.143	0.177	0.007	0.298	0.079	0.001	1217	44	1053	36	1172	21	90	1101	65	0.00	0.340
mr12b56	0.944	0.040	0.098	0.002	0.273	0.061	0.001	675	21	603	13	652	30	92	617	25	0.00	0.978
mr12b20	1.236	0.139	0.097	0.006	0.270	0.080	0.002	817	63	597	35	1189	55	50	618	68	0.00	0.815
mr11c70	1.798	0.075	0.158	0.006	0.425	0.075	0.001	1045	27	945	31	1057	27	89	1003	50	0.00	0.632
mr12b23	3.993	0.267	0.246	0.013	0.382	0.094	0.001	1633	54	1420	65	1510	18	94	1542	102	0.00	0.625
mr11c61	6.516	0.113	0.356	0.007	0.535	0.123	0.001	2048	15	1965	32	2000	13	98	2051	30	0.00	0.219
mr11b48	0.990	0.034	0.105	0.002	0.303	0.063	0.001	698	17	643	13	696	29	92	658	23	0.00	0.395
mr12b27	2.188	0.172	0.166	0.009	0.335	0.080	0.001	1177	55	989	48	1186	30	83	1051	87	0.00	1.324
mr11c82	1.617	0.037	0.155	0.003	0.388	0.071	0.001	977	15	927	15	967	17	96	954	25	0.00	0.322
mr12a31	3.524	0.086	0.254	0.005	0.380	0.096	0.001	1533	19	1459	24	1540	18	95	1507	36	0.00	0.452
mr11b23	2.646	0.109	0.207	0.004	0.237	0.089	0.001	1313	30	1214	22	1401	27	87	1239	39	0.00	0.329
mr11b21	1.820	0.085	0.160	0.005	0.353	0.077	0.001	1053	30	956	29	1128	28	85	997	50	0.00	0.100
mr11c41	5.731	0.116	0.335	0.006	0.425	0.125	0.001	1936	18	1864	28	2024	11	92	1925	34	0.00	0.353
mr12b11	1.660	0.325	0.095	0.008	0.210	0.126	0.004	993	124	586	46	2045	53	29	591	92	0.01	1.607
mr11b24	7.123	0.233	0.365	0.010	0.416	0.135	0.001	2127	29	2007	47	2166	16	93	2107	58	0.01	0.384
mr11b32	1.794	0.069	0.162	0.004	0.334	0.076	0.001	1043	25	967	23	1098	27	88	998	40	0.01	0.318
mr12b39	1.090	0.061	0.108	0.003	0.272	0.063	0.001	748	29	664	19	699	27	95	681	36	0.01	0.073
mr12a18	2.668	0.250	0.187	0.013	0.372	0.099	0.001	1320	69	1103	71	1602	18	69	1195	121	0.01	0.362

Tower	Measured Isotopic Ratios							Calculated Ages										
Hill Fm.	207Pb /235U	1s error	206Pb /238U	1s error	Rho	207Pb /206Pb	1s error	207Pb /235U	1s error	206Pb /238U	1s error	207Pb /206Pb	1s error	U-Pb/Pb-Pb Conc. %	Conc. Age	2s error	Prob. of conc.	Ratio Th/U
mr12a56	0.449	0.032	0.050	0.002	0.266	0.057	0.001	376	23	315	12	499	33	63	322	23	0.01	0.092
mr12b37	1.341	0.091	0.124	0.005	0.293	0.068	0.001	864	40	751	28	862	25	87	777	53	0.01	0.616
mr12a65	1.251	0.077	0.120	0.004	0.250	0.068	0.001	824	35	730	21	879	28	83	747	41	0.01	0.194
mr12b42	0.955	0.061	0.097	0.004	0.294	0.062	0.001	681	32	596	21	668	43	89	614	40	0.01	0.855
mr11c44	14.156	0.328	0.507	0.013	0.538	0.195	0.001	2760	22	2645	54	2783	8	95	2768	43	0.01	0.245
mr12a63	1.016	0.065	0.102	0.003	0.258	0.068	0.005	712	33	625	20	868	159	72	640	38	0.01	0.702
mr12b52	1.561	0.087	0.143	0.004	0.236	0.071	0.001	955	34	863	21	957	29	90	880	40	0.01	1.423
mr11c49	2.944	0.265	0.203	0.016	0.427	0.096	0.001	1393	68	1189	84	1548	21	77	1312	131	0.01	0.349
mr12b13	1.078	0.066	0.108	0.003	0.214	0.063	0.001	743	32	659	16	718	36	92	670	32	0.01	0.845
mr11c62	1.834	0.056	0.168	0.004	0.372	0.076	0.001	1058	20	1001	21	1096	23	91	1030	34	0.01	0.392
mr12a33	2.181	0.058	0.190	0.004	0.431	0.079	0.001	1175	19	1120	24	1170	21	96	1158	35	0.02	0.381
mr12b47	6.451	0.244	0.352	0.007	0.260	0.117	0.002	2039	33	1942	33	1916	23	101	1987	54	0.02	0.355
mr12b19	1.457	0.121	0.130	0.005	0.248	0.068	0.001	913	50	785	30	865	35	91	806	58	0.02	0.545
mr11c08	1.285	0.107	0.118	0.007	0.371	0.072	0.002	839	48	717	42	996	61	72	759	76	0.02	0.729
mr11b51	2.530	0.095	0.206	0.005	0.337	0.084	0.001	1281	27	1206	28	1285	25	94	1242	46	0.02	0.322
mr11b52	3.764	0.090	0.268	0.005	0.359	0.094	0.001	1585	19	1529	23	1514	15	101	1565	35	0.02	0.289
mr12a66	1.396	0.101	0.129	0.006	0.306	0.065	0.001	887	43	782	33	775	27	101	810	60	0.02	0.356
mr12a59	0.841	0.059	0.088	0.003	0.263	0.061	0.001	620	33	542	19	654	37	83	555	37	0.02	0.473
mr11c69	1.565	0.117	0.139	0.006	0.306	0.080	0.001	956	46	842	36	1200	19	70	874	66	0.02	0.131
mr12a19	2.366	0.097	0.196	0.007	0.458	0.082	0.001	1232	29	1153	39	1242	24	93	1212	56	0.03	0.399
mr11b46	0.747	0.020	0.087	0.002	0.360	0.057	0.000	567	12	540	10	496	18	109	550	18	0.03	0.588
mr11c71	1.200	0.039	0.125	0.003	0.369	0.065	0.001	801	18	758	17	785	25	97	777	29	0.03	0.860
mr11b38	1.845	0.094	0.163	0.008	0.452	0.074	0.001	1062	34	976	42	1036	20	94	1033	64	0.03	0.124
mr11b13	4.356	0.146	0.287	0.008	0.393	0.104	0.002	1704	28	1625	38	1703	30	95	1682	53	0.03	0.933
mr11c79	0.849	0.036	0.094	0.002	0.232	0.067	0.001	624	20	581	11	846	36	69	588	21	0.03	0.516
mr11c81	0.753	0.052	0.081	0.004	0.356	0.065	0.002	570	30	503	24	778	49	65	523	43	0.03	1.089
mr11c22	2.462	0.073	0.205	0.006	0.501	0.082	0.001	1261	21	1201	32	1234	16	97	1252	42	0.03	0.632
mr11b33	1.168	0.036	0.123	0.002	0.304	0.068	0.001	786	17	747	13	875	25	85	760	24	0.04	0.351
mr11b45	0.981	0.048	0.104	0.003	0.342	0.064	0.001	694	25	639	20	748	32	85	658	36	0.04	0.208

APPENDIX B

Tower Hill Fm.	Measured Isotopic Ratios 207Pb /235U	1s error	206Pb /238U	1s error	Rho	207Pb /206Pb	1s error	Calculated Ages 207Pb /235U	1s error	206Pb /238U	1s error	207Pb /206Pb	1s error	U-Pb/Pb-Pb Conc. %	Conc. Age	2s error	Prob. of conc.	Ratio Th/U
mr11b34	0.698	0.041	0.096	0.003	0.282	0.054	0.001	537	24	591	19	383	49	154	573	33	0.04	0.594
mr11b55	1.335	0.060	0.133	0.003	0.227	0.068	0.001	861	26	806	15	880	33	92	816	29	0.05	0.391
mr11b08	1.573	0.057	0.152	0.004	0.358	0.073	0.001	960	22	911	22	1017	28	89	933	37	0.05	0.953
mr11c18	1.386	0.055	0.138	0.004	0.331	0.069	0.001	883	23	834	20	886	29	94	853	36	0.05	0.226
mr12a20	1.931	0.097	0.171	0.005	0.293	0.073	0.001	1092	34	1020	28	1020	33	100	1044	49	0.05	1.032
mr11c29	1.546	0.084	0.173	0.007	0.367	0.057	0.001	949	33	1026	38	477	47	215	978	57	0.05	0.332
mr12b59	0.958	0.044	0.104	0.002	0.207	0.066	0.001	682	23	636	12	793	39	80	642	22	0.06	0.639
mr11c31	0.943	0.045	0.102	0.003	0.280	0.065	0.001	674	23	627	16	782	36	80	638	30	0.06	0.616
mr12a53	0.886	0.071	0.092	0.004	0.271	0.062	0.001	644	38	568	24	666	40	85	582	45	0.06	0.169
mr11b44	2.256	0.082	0.193	0.006	0.399	0.078	0.001	1199	26	1140	30	1141	32	100	1176	47	0.06	0.615
mr11c59	0.940	0.033	0.104	0.003	0.342	0.062	0.001	673	17	638	15	670	28	95	650	26	0.06	0.384
mr11c65	0.914	0.037	0.101	0.002	0.270	0.064	0.001	659	19	621	13	733	38	85	629	24	0.06	0.424
mr12b17	1.358	0.103	0.129	0.005	0.237	0.068	0.001	871	45	783	27	881	31	89	798	50	0.06	0.716
mr12a35	3.823	0.242	0.259	0.012	0.372	0.102	0.002	1598	51	1484	63	1652	32	90	1555	94	0.08	1.241
mr12a64	0.999	0.089	0.101	0.004	0.250	0.066	0.001	704	45	620	26	793	31	78	634	50	0.08	0.259
mr12a67	0.783	0.104	0.112	0.004	0.118	0.062	0.002	587	59	687	21	689	59	100	678	40	0.09	0.164
mr12a54	1.029	0.087	0.104	0.004	0.249	0.066	0.001	718	43	641	26	793	28	81	654	49	0.09	0.381
mr11b19	0.932	0.038	0.103	0.003	0.317	0.061	0.001	669	20	633	16	639	26	99	644	28	0.10	1.137
mr12b61	0.901	0.080	0.094	0.004	0.229	0.065	0.001	652	43	580	23	781	45	74	590	44	0.11	0.825
mr12b09	2.683	0.132	0.215	0.006	0.278	0.085	0.001	1324	36	1257	31	1325	32	95	1282	54	0.11	0.246
mr12b16	0.797	0.095	0.082	0.005	0.235	0.065	0.001	595	53	506	27	782	45	65	516	53	0.11	0.650
mr11b17	0.845	0.032	0.096	0.002	0.289	0.062	0.001	622	17	593	12	680	25	87	601	23	0.12	0.946
mr11b09	1.317	0.058	0.149	0.004	0.320	0.061	0.001	853	25	897	24	650	29	138	877	39	0.12	0.366
mr11c09	1.851	0.097	0.169	0.005	0.274	0.078	0.002	1064	35	1005	27	1135	39	89	1023	48	0.12	0.548
mr11c83	0.715	0.023	0.085	0.002	0.306	0.057	0.001	547	14	526	10	509	24	103	532	18	0.13	0.484
mr12b32	1.672	0.177	0.148	0.009	0.280	0.075	0.001	998	67	888	49	1080	38	82	916	91	0.13	0.382
mr11b28	0.869	0.027	0.100	0.002	0.292	0.059	0.001	635	15	612	11	555	27	110	618	19	0.13	0.555
mr11c45	0.902	0.049	0.114	0.004	0.291	0.059	0.001	653	26	694	21	576	42	121	679	37	0.14	0.729
mr12a38	0.966	0.033	0.108	0.002	0.266	0.060	0.001	686	17	660	11	612	30	108	667	21	0.14	0.525

APPENDIX B

	Measured Isotopic Ratios							Calculated Ages										
Tower Hill Fm.	207Pb /235U	1s error	206Pb /238U	1s error	Rho	207Pb /206Pb	1s error	207Pb /235U	1s error	206Pb /238U	1s error	207Pb /206Pb	1s error	U-Pb/Pb-Pb Conc. %	Conc. Age	2s error	Prob. of conc.	Ratio Th/U
mr12b30	0.835	0.074	0.090	0.003	0.212	0.063	0.001	617	41	555	20	707	33	78	562	39	0.15	0.266
mr12b51	1.977	0.515	0.136	0.022	0.317	0.096	0.001	1108	176	823	128	1551	24	53	871	245	0.15	0.145
mr12b40	8.309	0.612	0.394	0.017	0.294	0.131	0.002	2265	67	2143	79	2116	26	101	2214	119	0.16	0.486
mr11c58	4.776	0.126	0.327	0.007	0.393	0.107	0.001	1781	22	1825	33	1742	12	105	1789	42	0.16	0.195
mr11b12	1.836	0.065	0.172	0.004	0.321	0.075	0.001	1059	23	1022	22	1065	29	96	1038	37	0.17	0.365
mr12b08	0.832	0.057	0.092	0.003	0.209	0.058	0.001	614	32	570	16	537	54	106	575	30	0.17	1.365
mr12b60	0.943	0.096	0.098	0.004	0.181	0.068	0.002	674	50	604	21	857	50	70	610	42	0.18	0.819
mr11b41	0.971	0.036	0.108	0.003	0.345	0.063	0.001	689	18	663	16	697	20	95	673	28	0.18	0.102
mr11c63	0.849	0.069	0.093	0.006	0.391	0.064	0.002	624	38	572	35	726	65	79	593	61	0.20	1.605
mr11c52	1.052	0.047	0.125	0.004	0.325	0.065	0.001	730	23	761	21	772	39	99	747	35	0.23	0.583
mr12a14	1.009	0.069	0.109	0.005	0.313	0.062	0.001	708	35	665	27	688	40	97	678	49	0.24	1.465
mr12b33	1.324	0.104	0.132	0.004	0.184	0.079	0.002	856	46	801	22	1174	48	68	808	42	0.25	0.308
mr11c10	0.982	0.034	0.110	0.003	0.345	0.064	0.001	695	17	673	15	735	23	92	682	27	0.26	0.149
mr11c54	0.751	0.077	0.101	0.004	0.181	0.062	0.001	569	45	619	22	674	39	92	611	42	0.27	0.314
mr11b20	2.451	0.070	0.211	0.004	0.321	0.082	0.001	1258	20	1232	20	1236	21	100	1245	33	0.28	0.314
mr11c30	1.243	0.048	0.131	0.003	0.298	0.067	0.001	820	22	795	17	842	20	94	803	30	0.29	0.096
mr12a58	1.373	0.200	0.129	0.007	0.176	0.069	0.002	877	86	785	38	906	45	87	794	73	0.31	0.166
mr12a10	1.285	0.098	0.147	0.005	0.228	0.069	0.002	839	44	885	29	894	48	99	873	52	0.32	0.276
mr12a40	2.455	0.155	0.206	0.007	0.252	0.080	0.002	1259	46	1210	35	1194	38	101	1225	63	0.33	0.283
mr12b53	0.686	0.068	0.079	0.003	0.189	0.058	0.001	531	41	490	18	530	41	93	494	34	0.34	1.247
mr11b14	1.953	0.069	0.191	0.005	0.392	0.068	0.001	1099	24	1125	29	858	31	131	1108	43	0.37	0.870
mr11c64	0.717	0.034	0.086	0.003	0.307	0.061	0.001	549	20	530	15	633	40	84	535	27	0.38	0.658
mr12b48	0.906	0.078	0.101	0.004	0.240	0.064	0.001	655	42	618	24	735	42	84	624	46	0.39	0.014
mr12b63	0.894	0.055	0.101	0.003	0.250	0.061	0.001	649	29	623	18	628	39	99	628	34	0.40	0.710
mr11b11	0.690	0.031	0.083	0.002	0.300	0.057	0.001	533	19	517	13	476	28	108	521	24	0.40	1.403
mr11c23	0.661	0.035	0.080	0.002	0.283	0.060	0.001	515	21	497	14	601	24	83	501	26	0.40	0.957
mr12a43	1.339	0.050	0.140	0.003	0.326	0.066	0.001	863	22	843	19	811	26	104	851	33	0.41	0.129
mr12b28	0.942	0.069	0.105	0.004	0.268	0.054	0.001	674	36	643	24	385	40	167	650	45	0.41	0.875
mr11b54	0.761	0.044	0.097	0.004	0.314	0.056	0.001	574	25	597	21	468	44	127	588	36	0.41	0.776

APPENDIX B

Tower Hill Fm.	Measured Isotopic Ratios 207Pb /235U	1s error	206Pb /238U	1s error	Rho	207Pb /206Pb	1s error	Calculated Ages 207Pb /235U	1s error	206Pb /238U	1s error	207Pb /206Pb	1s error	U-Pb/Pb-Pb Conc. %	Conc. Age	2s error	Prob. of conc.	Ratio Th/U
mr11c55	7.647	0.171	0.410	0.008	0.441	0.130	0.001	2190	20	2216	37	2103	15	105	2192	40	0.45	0.276
mr11c74	1.038	0.050	0.115	0.003	0.280	0.065	0.001	723	25	703	18	780	29	90	709	33	0.46	1.234
mr12b36	0.724	0.072	0.095	0.004	0.194	0.057	0.001	553	43	585	22	509	50	115	580	41	0.46	0.737
mr11b10	0.917	0.037	0.111	0.003	0.374	0.057	0.001	661	20	676	19	504	32	134	669	32	0.48	0.683
mr11c72	0.775	0.065	0.090	0.003	0.228	0.070	0.002	583	37	556	20	925	47	60	560	39	0.49	1.444
mr12b18	1.259	0.137	0.129	0.004	0.150	0.070	0.001	828	61	785	24	923	37	85	789	47	0.50	0.421
mr11c40	2.184	0.066	0.197	0.005	0.385	0.081	0.001	1176	21	1159	25	1216	19	95	1170	38	0.52	0.446
mr11c34	1.696	0.069	0.172	0.004	0.264	0.076	0.001	1007	26	1026	20	1098	27	93	1019	36	0.52	0.378
mr12a52	1.408	0.145	0.156	0.005	0.161	0.067	0.001	892	61	933	29	849	46	110	927	55	0.52	0.742
mr12b26	1.338	0.153	0.135	0.006	0.192	0.066	0.001	862	66	818	34	804	42	102	824	64	0.52	0.455
mr11b56	1.323	0.106	0.136	0.006	0.279	0.073	0.002	856	46	825	35	1023	56	81	834	63	0.53	0.763
mr12b07	0.846	0.079	0.097	0.004	0.216	0.063	0.001	622	44	596	23	699	47	85	600	44	0.56	0.577
mr11c51	0.882	0.035	0.107	0.003	0.320	0.062	0.001	642	19	654	16	657	30	99	649	27	0.56	0.530
mr11b37	2.123	0.098	0.200	0.005	0.280	0.075	0.001	1156	32	1177	28	1058	31	111	1169	47	0.56	0.282
mr11c13	0.945	0.040	0.108	0.003	0.297	0.060	0.001	675	21	663	16	611	31	109	667	28	0.56	0.858
mr12a55	0.829	0.073	0.104	0.003	0.176	0.063	0.002	613	40	636	19	694	62	92	633	36	0.57	0.595
mr12a09	0.832	0.032	0.098	0.003	0.384	0.059	0.001	615	18	605	17	578	24	105	610	29	0.61	0.844
mr12a42	0.705	0.039	0.086	0.002	0.242	0.059	0.001	542	24	530	14	576	31	92	532	26	0.62	0.985
mr11c60	0.860	0.058	0.106	0.004	0.282	0.063	0.001	630	32	647	23	722	45	90	642	42	0.63	1.072
mr11c43	0.977	0.026	0.112	0.002	0.369	0.062	0.001	692	13	685	13	665	22	103	688	22	0.64	0.485
mr12b21	2.160	0.163	0.203	0.006	0.195	0.083	0.002	1168	52	1191	32	1277	49	93	1186	59	0.68	0.796
mr11b53	1.738	0.066	0.170	0.004	0.282	0.073	0.001	1023	24	1012	20	1008	24	100	1016	35	0.69	0.628
mr11c27	0.791	0.041	0.095	0.002	0.230	0.062	0.001	592	23	583	13	660	29	88	584	25	0.70	0.369
mr12b58	1.068	0.077	0.119	0.003	0.176	0.067	0.001	738	38	723	17	840	44	86	725	33	0.71	0.572
mr12a13	2.137	0.079	0.196	0.005	0.371	0.077	0.001	1161	26	1151	29	1129	23	102	1157	45	0.75	0.271
mr11c33	1.617	0.063	0.162	0.004	0.344	0.069	0.001	977	25	968	24	908	31	107	972	40	0.76	0.679
mr11b42	1.350	0.124	0.141	0.007	0.280	0.076	0.002	867	54	850	41	1104	59	77	855	74	0.76	1.048
mr12a57	1.833	0.123	0.176	0.004	0.171	0.076	0.001	1057	44	1044	22	1108	29	94	1046	42	0.78	0.289
mr12b38	18.029	1.144	0.599	0.033	0.437	0.210	0.002	2991	61	3025	134	2906	13	104	2992	122	0.78	0.109

APPENDIX B

	Measured Isotopic Ratios							Calculated Ages										
Tower Hill Fm.	207Pb /235U	1s error	206Pb /238U	1s error	Rho	207Pb /206Pb	1s error	207Pb /235U	1s error	206Pb /238U	1s error	207Pb /206Pb	1s error	U-Pb/Pb-Pb Conc. %	Conc. Age	2s error	Prob. of conc.	Ratio Th/U
~~mr11c48~~	~~0.299~~	~~1.790~~	~~0.089~~	~~0.018~~	~~0.017~~	~~0.199~~	~~0.014~~	~~265~~	~~1399~~	~~547~~	~~105~~	~~2818~~	~~114~~	~~19~~	~~545~~	~~210~~	~~0.82~~	~~1.322~~
mr12a32	1.425	0.056	0.149	0.004	0.322	0.069	0.001	899	23	893	21	889	34	101	896	36	0.82	0.416
mr11b29	0.845	0.037	0.101	0.002	0.282	0.059	0.001	622	20	617	14	562	32	110	619	26	0.83	0.613
mr12a34	1.690	0.062	0.168	0.004	0.331	0.071	0.001	1005	23	999	22	964	28	104	1002	37	0.84	0.291
mr11b07	0.700	0.036	0.088	0.003	0.326	0.058	0.001	539	22	543	18	546	45	100	542	31	0.85	1.041
mr12a08	0.732	0.058	0.089	0.004	0.252	0.063	0.001	558	34	552	21	694	35	80	553	39	0.87	0.635
mr11c50	0.899	0.048	0.106	0.003	0.252	0.062	0.001	651	26	647	17	658	33	98	648	31	0.87	0.460
mr11c38	0.740	0.072	0.090	0.006	0.313	0.061	0.001	563	42	557	33	640	42	87	558	59	0.89	0.824
mr11c53	3.383	0.225	0.264	0.010	0.296	0.089	0.001	1500	52	1508	53	1395	25	108	1504	84	0.90	0.106
mr12a05	0.935	0.043	0.109	0.002	0.241	0.064	0.001	670	23	668	14	736	28	91	668	26	0.91	0.757
mr11c42	0.996	0.069	0.114	0.004	0.226	0.066	0.001	702	35	698	21	800	40	87	698	39	0.91	0.601
mr11c80	1.002	0.062	0.116	0.004	0.295	0.065	0.001	705	32	709	25	775	43	91	707	44	0.91	1.106
mr11c35	1.222	0.058	0.135	0.004	0.318	0.067	0.001	811	27	814	23	842	22	97	812	40	0.92	0.198
mr12a21	1.248	0.067	0.137	0.004	0.290	0.066	0.001	822	30	826	24	814	41	101	824	43	0.92	0.348
mr12b41	0.959	0.651	0.107	0.020	0.141	0.061	0.001	683	337	653	118	639	51	102	655	232	0.93	0.159
mr11b43	0.690	0.030	0.086	0.002	0.328	0.053	0.001	533	18	531	14	310	37	171	532	26	0.94	0.910
mr12a30	0.576	0.020	0.074	0.001	0.286	0.057	0.001	462	13	463	9	472	28	98	463	16	0.94	0.501
mr12a07	0.951	0.036	0.111	0.002	0.266	0.062	0.001	678	19	677	13	659	24	103	677	23	0.94	0.145
mr11c73	0.765	0.028	0.094	0.002	0.262	0.058	0.001	577	16	578	11	535	32	108	578	20	0.96	0.373
mr11c68	0.666	0.033	0.084	0.002	0.224	0.059	0.001	518	20	519	11	583	33	89	519	21	0.98	2.675
mr11c39	0.856	0.047	0.102	0.002	0.198	0.068	0.001	628	26	629	13	855	34	74	629	25	0.99	1.333

	Measured Isotopic Ratios							Calculated Ages										
Worcester Fm.	207Pb /235U	1s error	206Pb /238U	1s error	Rho	207Pb /206Pb	1s error	207Pb /235U	1s error	206Pb /238U	1s error	207Pb /206Pb	1s error	U-Pb/Pb-Pb conc. %	Conc. Age	2s error	Prob. of conc.	Ratio Th/U
mr04a08	0.626	0.014	0.070	0.001	0.413	0.058	0.001	494	9	434	8	519	20	84	456	14	0.00	0.68
mr03a98	5.771	0.105	0.322	0.006	0.480	0.121	0.001	1942	16	1799	28	1966	9	92	1930	32	0.00	0.93
mr03a74	3.443	0.124	0.225	0.007	0.446	0.102	0.001	1514	28	1306	38	1669	13	78	1450	56	0.00	0.54
mr04a10	3.143	0.059	0.231	0.004	0.451	0.091	0.001	1443	15	1341	21	1440	14	93	1420	28	0.00	0.34
mr03a104	4.680	0.167	0.276	0.007	0.376	0.120	0.001	1764	30	1569	37	1960	15	80	1689	57	0.00	0.82
~~mr03a66~~	~~0.681~~	~~0.024~~	~~0.073~~	~~0.002~~	~~0.352~~	~~0.062~~	~~0.001~~	~~528~~	~~15~~	~~457~~	~~11~~	~~675~~	~~23~~	~~68~~	~~475~~	~~21~~	~~0.00~~	~~0.67~~
mr02a139	1.478	0.096	0.119	0.007	0.442	0.082	0.001	921	39	726	39	1257	34	58	805	70	0.00	0.20
mr02a124	2.012	0.138	0.146	0.010	0.476	0.097	0.001	1120	46	880	54	1560	15	56	1006	90	0.00	0.66
mr03a64	2.261	0.041	0.191	0.003	0.421	0.079	0.001	1200	13	1128	16	1171	14	96	1176	24	0.00	0.69
mr02a54	2.682	0.091	0.253	0.006	0.352	0.080	0.001	1323	25	1456	31	1192	25	122	1364	44	0.00	0.52
mr03a55	4.493	0.089	0.290	0.005	0.403	0.104	0.001	1730	16	1641	23	1702	13	96	1707	31	0.00	0.79
mr03a81	3.897	0.074	0.268	0.004	0.403	0.096	0.001	1613	15	1532	21	1549	15	99	1591	29	0.00	0.38
mr02a12	5.422	0.141	0.365	0.006	0.314	0.111	0.001	1888	22	2006	28	1818	17	110	1924	39	0.00	0.56
mr03a103	1.337	0.084	0.117	0.006	0.397	0.077	0.001	862	36	714	34	1131	28	63	768	60	0.00	0.73
mr02a141	3.510	0.120	0.246	0.006	0.331	0.096	0.001	1530	27	1416	29	1553	21	91	1474	47	0.00	0.43
mr02a21	2.518	0.086	0.237	0.004	0.230	0.083	0.001	1277	25	1369	19	1269	20	108	1335	33	0.00	0.13
mr02a22	2.259	0.102	0.182	0.005	0.326	0.088	0.001	1200	32	1078	29	1373	31	78	1125	51	0.00	0.22
mr04a32	0.710	0.020	0.081	0.002	0.332	0.060	0.000	545	12	503	9	597	18	84	515	17	0.00	0.13
mr04a09	0.933	0.031	0.099	0.002	0.298	0.065	0.001	669	17	611	12	770	25	79	625	22	0.00	0.49
~~mr02a27~~	~~14.852~~	~~4.018~~	~~0.229~~	~~0.037~~	~~0.294~~	~~0.454~~	~~0.014~~	~~2806~~	~~257~~	~~1330~~	~~191~~	~~4100~~	~~45~~	~~32~~	~~1247~~	~~384~~	~~0.00~~	~~0.50~~
mr02a49	0.972	0.072	0.093	0.006	0.416	0.078	0.001	689	37	571	34	1142	25	50	613	61	0.00	1.15
mr03a59	0.674	0.019	0.079	0.002	0.355	0.057	0.001	523	11	488	9	503	20	97	499	17	0.00	0.48
mr04a17	4.317	0.109	0.284	0.006	0.401	0.104	0.001	1697	21	1613	29	1690	16	95	1675	40	0.00	0.55
mr03a33	0.633	0.029	0.071	0.002	0.383	0.059	0.001	498	18	443	15	558	31	79	461	27	0.00	0.72
mr02a48	2.083	0.053	0.183	0.004	0.436	0.080	0.001	1143	17	1081	22	1201	15	90	1123	33	0.00	0.33
mr02a13	0.643	0.070	0.102	0.003	0.131	0.058	0.001	504	43	627	17	547	41	115	612	33	0.00	0.11
mr03a90	0.736	0.016	0.086	0.002	0.418	0.058	0.000	560	10	531	9	545	14	97	545	16	0.00	0.53
mr03a50	0.624	0.020	0.073	0.002	0.370	0.057	0.001	492	13	455	11	490	23	93	468	19	0.00	0.52
mr02a57	0.542	0.023	0.078	0.002	0.255	0.055	0.001	440	15	483	10	405	25	119	472	18	0.00	0.42

APPENDIX B

Worcester Fm.	Measured Isotopic Ratios 207Pb /235U	1s error	206Pb /238U	1s error	Rho	207Pb /206Pb	1s error	Calculated Ages 207Pb /235U	1s error	206Pb /238U	1s error	207Pb /206Pb	1s error	U-Pb/Pb-Pb conc. %	Conc. Age	2s error	Prob. of conc.	Ratio Th/U
mr03a80	1.234	0.041	0.125	0.003	0.418	0.065	0.001	816	18	759	20	774	23	98	790	32	0.01	0.44
mr02a29	0.570	0.027	0.082	0.002	0.209	0.057	0.001	458	17	506	9	478	24	106	497	18	0.01	0.10
mr04a28	0.711	0.028	0.081	0.002	0.370	0.058	0.001	546	17	499	14	544	27	92	515	25	0.01	1.19
mr02a88	1.524	0.057	0.169	0.004	0.290	0.068	0.001	940	23	1005	20	858	22	117	977	34	0.01	1.21
mr04a12	1.860	0.061	0.169	0.004	0.332	0.075	0.001	1067	22	1005	20	1073	28	94	1031	35	0.01	0.41
mr03a84	0.930	0.044	0.099	0.002	0.225	0.065	0.001	668	23	609	12	768	32	79	617	24	0.01	0.63
mr02a47	1.728	0.083	0.187	0.006	0.307	0.073	0.001	1019	31	1107	30	1004	27	110	1062	48	0.01	0.80
mr03a41	3.346	0.225	0.231	0.011	0.362	0.103	0.002	1492	53	1338	59	1679	40	80	1420	94	0.02	0.12
mr02a150	0.770	0.053	0.082	0.003	0.280	0.064	0.001	580	30	505	19	756	41	67	519	35	0.02	0.62
mr02a80	2.352	0.065	0.220	0.004	0.299	0.083	0.001	1228	20	1282	19	1258	24	102	1255	31	0.02	0.36
mr04a23	0.687	0.027	0.079	0.002	0.254	0.060	0.001	531	16	493	9	605	24	81	499	18	0.02	0.82
mr02a60	0.634	0.023	0.086	0.002	0.279	0.056	0.001	499	14	533	10	457	21	117	523	19	0.02	0.54
mr03a99	0.632	0.017	0.076	0.001	0.336	0.057	0.000	497	10	473	8	476	18	99	481	15	0.03	0.30
mr03a69	0.607	0.021	0.073	0.002	0.373	0.057	0.000	482	13	451	11	500	18	90	462	20	0.03	0.22
mr03a61	0.856	0.027	0.097	0.002	0.323	0.060	0.001	628	15	594	11	620	25	96	605	21	0.03	0.53
mr02a73	1.589	0.059	0.172	0.004	0.292	0.070	0.001	966	23	1023	21	931	24	110	998	35	0.03	0.62
mr03a51	0.630	0.021	0.075	0.001	0.256	0.059	0.001	496	13	466	8	552	24	84	472	15	0.03	0.52
mr04a30	0.683	0.026	0.091	0.002	0.279	0.056	0.001	529	15	563	11	469	33	120	553	20	0.03	1.27
mr03a88	1.523	0.035	0.151	0.002	0.344	0.071	0.001	940	14	906	13	957	15	95	921	23	0.03	0.65
mr02a89	1.432	0.134	0.173	0.007	0.212	0.070	0.001	902	56	1027	38	915	35	112	989	67	0.03	0.93
mr04a18	0.607	0.017	0.074	0.001	0.358	0.056	0.000	482	11	458	9	469	17	98	466	16	0.04	0.11
mr03a76	0.803	0.030	0.091	0.003	0.377	0.059	0.001	599	17	561	15	583	20	96	576	26	0.04	0.78
mr03a68	2.097	0.064	0.186	0.004	0.345	0.077	0.001	1148	21	1098	21	1113	18	99	1123	35	0.04	0.38
mr02a34	4.568	0.113	0.299	0.006	0.384	0.110	0.001	1743	21	1687	28	1797	10	94	1728	39	0.04	0.87
mr03a57	1.718	0.062	0.161	0.004	0.313	0.073	0.001	1015	23	963	20	1021	26	94	983	35	0.04	1.74
mr02a37	2.194	0.066	0.191	0.005	0.396	0.080	0.001	1179	21	1128	25	1198	15	94	1159	38	0.04	0.67
mr02a19	0.579	0.034	0.082	0.002	0.226	0.056	0.001	464	22	508	13	465	28	109	498	24	0.05	0.77
mr04a31	1.143	0.043	0.120	0.003	0.309	0.065	0.001	774	20	732	16	776	19	94	745	29	0.06	0.41
mr02a121	0.997	0.111	0.096	0.004	0.188	0.085	0.001	702	56	591	24	1307	33	45	600	46	0.06	1.25

APPENDIX B

Worcester Fm.	Measured Isotopic Ratios 207Pb /235U	1s error	206Pb /238U	1s error	Rho	207Pb /206Pb	1s error	Calculated Ages 207Pb /235U	1s error	206Pb /238U	1s error	207Pb /206Pb	1s error	U-Pb/Pb-Pb conc. %	Conc. Age	2s error	Prob. of conc.	Ratio Th/U
mr03a89	2.142	0.056	0.190	0.003	0.318	0.079	0.001	1162	18	1124	17	1172	17	96	1141	29	0.07	0.37
mr02a82	2.099	0.076	0.205	0.005	0.306	0.077	0.001	1148	25	1202	24	1118	23	107	1175	39	0.07	0.38
mr03a56	0.656	0.025	0.078	0.002	0.369	0.058	0.001	512	16	483	13	514	24	94	493	24	0.07	0.26
mr02a94	4.296	0.194	0.317	0.008	0.278	0.102	0.001	1693	37	1775	39	1670	21	106	1729	60	0.07	0.96
mr02a39	2.569	0.093	0.212	0.005	0.311	0.092	0.001	1292	26	1237	25	1468	17	84	1262	42	0.07	0.62
mr02a92	2.167	0.110	0.212	0.005	0.240	0.077	0.001	1171	35	1240	27	1117	24	111	1214	47	0.07	0.18
mr03a26	0.649	0.034	0.075	0.003	0.399	0.058	0.001	508	21	469	19	536	27	88	485	33	0.08	0.77
mr02a102	2.386	0.083	0.221	0.005	0.298	0.081	0.001	1238	25	1287	24	1232	17	105	1263	39	0.09	0.58
mr02a123	0.579	0.026	0.070	0.002	0.364	0.057	0.000	464	17	434	14	480	19	90	444	25	0.09	0.19
mr02a143	3.384	0.147	0.247	0.009	0.425	0.093	0.001	1501	34	1425	47	1481	11	96	1482	65	0.09	0.35
mr02a42	0.745	0.053	0.101	0.003	0.224	0.058	0.001	565	31	618	19	540	34	115	606	35	0.10	0.36
mr02a107	0.607	0.023	0.073	0.002	0.408	0.057	0.001	481	14	457	13	487	25	94	467	23	0.10	0.38
mr02a117	0.491	0.025	0.070	0.003	0.400	0.055	0.001	406	17	436	17	412	39	106	420	28	0.10	0.99
mr02a10	0.798	0.026	0.092	0.002	0.391	0.063	0.001	596	15	570	14	702	19	81	581	24	0.11	0.51
mr02a18	2.309	0.088	0.216	0.005	0.273	0.081	0.001	1215	27	1263	24	1219	19	104	1242	40	0.12	0.61
mr02a83	0.641	0.027	0.086	0.002	0.274	0.057	0.001	503	17	530	12	500	23	106	522	21	0.12	0.48
mr03a44	0.886	0.095	0.091	0.006	0.327	0.069	0.001	644	51	561	38	896	24	63	582	70	0.12	0.13
~~mr03a100~~	~~2.357~~	~~0.164~~	~~0.233~~	~~0.017~~	~~0.535~~	~~0.067~~	~~0.001~~	~~1230~~	~~50~~	~~1348~~	~~91~~	~~841~~	~~27~~	~~160~~	~~1230~~	~~99~~	~~0.13~~	~~0.49~~
mr02a101	3.153	0.127	0.262	0.005	0.252	0.091	0.001	1446	31	1500	27	1455	19	103	1476	45	0.13	0.69
mr02a103	2.648	0.090	0.235	0.005	0.307	0.083	0.001	1314	25	1359	26	1265	28	107	1335	41	0.13	0.49
mr03a87	1.221	0.053	0.127	0.004	0.317	0.067	0.001	810	24	771	20	836	30	92	785	36	0.14	0.79
mr02a43	0.886	0.043	0.099	0.004	0.415	0.068	0.001	644	23	607	23	862	31	70	625	39	0.14	1.61
mr02a64	0.553	0.030	0.077	0.002	0.219	0.058	0.001	447	20	477	11	517	28	92	471	21	0.14	0.59
mr02a97	0.576	0.035	0.080	0.002	0.205	0.057	0.001	462	22	494	12	489	51	101	489	22	0.15	0.54
mr02a120	0.558	0.028	0.077	0.002	0.257	0.055	0.000	450	18	476	12	432	19	110	470	22	0.16	0.12
mr02a140	0.770	0.123	0.077	0.004	0.170	0.076	0.001	580	70	479	25	1083	39	44	484	49	0.17	0.55
mr02a104	0.619	0.022	0.082	0.002	0.262	0.056	0.001	490	14	509	9	453	22	112	504	17	0.17	0.53
mr04a11	6.892	0.143	0.376	0.007	0.422	0.123	0.001	2098	18	2059	31	2007	14	103	2093	36	0.17	0.48
mr03a45	0.564	0.017	0.070	0.001	0.245	0.056	0.001	454	11	439	6	448	24	98	441	12	0.18	1.05

APPENDIX B

	Measured Isotopic Ratios							Calculated Ages										
Worcester Fm.	207Pb /235U	1s error	206Pb /238U	1s error	Rho	207Pb /206Pb	1s error	207Pb /235U	1s error	206Pb /238U	1s error	207Pb /206Pb	1s error	U-Pb/Pb-Pb conc. %	Conc. Age	2s error	Prob. of conc.	Ratio Th/U
mr02a63	0.514	0.025	0.071	0.002	0.244	0.055	0.001	421	17	444	10	423	28	105	439	19	0.18	0.50
mr02a11	1.799	0.066	0.182	0.004	0.263	0.076	0.001	1045	24	1080	19	1097	22	98	1067	33	0.18	0.28
mr02a87	1.679	0.059	0.162	0.004	0.346	0.076	0.001	1001	23	967	22	1086	24	89	983	37	0.18	0.59
mr02a33	0.655	0.041	0.088	0.002	0.178	0.057	0.001	512	25	546	12	482	28	113	541	23	0.19	0.48
mr04a22	0.606	0.019	0.075	0.001	0.309	0.056	0.000	481	12	465	9	453	18	103	469	16	0.19	0.21
mr02a74	0.674	0.039	0.079	0.003	0.322	0.061	0.001	523	24	491	17	652	37	75	500	32	0.19	0.49
mr02a71	0.808	0.047	0.104	0.003	0.246	0.059	0.001	601	27	637	17	567	34	112	628	32	0.20	0.41
mr02a72	2.581	0.097	0.231	0.007	0.396	0.081	0.001	1295	27	1341	36	1222	26	110	1308	51	0.20	0.39
mr02a84	0.535	0.017	0.072	0.001	0.292	0.055	0.000	435	12	450	8	417	18	108	446	15	0.21	0.13
mr03a85	0.595	0.019	0.074	0.001	0.270	0.057	0.001	474	12	459	8	486	31	94	462	14	0.21	0.60
mr02a99	0.602	0.028	0.073	0.003	0.399	0.057	0.001	479	18	455	16	496	21	92	465	28	0.21	0.17
mr02a61	2.645	0.072	0.220	0.004	0.356	0.086	0.001	1313	20	1283	23	1347	13	95	1301	35	0.22	0.35
mr02a68	5.744	0.132	0.343	0.007	0.444	0.117	0.001	1938	20	1901	33	1908	13	100	1934	39	0.22	1.03
mr02a109	0.622	0.020	0.076	0.002	0.382	0.057	0.001	491	13	475	11	494	21	96	482	20	0.22	0.62
mr03a75	0.590	0.023	0.073	0.001	0.240	0.058	0.001	471	15	453	8	515	29	88	456	16	0.24	1.37
mr02a53	3.259	0.077	0.250	0.006	0.472	0.087	0.001	1471	18	1441	29	1353	18	107	1467	36	0.24	0.89
mr02a146	0.543	0.020	0.068	0.002	0.309	0.056	0.001	440	13	424	9	447	23	95	428	17	0.25	0.14
mr03a105	0.877	0.046	0.099	0.003	0.243	0.062	0.001	640	25	610	15	677	34	90	616	28	0.26	1.95
mr04a07	1.651	0.090	0.158	0.005	0.304	0.073	0.001	990	35	947	29	1006	18	94	963	51	0.26	0.36
mr02a100	0.599	0.024	0.080	0.002	0.326	0.055	0.001	477	15	495	13	425	22	117	488	22	0.26	0.56
mr02a78	3.422	0.115	0.256	0.007	0.412	0.094	0.001	1510	26	1470	36	1503	14	98	1500	50	0.26	0.51
mr02a20	0.652	0.037	0.087	0.002	0.183	0.065	0.001	510	23	536	11	790	29	68	532	21	0.26	0.48
mr02a58	0.567	0.019	0.076	0.001	0.273	0.057	0.000	456	13	470	8	492	19	96	467	16	0.27	0.14
mr03a47	1.066	0.205	0.101	0.013	0.342	0.074	0.001	737	101	620	78	1052	27	59	650	144	0.27	0.52
mr03a70	0.609	0.024	0.075	0.002	0.275	0.057	0.000	483	15	467	10	504	19	93	471	18	0.30	0.28
mr02a113	0.623	0.040	0.075	0.003	0.297	0.060	0.001	492	25	466	17	586	35	79	472	32	0.31	0.43
mr02a44	0.766	0.070	0.101	0.003	0.182	0.059	0.001	578	40	619	20	579	35	107	613	37	0.31	0.58
mr03a97	2.665	0.126	0.219	0.008	0.392	0.082	0.001	1319	35	1276	43	1245	26	102	1304	64	0.32	0.41
mr02a60	1.325	0.083	0.124	0.004	0.307	0.070	0.001	767	29	744	23	844	26	91	750	40	0.33	0.50

APPENDIX B

Worcester Fm.	Measured Isotopic Ratios 207Pb /235U	1s error	206Pb /238U	1s error	Rho	207Pb /206Pb	1s error	Calculated Ages 207Pb /235U	1s error	206Pb /238U	1s error	207Pb /206Pb	1s error	U-Pb/Pb-Pb conc. %	Conc. Age	2s error	Prob. of conc.	Ratio Th/U
mr04a24	0.625	0.021	0.082	0.001	0.246	0.055	0.001	493	13	506	8	431	29	117	503	15	0.33	0.70
mr02a31	0.812	0.061	0.092	0.004	0.253	0.063	0.001	604	34	569	21	717	33	79	576	39	0.33	0.57
mr03a67	5.273	0.177	0.328	0.008	0.367	0.112	0.001	1865	29	1828	39	1832	18	100	1854	54	0.35	0.77
mr02a90	0.569	0.029	0.076	0.001	0.175	0.056	0.001	457	19	475	8	461	28	103	473	16	0.35	0.85
mr03a77	0.873	0.057	0.099	0.003	0.261	0.062	0.001	637	31	607	20	662	35	92	614	37	0.35	1.51
mr03a58	0.771	0.042	0.090	0.003	0.260	0.062	0.001	580	24	557	15	658	37	85	562	28	0.35	1.05
mr02a17	1.779	0.104	0.167	0.008	0.425	0.085	0.001	1038	38	996	46	1314	28	76	1023	70	0.36	0.65
mr04a20	0.766	0.061	0.088	0.003	0.229	0.056	0.003	578	35	545	19	457	120	119	550	36	0.37	0.92
mr03a20	0.948	0.085	0.118	0.005	0.236	0.063	0.001	677	44	717	29	710	39	101	707	53	0.38	0.97
mr04a14	2.208	0.097	0.207	0.004	0.219	0.078	0.001	1184	31	1212	21	1141	20	106	1204	38	0.39	0.18
mr03a96	0.819	0.041	0.095	0.002	0.252	0.062	0.001	607	23	588	14	658	41	89	592	27	0.41	0.87
mr02a28	0.579	0.023	0.077	0.001	0.242	0.058	0.001	464	15	476	9	539	26	88	474	16	0.41	0.52
mr03a91	0.585	0.015	0.074	0.001	0.254	0.056	0.000	468	9	460	6	447	18	103	462	11	0.42	0.08
mr03a49	1.245	0.068	0.131	0.004	0.277	0.065	0.001	821	31	795	23	780	37	102	802	41	0.43	0.80
mr02a62	0.546	0.039	0.074	0.003	0.242	0.056	0.001	442	26	462	15	468	31	99	458	29	0.46	0.59
mr02a32	3.243	0.170	0.262	0.007	0.253	0.093	0.001	1467	41	1502	36	1489	18	101	1487	59	0.46	0.33
mr02a70	0.699	0.023	0.089	0.002	0.290	0.059	0.001	538	14	549	10	551	24	100	546	18	0.46	0.59
mr02a118	1.464	0.061	0.156	0.004	0.281	0.071	0.001	915	25	936	20	954	25	98	928	36	0.47	0.39
mr02a59	0.702	0.038	0.085	0.003	0.346	0.059	0.001	540	22	524	19	578	24	91	530	33	0.49	0.29
mr03a65	4.137	0.236	0.286	0.009	0.290	0.108	0.002	1662	47	1623	47	1765	33	92	1642	76	0.49	1.53
mr02a38	0.548	0.022	0.073	0.002	0.270	0.058	0.001	444	14	454	9	538	22	84	451	17	0.49	0.84
mr02a51	3.782	0.109	0.275	0.006	0.409	0.097	0.001	1589	23	1568	33	1563	12	100	1584	44	0.51	0.33
mr04a29	1.223	0.046	0.132	0.003	0.289	0.063	0.001	811	21	797	16	704	31	113	801	29	0.52	0.54
mr04a13	0.899	0.035	0.104	0.002	0.231	0.061	0.001	651	18	639	11	648	33	99	641	20	0.52	0.74
mr03a27	0.925	0.069	0.113	0.004	0.213	0.066	0.001	665	36	689	21	799	29	86	684	39	0.53	0.29
mr02a111	1.704	0.082	0.174	0.005	0.303	0.072	0.001	1010	31	1032	28	986	19	105	1022	47	0.53	0.33
mr04a21	0.597	0.022	0.075	0.002	0.280	0.055	0.001	475	14	466	9	431	27	108	469	17	0.54	0.85
mr03a25	0.822	0.047	0.096	0.002	0.227	0.065	0.001	609	26	592	15	762	37	78	595	28	0.54	0.61
mr03a107	0.699	0.028	0.085	0.002	0.232	0.056	0.001	538	17	528	9	440	29	120	530	18	0.54	0.95

	Measured Isotopic Ratios							Calculated Ages										
Worcester Fm.	207Pb /235U	1s error	206Pb /238U	1s error	Rho	207Pb /206Pb	1s error	207Pb /235U	1s error	206Pb /238U	1s error	207Pb /206Pb	1s error	U-Pb/Pb-Pb conc. %	Conc. Age	2s error	Prob. of conc.	Ratio Th/U
mr03a71	0.692	0.033	0.088	0.002	0.232	0.054	0.001	534	20	546	11	380	43	144	544	22	0.54	0.59
mr02a122	0.580	0.042	0.072	0.004	0.400	0.055	0.001	465	27	448	25	421	25	106	455	43	0.55	0.17
mr03a21	0.670	0.048	0.081	0.003	0.267	0.060	0.001	521	29	504	18	596	41	84	507	34	0.56	1.10
mr02a98	0.647	0.018	0.083	0.001	0.292	0.059	0.001	507	11	513	8	553	21	93	512	15	0.57	1.05
mr03a32	2.440	0.176	0.209	0.010	0.322	0.084	0.001	1254	52	1221	52	1290	18	95	1237	85	0.58	0.71
mr03a31	0.539	0.059	0.074	0.004	0.235	0.059	0.001	438	39	460	23	558	42	82	455	43	0.59	0.81
mr02a23	0.676	0.020	0.086	0.002	0.292	0.058	0.001	524	12	531	9	535	22	99	529	16	0.59	0.71
mr02a93	2.530	0.153	0.225	0.009	0.337	0.082	0.001	1281	44	1309	48	1235	15	106	1293	75	0.60	0.09
mr02a77	0.599	0.024	0.078	0.002	0.266	0.057	0.001	477	15	485	10	496	26	98	483	18	0.60	0.57
mr02a110	2.226	0.166	0.208	0.010	0.310	0.080	0.001	1189	52	1219	51	1189	19	103	1204	83	0.62	0.32
mr02a91	2.135	0.137	0.201	0.006	0.225	0.079	0.001	1160	44	1183	31	1162	30	102	1176	56	0.63	0.40
mr02a119	0.494	0.026	0.064	0.002	0.284	0.058	0.001	408	17	399	11	527	22	76	401	21	0.64	0.90
mr03a30	0.584	0.034	0.073	0.002	0.296	0.058	0.001	467	22	456	15	527	21	87	459	28	0.64	0.37
mr03a106	0.600	0.019	0.076	0.001	0.253	0.057	0.001	477	12	472	7	487	27	97	473	14	0.65	0.62
mr02a50	0.669	0.024	0.083	0.002	0.278	0.059	0.001	520	15	513	10	549	21	93	515	18	0.65	0.15
mr02a145	2.504	0.095	0.216	0.005	0.306	0.087	0.001	1273	28	1259	27	1367	25	92	1266	44	0.66	0.85
mr02a24	0.558	0.018	0.073	0.001	0.305	0.057	0.000	450	12	456	9	494	17	92	454	16	0.67	0.08
mr03a23	1.748	0.266	0.164	0.018	0.357	0.076	0.001	1026	98	980	99	1090	21	90	1002	164	0.68	0.29
mr03a94	1.774	0.076	0.172	0.004	0.252	0.073	0.001	1036	28	1024	20	1024	19	100	1027	37	0.68	0.21
mr02a41	0.634	0.027	0.082	0.002	0.269	0.057	0.001	499	17	506	11	505	22	100	504	20	0.70	0.12
mr02a67	0.560	0.037	0.074	0.003	0.261	0.056	0.001	451	24	461	15	437	25	105	459	29	0.71	0.77
mr02a108	0.584	0.040	0.077	0.003	0.246	0.058	0.001	467	25	477	15	536	22	89	475	29	0.71	0.68
mr03a46	0.642	0.025	0.080	0.001	0.204	0.058	0.001	504	15	498	8	534	28	93	499	14	0.72	0.99
mr03a79	0.604	0.022	0.076	0.002	0.356	0.055	0.000	480	14	475	12	424	20	112	476	21	0.72	0.13
mr02a08	4.864	0.154	0.319	0.007	0.345	0.113	0.001	1796	27	1783	34	1847	18	97	1792	48	0.72	1.01
mr03a60	0.812	0.033	0.097	0.003	0.387	0.056	0.001	604	19	597	18	470	25	127	600	30	0.73	0.31
mr02a144	0.702	0.054	0.086	0.003	0.229	0.058	0.001	540	32	529	18	539	37	98	531	34	0.74	1.00
mr03a95	0.762	0.041	0.092	0.003	0.269	0.060	0.001	575	24	567	16	614	36	92	569	29	0.75	0.86
mr03a48	0.592	0.021	0.075	0.002	0.323	0.055	0.001	472	13	468	10	406	25	115	469	19	0.76	0.62

Worcester Fm.	Measured Isotopic Ratios 207Pb /235U	1s error	206Pb /238U	1s error	Rho	207Pb /206Pb	1s error	Calculated Ages 207Pb /235U	1s error	206Pb /238U	1s error	207Pb /206Pb	1s error	U-Pb/Pb-Pb conc. %	Conc. Age	2s error	Prob. of conc.	Ratio Th/U
mr02a30	1.738	0.085	0.174	0.004	0.249	0.084	0.001	1023	31	1033	23	1297	30	80	1030	41	0.77	0.92
mr02a142	0.541	0.021	0.070	0.002	0.289	0.058	0.001	439	14	435	9	532	25	82	436	17	0.77	0.45
mr03a22	1.666	0.184	0.163	0.012	0.335	0.073	0.002	996	70	975	67	1020	57	96	984	112	0.79	0.47
mr02a07	1.998	0.058	0.190	0.004	0.333	0.077	0.001	1115	20	1121	20	1111	21	101	1118	32	0.80	0.34
mr02a81	0.706	0.034	0.089	0.003	0.298	0.057	0.001	542	20	548	15	510	22	107	546	27	0.80	0.11
mr03a34	8.083	0.269	0.418	0.010	0.355	0.136	0.001	2240	30	2251	45	2180	17	103	2243	57	0.81	0.38
mr02a40	0.991	0.047	0.115	0.003	0.282	0.065	0.001	699	24	704	18	769	28	92	703	32	0.84	0.35
mr02a114	0.502	0.022	0.066	0.002	0.260	0.059	0.001	413	15	410	9	553	26	74	410	17	0.85	0.14
mr02a52	1.631	0.047	0.165	0.003	0.327	0.072	0.001	982	18	986	17	974	17	101	984	29	0.85	0.30
mr04a19	0.582	0.024	0.075	0.001	0.240	0.056	0.001	466	15	469	9	453	27	103	468	17	0.87	1.25
mr03a86	0.571	0.024	0.074	0.001	0.236	0.055	0.001	459	15	461	9	412	33	112	461	17	0.89	0.71
mr02a79	0.609	0.055	0.079	0.003	0.244	0.059	0.001	483	35	487	21	580	32	84	487	39	0.90	0.67
mr02a16	0.596	0.034	0.077	0.002	0.271	0.058	0.001	475	21	477	14	525	26	91	476	26	0.91	0.41
mr03a24	0.605	0.058	0.077	0.004	0.290	0.058	0.001	480	37	476	26	529	24	90	477	47	0.91	0.83
mr03a54	0.898	0.036	0.106	0.002	0.290	0.061	0.001	651	19	649	14	630	23	103	649	26	0.91	0.22
mr02a112	0.605	0.029	0.077	0.002	0.301	0.058	0.001	481	19	480	14	534	21	90	480	25	0.95	0.13
mr04a27	0.635	0.028	0.081	0.002	0.244	0.058	0.001	499	17	500	10	518	24	97	500	19	0.97	1.12
mr03a78	0.658	0.122	0.083	0.007	0.245	0.062	0.001	514	75	511	45	670	30	76	512	84	0.97	0.10
mr02a69	1.780	0.090	0.175	0.007	0.385	0.073	0.001	1038	33	1039	37	1009	22	103	1038	58	0.99	0.51
mr02a09	0.854	0.036	0.102	0.003	0.293	0.061	0.001	627	20	627	15	651	22	96	627	27	0.99	0.36

Paxton Fm.	Measured Isotopic Ratios 207Pb /235U	1s error	206Pb /238U	1s error	Rho	207Pb /206Pb	1s error	Calculated Ages 207Pb /235U	1s error	206Pb /238U	1s error	207Pb /206Pb	1s error	U-Pb/Pb-Pb conc. %	Conc. age	2s error	Prob. of conc.	Ratio Th/U
se08b13	.	0.283	0.368	0.009	0.424	0.182	0.001	2379	28	2022	44	2669	10	76	2305	57	0.00	0.501
au26a62	11.667	0.252	0.437	0.008	0.441	0.183	0.001	2578	20	2337	37	2676	11	87	2557	41	0.00	0.579
se08b28	9.334	0.301	0.375	0.011	0.466	0.179	0.001	2371	30	2052	53	2646	10	78	2339	60	0.00	0.673
~~se09a51~~	~~1.396~~	~~0.045~~	~~0.124~~	~~0.003~~	~~0.333~~	~~0.074~~	~~0.001~~	~~887~~	~~19~~	~~756~~	~~15~~	~~1032~~	~~21~~	~~73~~	~~794~~	~~28~~	~~0.00~~	~~0.673~~
se09a57	4.898	0.120	0.288	0.006	0.424	0.120	0.001	1802	21	1629	30	1964	12	83	1760	41	0.00	0.189
au26a24	2.723	0.094	0.195	0.005	0.394	0.094	0.001	1335	26	1151	29	1517	16	76	1247	47	0.00	0.272
se09a20	3.159	0.046	0.235	0.003	0.451	0.091	0.000	1447	11	1361	16	1442	9	94	1428	22	0.00	0.390
se09a08	12.934	0.258	0.481	0.009	0.457	0.183	0.001	2675	19	2531	38	2678	8	95	2670	38	0.00	1.163
se09a18	2.219	0.112	0.171	0.007	0.382	0.091	0.001	1187	35	1016	36	1453	21	70	1093	62	0.00	0.737
se09a11	2.927	0.065	0.224	0.004	0.413	0.089	0.001	1389	17	1301	22	1413	16	92	1361	32	0.00	0.610
se07b08	3.513	0.088	0.247	0.005	0.410	0.101	0.001	1530	20	1424	26	1647	10	86	1498	38	0.00	0.304
se09a12	0.581	0.020	0.067	0.001	0.304	0.059	0.001	465	13	417	9	555	29	75	427	16	0.00	0.458
au26a49	4.173	0.116	0.274	0.007	0.434	0.101	0.001	1669	23	1561	33	1648	17	95	1646	44	0.00	0.542
au26a39	0.675	0.025	0.076	0.002	0.308	0.059	0.001	524	15	471	10	564	32	84	483	19	0.00	0.169
au26a34	2.895	0.127	0.214	0.007	0.389	0.092	0.001	1381	33	1249	39	1461	25	86	1326	61	0.00	0.630
au26a51	2.017	0.061	0.176	0.004	0.361	0.077	0.001	1121	20	1045	21	1109	24	94	1083	35	0.00	0.421
au26a48	3.602	0.190	0.240	0.010	0.379	0.092	0.001	1550	42	1384	50	1468	24	94	1481	78	0.00	0.112
se09a50	4.016	0.108	0.270	0.006	0.444	0.104	0.001	1638	22	1542	33	1697	16	91	1619	43	0.00	0.744
au26a31	3.448	0.079	0.251	0.004	0.384	0.092	0.001	1515	18	1443	23	1474	14	98	1491	33	0.00	0.698
se09a45	2.463	0.091	0.197	0.005	0.376	0.088	0.001	1261	27	1162	30	1393	18	83	1216	47	0.00	0.349
se09a64	3.728	0.114	0.252	0.012	0.794	0.102	0.001	1577	24	1449	63	1653	13	88	1615	39	0.00	0.138
au26a42	3.958	0.074	0.275	0.004	0.423	0.099	0.001	1626	15	1567	22	1601	10	98	1613	29	0.00	0.738
se09a10	4.336	0.097	0.289	0.005	0.368	0.103	0.001	1700	18	1636	24	1671	17	98	1679	34	0.01	0.704
au26a53	3.467	0.080	0.253	0.005	0.435	0.093	0.001	1520	18	1455	26	1485	15	98	1506	35	0.01	0.394
au26a21	0.644	0.019	0.076	0.001	0.303	0.058	0.001	505	12	473	8	538	24	88	480	15	0.01	0.140
~~se09a19~~	~~0.541~~	~~0.016~~	~~0.066~~	~~0.001~~	~~0.289~~	~~0.057~~	~~0.001~~	~~439~~	~~11~~	~~410~~	~~7~~	~~481~~	~~23~~	~~85~~	~~416~~	~~13~~	~~0.01~~	~~1.106~~
se09a49	2.340	0.076	0.196	0.005	0.390	0.087	0.001	1225	23	1152	27	1367	21	84	1195	42	0.01	0.448
se08b40	1.954	0.045	0.177	0.003	0.404	0.078	0.001	1100	15	1053	18	1137	17	93	1082	28	0.01	0.801
se08b29	4.355	0.062	0.294	0.003	0.409	0.105	0.000	1704	12	1663	17	1708	9	97	1695	23	0.01	0.479

APPENDIX B

Paxton Fm.	Measured Isotopic Ratios 207Pb /235U	1s error	206Pb /238U	1s error	Rho	207Pb /206Pb	1s error	Calculated Ages 207Pb /235U	1s error	206Pb /238U	1s error	207Pb /206Pb	1s error	U-Pb/Pb-Pb conc. %	Conc. age	2s error	Prob. of conc.	Ratio Th/U
se09a17	0.797	0.035	0.088	0.002	0.313	0.061	0.001	595	20	544	15	651	28	84	557	27	0.01	0.585
se09a60	1.896	0.054	0.172	0.005	0.477	0.080	0.001	1080	19	1023	26	1189	18	86	1066	37	0.02	0.271
se07b23	3.027	0.091	0.233	0.006	0.430	0.092	0.001	1415	23	1350	31	1458	26	93	1398	44	0.03	0.674
se07b07	2.279	0.079	0.194	0.005	0.383	0.084	0.001	1206	24	1145	28	1304	12	88	1180	44	0.04	0.265
au26a32	5.012	0.139	0.314	0.006	0.346	0.107	0.001	1821	23	1760	30	1748	18	101	1800	43	0.04	0.470
se07b20	4.029	0.080	0.282	0.004	0.362	0.101	0.001	1640	16	1599	20	1648	16	97	1626	29	0.05	0.263
se09a58	2.671	0.097	0.214	0.007	0.465	0.089	0.001	1321	27	1252	38	1406	14	89	1306	52	0.05	0.204
se08b09	4.147	0.085	0.285	0.005	0.443	0.104	0.001	1664	17	1617	26	1690	10	96	1656	33	0.05	0.339
au26a27	2.877	0.066	0.230	0.003	0.306	0.087	0.001	1376	17	1337	17	1368	15	98	1355	28	0.05	0.394
se08b19	1.536	0.054	0.149	0.005	0.461	0.082	0.001	945	21	895	27	1246	27	72	929	40	0.05	0.225
au26a43	1.813	0.069	0.167	0.004	0.317	0.074	0.001	1050	25	996	22	1051	31	95	1017	39	0.05	0.337
au26a30	1.534	0.053	0.150	0.003	0.276	0.072	0.001	944	21	899	16	989	26	91	913	29	0.05	0.387
au26a68	4.985	0.125	0.315	0.005	0.346	0.108	0.001	1817	21	1763	27	1766	16	100	1798	39	0.06	0.911
se08a07	3.290	0.082	0.248	0.006	0.484	0.090	0.001	1479	19	1429	31	1424	18	100	1473	39	0.07	0.117
au26a18	3.952	0.195	0.267	0.012	0.462	0.099	0.001	1624	40	1525	62	1605	16	95	1608	79	0.07	0.331
au26a44	4.184	0.070	0.289	0.004	0.400	0.099	0.001	1671	14	1638	19	1608	10	102	1663	26	0.08	0.399
se09a44	3.372	0.089	0.252	0.007	0.497	0.094	0.001	1498	21	1447	34	1516	12	95	1493	41	0.09	0.275
se09a53	2.627	0.043	0.220	0.003	0.466	0.085	0.001	1308	12	1281	18	1305	13	98	1303	23	0.09	0.317
au26a19	0.612	0.022	0.074	0.002	0.290	0.058	0.001	485	14	460	9	526	22	87	466	18	0.09	0.600
se09a59	3.831	0.093	0.274	0.005	0.345	0.100	0.001	1599	19	1560	23	1632	17	96	1584	35	0.11	0.932
se09a48	3.244	0.051	0.250	0.004	0.494	0.092	0.001	1468	12	1439	20	1472	12	98	1465	24	0.11	0.736
au26a59	3.058	0.079	0.239	0.004	0.349	0.091	0.001	1422	20	1383	23	1453	16	95	1406	35	0.11	0.848
se07b13	0.548	0.013	0.069	0.002	0.457	0.055	0.001	444	9	428	9	430	25	100	437	15	0.11	0.948
au26a40	4.589	0.125	0.302	0.006	0.375	0.104	0.001	1747	23	1702	31	1698	21	100	1734	43	0.13	0.711
au26a22	4.303	0.165	0.288	0.009	0.391	0.102	0.001	1694	32	1630	43	1667	16	98	1677	60	0.13	0.441
se07b19	0.638	0.021	0.077	0.001	0.285	0.059	0.001	501	13	481	9	578	32	83	485	16	0.14	0.834
au26a67	2.704	0.076	0.222	0.004	0.347	0.085	0.001	1330	21	1293	23	1304	16	99	1313	36	0.14	0.718
au26a57	0.541	0.025	0.066	0.002	0.318	0.054	0.001	439	17	415	12	380	42	109	421	22	0.15	0.905
se09a07	1.642	0.057	0.159	0.003	0.269	0.073	0.001	987	22	953	16	1008	29	95	963	30	0.16	1.120

APPENDIX B

Paxton Fm.	Measured Isotopic Ratios 207Pb /235U	1s error	206Pb /238U	1s error	Rho	207Pb /206Pb	1s error	Calculated Ages 207Pb /235U	1s error	206Pb /238U	1s error	207Pb /206Pb	1s error	U-Pb/Pb-Pb conc. %	Conc. age	2s error	Prob. of conc.	Ratio Th/U
se08a09	12.907	0.182	0.505	0.007	0.515	0.181	0.001	2673	13	2635	31	2662	7	99	2675	26	0.16	0.463
au26a58	1.960	0.105	0.176	0.006	0.303	0.076	0.001	1102	36	1046	31	1087	34	96	1067	55	0.16	0.384
se07b09	4.135	0.096	0.287	0.005	0.367	0.100	0.001	1661	19	1626	25	1624	14	100	1650	35	0.16	0.435
se09a46	0.544	0.024	0.075	0.002	0.246	0.056	0.001	441	16	463	10	434	31	107	459	18	0.16	0.082
au26a64	0.596	0.030	0.072	0.002	0.268	0.061	0.001	475	19	448	12	622	40	72	453	22	0.16	0.932
au26a09	0.669	0.035	0.079	0.002	0.265	0.062	0.001	520	21	490	13	691	38	71	496	24	0.16	0.820
se09a63	0.598	0.020	0.074	0.002	0.342	0.057	0.001	476	13	457	10	510	23	90	463	18	0.17	0.589
se09a13	0.530	0.019	0.066	0.001	0.307	0.055	0.001	432	12	414	9	415	26	100	418	16	0.17	0.643
se07b28	1.695	0.044	0.164	0.004	0.464	0.072	0.001	1007	16	979	22	972	17	101	999	31	0.17	0.572
au26a23	3.925	0.227	0.266	0.017	0.544	0.096	0.001	1619	47	1523	85	1558	24	98	1618	93	0.18	0.281
se08a08	3.563	0.097	0.263	0.005	0.338	0.094	0.001	1541	22	1505	25	1507	24	100	1527	38	0.18	0.962
au26a50	3.133	0.058	0.246	0.003	0.370	0.087	0.001	1441	14	1417	17	1361	13	104	1432	26	0.19	0.453
se09a33	1.925	0.038	0.180	0.003	0.398	0.075	0.000	1090	13	1069	16	1079	11	99	1082	24	0.19	0.933
se07b11	0.639	0.025	0.077	0.002	0.267	0.058	0.001	502	16	481	10	535	23	90	485	18	0.19	0.075
se09a32	3.187	0.103	0.245	0.005	0.343	0.094	0.001	1454	25	1414	28	1501	23	94	1437	43	0.19	0.295
se08b10	3.521	0.066	0.263	0.004	0.398	0.097	0.001	1532	15	1507	20	1559	13	97	1525	28	0.20	0.482
au26a12	0.596	0.020	0.074	0.001	0.268	0.056	0.001	475	13	458	8	465	26	99	462	15	0.21	0.431
se09a09	0.815	0.027	0.095	0.002	0.262	0.062	0.001	605	15	586	10	677	25	87	591	18	0.23	1.340
au26a54	1.834	0.058	0.173	0.004	0.350	0.074	0.001	1058	21	1029	21	1033	21	100	1043	34	0.23	0.607
se09a52	0.596	0.020	0.074	0.002	0.348	0.057	0.001	474	13	459	10	489	22	94	464	18	0.25	0.365
se08b23	2.409	0.073	0.207	0.005	0.434	0.087	0.001	1245	22	1215	29	1361	23	89	1237	41	0.27	0.797
se08b33	1.762	0.078	0.167	0.005	0.351	0.076	0.001	1032	29	996	29	1085	28	92	1013	48	0.28	0.335
se08b27	4.225	0.071	0.301	0.003	0.341	0.102	0.001	1679	14	1697	17	1655	13	103	1685	25	0.30	1.270
au26a63	0.617	0.032	0.075	0.002	0.235	0.060	0.001	488	20	468	11	615	39	76	471	21	0.33	0.522
se08b30	0.547	0.031	0.075	0.002	0.237	0.056	0.001	443	20	463	12	442	41	105	459	23	0.33	0.747
au26a11	0.918	0.049	0.103	0.003	0.311	0.063	0.001	661	26	635	20	697	24	91	643	36	0.34	0.021
se07b22	1.846	0.054	0.175	0.003	0.269	0.076	0.001	1062	19	1042	15	1103	23	94	1048	27	0.34	0.420
se09a54	2.072	0.071	0.188	0.006	0.447	0.080	0.001	1140	23	1112	31	1200	12	93	1132	44	0.36	0.353
se07b10	2.588	0.095	0.217	0.007	0.432	0.084	0.001	1297	27	1267	36	1282	28	99	1290	51	0.39	0.853

APPENDIX B

	Measured Isotopic Ratios							Calculated Ages										
Paxton Fm.	207Pb /235U	1s error	206Pb /238U	1s error	Rho	207Pb /206Pb	1s error	207Pb /235U	1s error	206Pb /238U	1s error	207Pb /206Pb	1s error	U-Pb/Pb-Pb conc. %	Conc. age	2s error	Prob. of conc.	Ratio Th/U
au26a38	3.451	0.192	0.274	0.008	0.266	0.098	0.002	1516	44	1559	41	1582	42	99	1539	67	0.40	0.965
au26a29	4.137	0.111	0.289	0.005	0.353	0.103	0.001	1662	22	1639	27	1685	21	97	1654	40	0.42	0.953
au26a14	1.983	0.134	0.180	0.007	0.285	0.080	0.001	1110	46	1069	38	1199	35	89	1083	66	0.42	0.732
se07b24	1.561	0.065	0.156	0.004	0.278	0.073	0.001	955	26	932	20	1011	25	92	939	36	0.42	0.389
au26a08	0.512	0.028	0.065	0.002	0.274	0.057	0.001	420	19	405	12	479	34	84	408	22	0.44	0.472
au26a13	0.625	0.029	0.077	0.002	0.284	0.058	0.001	493	18	479	12	544	41	88	482	22	0.45	0.670
au26a07	3.903	0.164	0.290	0.006	0.248	0.100	0.001	1614	34	1643	30	1620	25	101	1631	50	0.46	0.913
au26a37	3.554	0.097	0.266	0.004	0.298	0.094	0.001	1539	22	1520	22	1499	19	101	1530	35	0.47	0.581
se08b12	0.647	0.016	0.080	0.001	0.313	0.057	0.001	507	10	499	8	508	20	98	501	14	0.47	0.541
se09a47	3.406	0.079	0.259	0.006	0.508	0.093	0.001	1506	18	1487	31	1497	12	99	1505	36	0.49	0.110
se09a34	0.538	0.019	0.069	0.001	0.262	0.056	0.001	437	12	428	8	470	27	91	430	14	0.49	0.489
se07b25	1.565	0.079	0.156	0.004	0.276	0.075	0.001	957	31	933	24	1066	39	88	941	43	0.49	0.773
se09a67	0.646	0.030	0.079	0.003	0.355	0.058	0.001	506	19	492	16	544	34	90	497	28	0.49	0.583
au26a17	0.602	0.046	0.074	0.003	0.282	0.061	0.001	478	29	458	19	624	30	73	462	35	0.49	0.149
au26a28	2.982	0.150	0.249	0.006	0.220	0.091	0.001	1403	38	1431	28	1441	27	99	1422	50	0.50	0.354
au26a60	0.583	0.037	0.072	0.003	0.370	0.056	0.001	466	24	450	21	454	46	99	456	37	0.51	0.518
se08a11	4.041	0.082	0.287	0.004	0.372	0.100	0.001	1643	17	1629	22	1629	14	100	1639	31	0.53	0.847
se08b17	0.562	0.023	0.074	0.002	0.304	0.056	0.000	453	15	463	11	446	20	104	460	20	0.54	0.234
se08b11	0.596	0.142	0.085	0.006	0.143	0.063	0.002	474	90	528	35	714	53	74	523	67	0.55	0.103
se07b14	0.535	0.025	0.068	0.002	0.272	0.056	0.001	435	16	426	10	443	31	96	428	19	0.58	0.804
se07b12	0.610	0.083	0.073	0.003	0.159	0.061	0.001	484	52	454	19	656	35	69	456	37	0.58	0.546
se09a22	0.660	0.103	0.077	0.007	0.284	0.066	0.001	515	63	479	41	809	26	59	486	77	0.58	0.175
se07b18	3.900	0.073	0.282	0.004	0.398	0.100	0.001	1614	15	1602	21	1620	13	99	1611	29	0.59	0.720
se07b21	4.089	0.112	0.289	0.005	0.328	0.105	0.001	1652	22	1638	26	1710	16	96	1646	39	0.60	0.359
au26a10	4.727	0.235	0.311	0.010	0.307	0.111	0.002	1772	42	1747	47	1819	35	96	1761	71	0.63	0.294
se09a24	4.157	0.060	0.293	0.004	0.455	0.101	0.001	1666	12	1657	19	1647	11	101	1665	23	0.63	0.282
se08b38	3.468	0.073	0.264	0.005	0.460	0.093	0.001	1520	17	1509	26	1492	15	101	1518	32	0.63	0.325
se08b37	3.481	0.184	0.262	0.006	0.199	0.103	0.001	1523	42	1501	28	1671	21	90	1507	51	0.63	0.727
se08b32	3.816	0.081	0.279	0.005	0.459	0.097	0.001	1596	17	1585	27	1563	11	101	1595	34	0.64	0.450

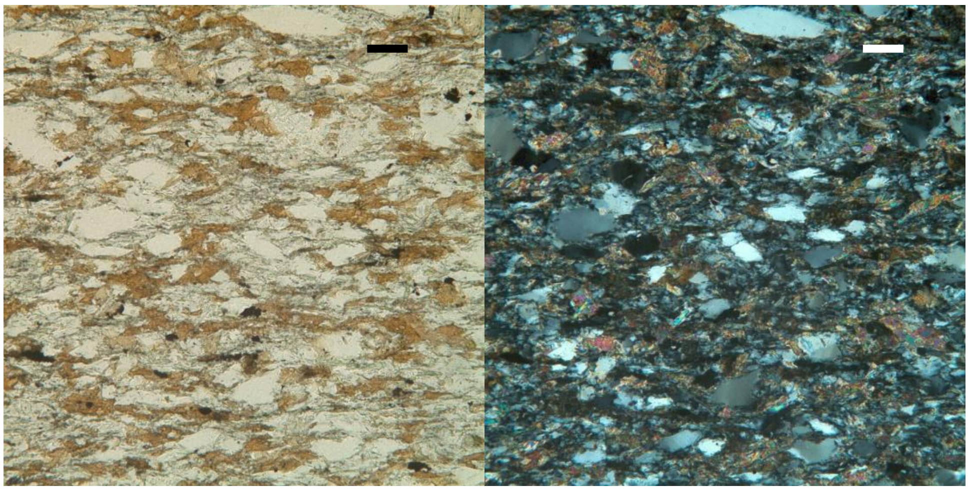
APPENDIX B

	Measured Isotopic Ratios							Calculated Ages										
Paxton Fm.	207Pb /235U	1s error	206Pb /238U	1s error	Rho	207Pb /206Pb	1s error	207Pb /235U	1s error	206Pb /238U	1s error	207Pb /206Pb	1s error	U-Pb/Pb-Pb conc. %	Conc. age	2s error	Prob. of conc.	Ratio Th/U
se08a10	3.607	0.082	0.274	0.004	0.330	0.096	0.001	1551	18	1561	21	1550	12	101	1555	31	0.65	0.299
au26a20	2.681	0.096	0.225	0.005	0.302	0.084	0.001	1323	26	1309	26	1300	22	101	1316	42	0.65	0.532
se09a43	1.767	0.045	0.175	0.003	0.349	0.074	0.001	1033	17	1041	17	1045	19	100	1037	28	0.68	0.583
se07b15	0.531	0.021	0.068	0.002	0.285	0.056	0.001	433	14	427	9	445	20	96	428	17	0.69	0.622
se09a28	0.725	0.051	0.088	0.003	0.247	0.061	0.001	553	30	541	18	647	28	84	543	34	0.69	0.081
se08b39	3.182	0.066	0.251	0.004	0.372	0.092	0.001	1453	16	1445	20	1473	11	98	1450	29	0.71	0.792
se08b21	1.145	0.054	0.126	0.006	0.519	0.064	0.001	775	26	764	35	752	18	102	773	50	0.71	0.064
se09a14	0.574	0.022	0.073	0.001	0.262	0.055	0.001	460	14	455	9	414	28	110	456	16	0.72	0.840
se08b08	3.295	0.077	0.257	0.004	0.373	0.091	0.001	1480	18	1472	23	1450	14	102	1477	33	0.74	0.356
se08b41	2.182	0.063	0.199	0.004	0.354	0.079	0.001	1175	20	1167	22	1170	17	100	1172	35	0.75	0.285
au26a33	0.581	0.049	0.073	0.003	0.232	0.058	0.001	465	32	457	17	518	37	88	458	33	0.81	0.139
se09a23	4.333	0.187	0.299	0.010	0.368	0.098	0.001	1700	36	1689	47	1582	20	107	1696	66	0.82	0.603
au26a52	0.558	0.029	0.072	0.002	0.326	0.055	0.001	450	19	445	15	415	21	107	447	27	0.82	0.524
se09a29	3.158	0.062	0.251	0.003	0.317	0.090	0.001	1447	15	1443	16	1420	15	102	1445	25	0.83	0.401
se08b20	3.619	0.123	0.271	0.008	0.416	0.096	0.001	1554	27	1546	39	1541	23	100	1552	52	0.83	0.176
se09a62	3.400	0.075	0.262	0.005	0.476	0.093	0.001	1504	17	1499	28	1482	14	101	1504	34	0.83	0.282
au26a41	1.552	0.065	0.158	0.004	0.301	0.069	0.001	951	26	945	22	902	32	105	948	38	0.84	0.440
se08b34	0.533	0.012	0.070	0.001	0.342	0.056	0.000	434	8	435	7	444	18	98	435	12	0.85	0.913
se09a21	0.584	0.015	0.075	0.001	0.375	0.056	0.000	467	10	469	9	440	17	106	468	15	0.86	0.008
se09a30	1.677	0.056	0.167	0.003	0.296	0.074	0.001	1000	21	996	18	1051	26	95	998	31	0.87	0.399
se09a31	3.732	0.169	0.276	0.007	0.267	0.096	0.002	1578	36	1572	34	1556	42	101	1575	56	0.88	0.507
au26a47	0.508	0.061	0.066	0.003	0.190	0.057	0.001	417	41	412	18	479	56	86	412	35	0.89	0.763
se08b24	13.554	0.235	0.526	0.008	0.438	0.184	0.001	2719	16	2723	34	2686	9	101	2719	33	0.89	0.475
se08b18	3.753	0.146	0.277	0.008	0.349	0.097	0.001	1583	31	1578	38	1575	19	100	1581	56	0.90	0.625
au26a61	0.526	0.024	0.069	0.002	0.259	0.056	0.001	429	16	428	10	464	22	92	428	18	0.93	0.630
se09a61	1.743	0.060	0.172	0.004	0.352	0.074	0.001	1024	22	1023	23	1049	28	98	1024	37	0.96	0.755
se08b07	4.418	0.074	0.305	0.005	0.484	0.104	0.001	1716	14	1716	24	1693	14	101	1716	27	0.98	0.576
se08b14	0.557	0.037	0.072	0.002	0.242	0.056	0.001	450	24	450	14	462	43	98	450	26	0.98	0.416
se08b31	0.520	0.014	0.068	0.001	0.337	0.055	0.000	425	9	425	7	427	19	100	425	13	0.98	0.522

APPENDIX B

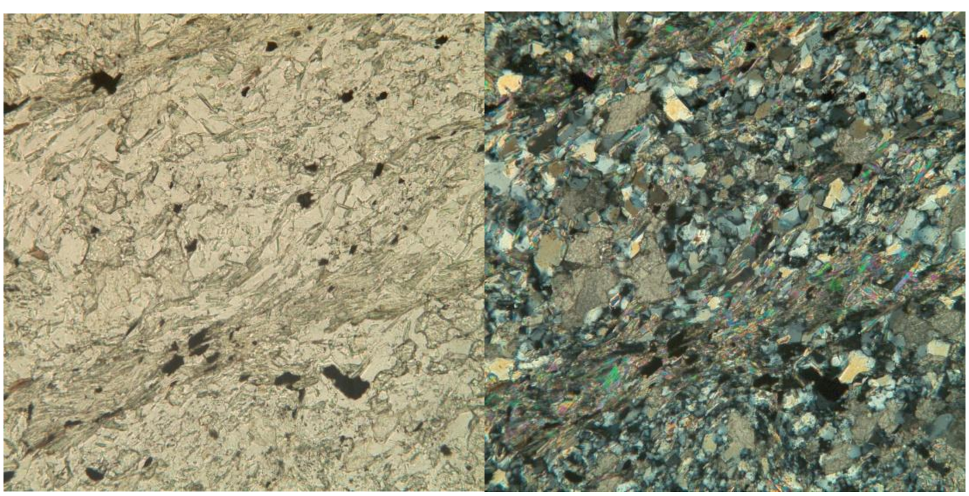
Paxton Fm.	Measured Isotopic Ratios 207Pb /235U	1s error	206Pb /238U	1s error	Rho	207Pb /206Pb	1s error	Calculated Ages 207Pb /235U	1s error	206Pb /238U	1s error	207Pb /206Pb	1s error	U-Pb/Pb-Pb conc. %	Conc. age	2s error	Prob. of conc.	Ratio Th/U
se09a27	2.360	0.052	0.210	0.003	0.353	0.081	0.001	1231	16	1231	18	1222	19	101	1231	27	0.99	0.699
se08b22	2.943	0.046	0.241	0.003	0.412	0.088	0.001	1393	12	1393	16	1382	14	101	1393	22	1.00	0.460

Appendix C. Thin sections images and modes



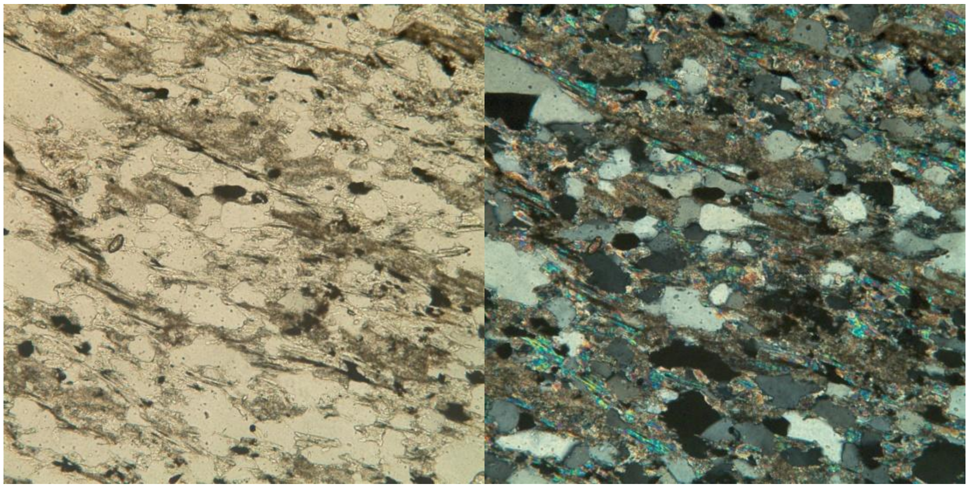
Thin section images for KSKTI (Kittery Formation). Right: plane polarized light, left: crossed polarized light

Scale 1.232 mm



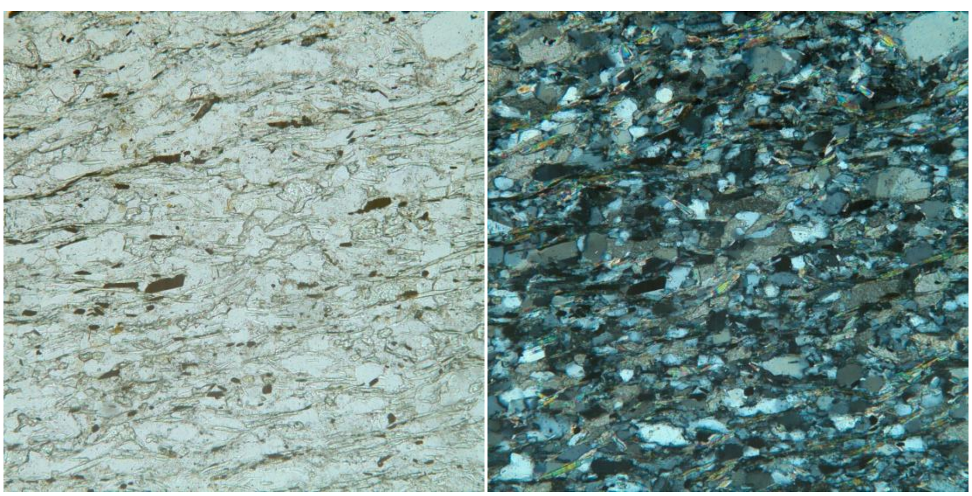
Thin section images for KSELI (Eliot Formation). Right: plane polarized light, left: crossed polarized light

Appendix C. Thin sections images and modes



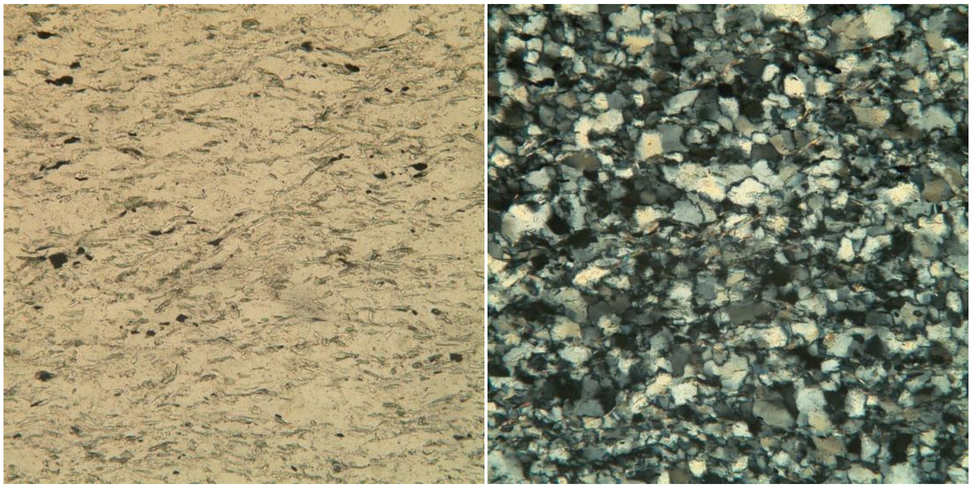
Thin section images for KSBWI (Berwick Formation). Right: plane polarized light, left: crossed polarized light

Scale 1.232 mm



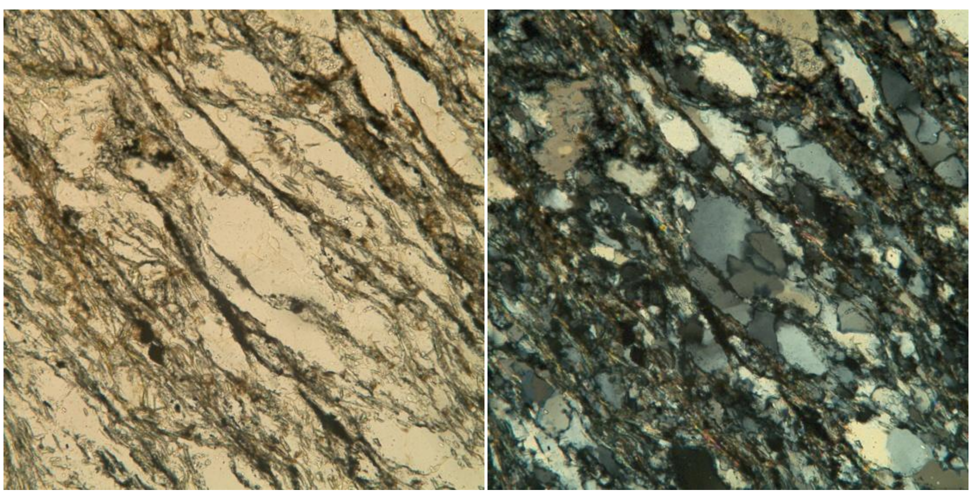
Thin section images for KSOKI (Oakdale Formation). Right: plane polarized light, left: crossed polarized light

Appendix C. Thin sections images and modes



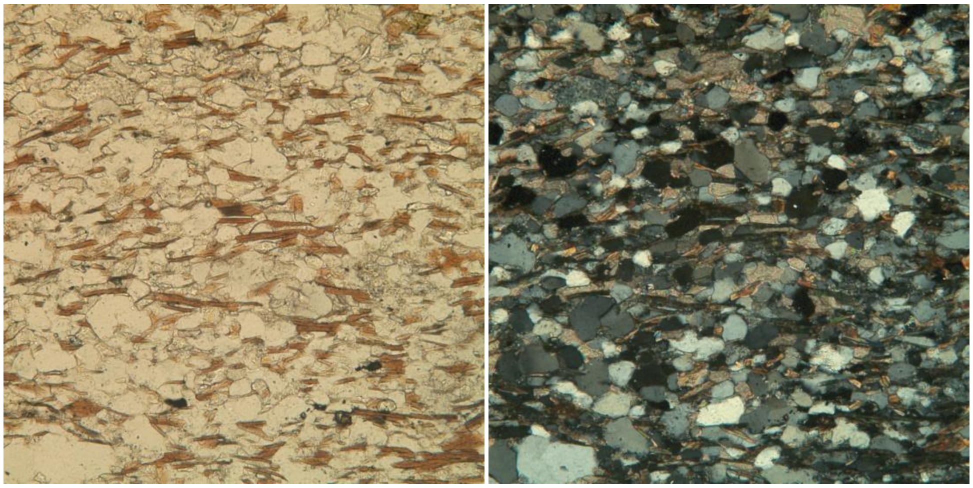
Thin section images for KSTHI (Tower Hill Formation). Right: plane polarized light, left: crossed polarized light

Scale 1.232 mm



Thin section images for KSWSI (Worcester Formation). Right: plane polarized light, left: crossed polarized light

Appendix C. Thin sections images and modes



Thin section images for KSPXIII (Paxton Formation). Right: plane polarized light, left: crossed polarized light

Scale 1.232 mm

Appendix C. Thin sections images and estimated modes

Table of estimated modal compositions for Merrimack terrane samples

	Quartz	Biotite	Muscovite	Carbonate	Zircon	Plagioclase	Opaques	Chlorite
KSKTI	55	25	<1	<1	<1	<1	2	15
KSELI	55	1	15	27	<1		2	
KSBWI	60		20	15	<1		5	
KSOKI	55	5	15	23	<1		2	
KSTHI	94		5		<1		1	
KSWSI	70	5	12		<1	<1	1	12
KSPXIII	65	20		15	<1		<1	