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James Brandon Shope April 19, 2011

Ichnology and Composition of the Pinelog Formation Quartzite, Jasper, Georgia: Situating the Formation in the Geologic Record.

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An abstract of
a thesis submitted to the Faculty of Emory College of Arts and Sciences
of Emory University in partial fulfillment
of the requirements of the degree of
Bachelor of Sciences with Honors

Department of Environmental Studies

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Abstract

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The Pinelog Formation Quartzite is a low-grade metamorphosed quartz arenite that crops out near Jasper, Georgia. Its lithology, physical sedimentary structures, and trace fossils indicate that its sediments were initially deposited in a shallow, near-shore marine environment. The presence of trace fossils (Palaeophycus) has been previously documented; however, this discovery was not examined in detail and the full implications of these fossils remained unresolved. Furthermore, despite this information about the original depositional environment of the Pinelog Formation, its age and occurrence have not been clearly defined. Previous work has placed the Pinelog in the Ediacaran Period; however, examples of Palaeophycus and trace fossils indicate the Pinelog is at least of Cambrian age. Samples of bedding and fossil burrows were collected from two different outcrops and burrow dimensions measured. These burrows are compared with descriptions of the identified trace fossils in the literature to determine if their classifications were appropriate. The mineral composition of each sample was analyzed through thin-section point counts, and mineral proportions were compared with the Snowbird Group (Ocoee Supergroup) and the Chilhowee Group to better determine the lithologic affinity of the Pinelog Formation. Locations of samples and associated features were mapped using ESRI's ArcGISTM software, which was used to show the distribution of physical and chemical features. Burrow samples collected by Martin and Crawford (1996) were then re-measured and in one instance reclassified as Taenidium. The presence of Taenidium indicates that the Pinelog Formation is at least Cambrian in age and most probably belongs to the Chilhowee Group based on that age.

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Acknowledgements

I would like to thank Dr. Anthony Martin for directing me through this entire process and helping to correct my numerous errors.

I would also like to thank Dr. William Size for helping me gain access to equipment, examine specimens, advice, and overall patience.

Thank you Dr. Henderson for giving me the base knowledge needed to undertake this project.

I would also like to acknowledge Mike Higgins and Ralph Crawford for showing me the site, accompanying me to outcrops, and providing information essential to the completion of this project.

Table of Contents

Introduction

The Pinelog Formation is a basal sequence of metasedimentary rocks that overlie basement rock in the Southern Appalachians. The Pinelog is divided into three separate subunits - Lower, Middle, and Upper (Li and Tull 1998) - but the focus of this study is on the lithology, physical sedimentary structures, and ichnology of the Middle Pinelog Formation on Henderson Mountain, Pickens County, Georgia.

The Middle Pinelog is an approximately 100-m thick sequence consisting mainly of light-yellow to light-grey, thinly bedded, trough cross-bedded quartzite that range from subarkosic to quartz arenite in the original source rock, or protolith (Li and Tull 1998). These layers grade downward into less mature, coarser metagraywackes and metaconglomerates that compose the Lower Pinelog. In general, grains are recrystallized, and intermittent relict primary grains indicate the grain size was initially fine to medium sand. The sequence then grades up into the quartz-mica phyllite/schist and the mica phyllite/schist of the Upper Pinelog (Li and Tull 1998). The transition from the coarser grains of the Lower Pinelog into the finer grains of the middle Pinelog has been interpreted as a transgressive sequence. In this scenario, sediments of the Lower Pinelog were deposited in a fluvial to alluvial fan environment, which were overlain by fine-grained sediments of a shallow-marine environment (Tull 2007). Li and Tull (1998) interpreted these Pinelog sequences as a result of deposition in a basin along the rifting Laurentian continental margin that was subsequently stabilized and inundated.

The age and stratigraphic grouping of the Pinelog Formation is still uncertain. Li and Tull (1998) interpret the age of the formation as Late Proterozoic and part of the Ocoee Snowbird Group. Another option presented by Crawford et al (1999) is that the Pinelog is Cambrian, or otherwise from the early Paleozoic Era, and belongs to the Chilhowee Group. Crawford et al. (1999), however, found that graphitic phyllites within the quartzite resemble layers in the Nantahala Formation of the Chilhowee Group, and that the Pinelog is nearly identical to sequences found on Chilhowee Mountain, Tennessee. The Lower Chilhowee Group stratigraphically overlies the Ocoee Group, and is a continental to marine-shelf clastic sequence. The Chilhowee marks the continental rifting of Pannotia that later formed Laurentia, Baltica, Siberia, and Gondwana, showing the transition from an actively rifting margin of Laurentia to a passive margin as the Iapetus Ocean widened (Rogers 1996, Tull 2007). The Ocoee Group is primarily composed of clastic sediments and interpreted to have formed within a rifting basin along the southern margin of Laurentia (Mack 1980).

Tull (2007) gave multiple reasons why the Pinelog Formation should belong to the Snowbird Group. For one, if the Pinelog were allied with the Chilhowee, the Georgia basement massifs would be the only places along a 200-km segment south of the Great Smoky Mountains where the Ocoee is absent between the Chilhowee and basement rocks. The Pinelog must also be separated by a large fault structure from the structurally overlying and upright Ocoee Supergroup to the east. In contrast to Crawford et al. (1999), who claim the Pinelog is structurally and lithologically most similar to the Chilhowee at Nantahala Mountain (Nantahala Formation), Tull (2007) argues that the similarity is relatively small. He also claims that the upper part of the Chilhowee must be missing from the Pinelog. Other Chilhowee sandstones are mostly grain-supported; the grain particles are in contact with one another to form the physical framework of the rock. Although the Middle Pinelog mostly exhibits these sedimentary textures, the matrix is composed of recrystallized quartz and mica (~ 37% matrix), demonstrating poorer grain support than would be expected from a member of the Chilhowee Group (Tull 2007). Additionally, the main feldspar in the Chilhowee is potassium feldspar (or K-feldspar), whereas the Pinelog exhibits a low K-feldspar to plagioclase-feldspar ratio. In general, the Pinelog could be part of the Chilhowee Group, but is more probably part of the Snowbird Group (Tull 2007). Despite this extensive research by Tull (2007), the presence of *Palaeophycus* and other trace fossils described earlier by Martin and Crawford (1996) would place the Pinelog minimally within the Cambrian, and the Chilhowee Group by extension.

The objectives of this paper are: (1) to describe possible origin for sedimentary and post-depositional features observed in the rocks at Henderson Mountain; (2) cartographically analyze the distribution of lithologic features such as grain size, maturity, and iron staining; (3) reexamine the structures described by Martin and Crawford (1996) and compare these to previous descriptions of *Palaeophycus, Skolithos,* and other trace fossils; and (4) petrographically analyze the mineral composition of the Pinelog quartzite to determine whether it is more similar to descriptions of the Chilhowee or Snowbird Groups.

Trace Fossil Descriptions

The ichnogenus *Palaeophycus* has been misused for a number of years and includes some 54 ichnospecies (Pemberton and Frey 1982). In many cases, each individual discovery of *Palaeophycus* between 1847 and 1883 was afforded its own ichnospecies instead of being properly described and placed into a pre-existing ichnospecies. Because of the confusion created by the multiple ichnospecies, Pemberton and Frey (1982) only recognized five different ichnospecies of *Palaeophycus* based on wall linings and burrow sculptings. These are *P. heberti*, *P. tubularis*, *P. striatus*, *P. sulcatus*, and *P. alternatus* (Pemberton and Frey 1982). In general, *Palaeophycus* burrows are lined by agglutinated sediment that can be either thin or thick

(Pemberton and Frey 1982). The shapes of the burrows themselves are cylindrical, rarely branch, and can be straight to slightly curved; burrow walls are unornamented and smooth (Pemberton and Frey 1982). There are limited reports of *Palaeophycus* in Ediacaran rock, thus *Palaeophycus* can be used as a limited index fossil for Cambrian and younger rocks, albeit with caution (Babcock et al. 2005, Jensen et al. 2006, Martin and Crawford 1996).

To test the findings of Martin and Crawford (1996), the reexamined burrows will be compared with other trace fossils reported near the Blue Ridge Province of Georgia. Trace fossils have been described in the Carolina Slate Belt from the late Precambrian, which extends from east-central Georgia up through South Carolina, North Carolina, and into southeast Virginia (Gibson 1989). The belt has been deformed by metamorphic and igneous activity, thus many of the physical structures have been lost or deformed themselves (Gibson 1989). Unverified early reports cite the existence of fossil structures resembling burrows in the slate, whereas later reports cite the presence Ediacaran body fossils (Gibson 1989; Tacker et al. 2010).

While somewhat problematic to readily identify, a potential candidate for the Carolina Slate Belt burrows could be *Skolithos*. *Skolithos* is an ichnogenus that is normally interpreted as dwelling burrows of annelids or phoronids (Alpert 1974). Annelids compose a large phylum of segmented worms, and phoronids are the relatively small phylum of horseshoe worms, both of which are common throughout the world's oceans (Ruppert and Fox 1988). *Skolithos* most commonly occurs in arenaceous rocks of the lower Paleozoic and younger, especially in the Cambrian to Devonian (Alpert 1974). These burrows may be densely crowded, but also occur isolated or in less densely populated groups (Alpert 1974). The length of the burrow can also be affected by the scouring of the overlying sediments, which may shorten the preserved burrow. The diameter of *Skolithos* burrows range from 1-15 mm (Alpert 1974). Martin and Crawford's

(1996) description of *Palaeophycus* at Henderson Mountain does not exclude the potential of the burrows to be *Skolithos*, thus these should be compared to descriptions of that ichnogenus as well.

Methods

Two sampling locations were selected along Henderson Mountain, Pickens County, Georgia, along the roads of Mulberry Circle and Oak Trace (Figure 1 – Locality Map). These areas were selected based on the proximity of each to the previously reported location of *Palaeophycus* by Martin and Crawford (1996) and the presence of outcrops. The area had been previously cleared for development and the underlying rocks exposed and displaced. Since clearing, development of the area has mostly subsided and now hosts a forest of new-growth pine trees.

Twenty-seven rock samples were collected and the location of each sample was recorded using a Garmin eTrex™ 12-channel handheld GPS unit. Elevation was not recorded, as a connection with four satellites is required; typically, the GPS unit could only connect with three during most field work at Henderson Mountain. Samples were selected based on the presence of bedding, cross-bedding, suspected burrows, or dark spots. Each sample was described, sketched to enhance features of interest, photographed, and collected if transportation of the sample was feasible.

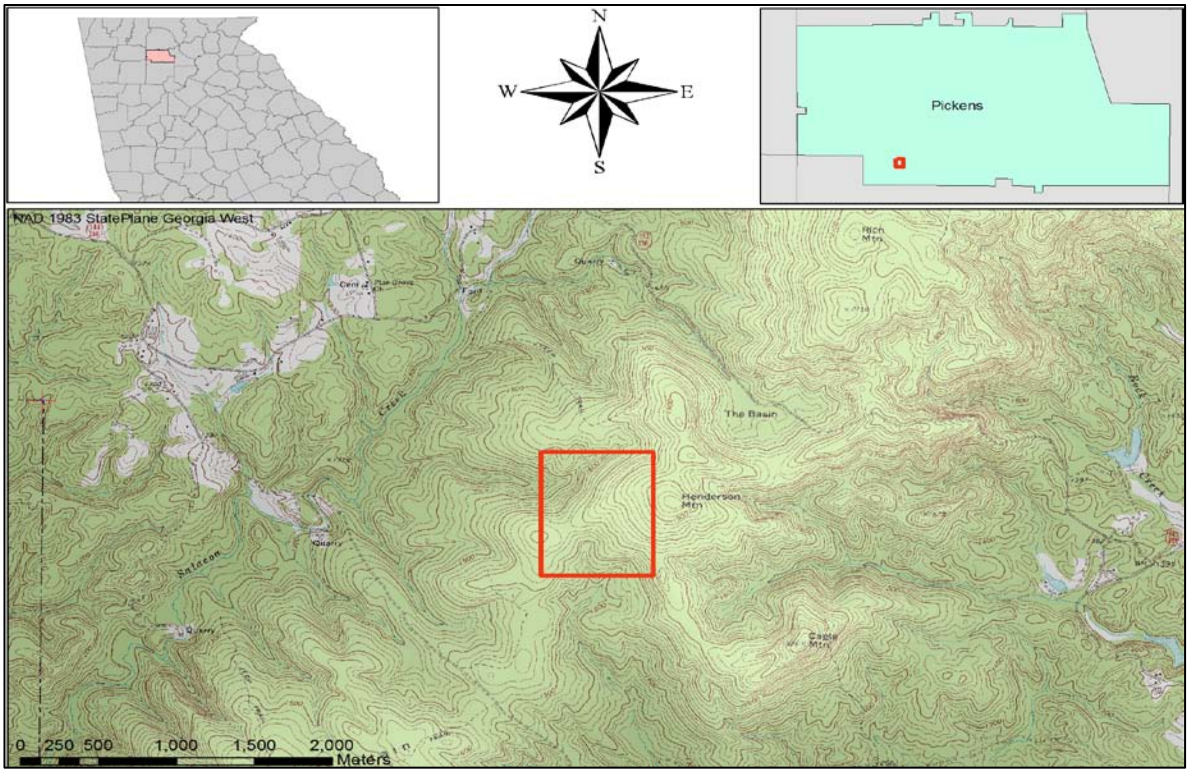

Figure 1. Locality map of the middle Pinelog Formation at Henderson Mountain, Pickens County, Georgia. Red box denotes sampling area.

Figure 2. Example of darker, possibly reduction spots prominent throughout much of the Henderson Mountain quartzite. Card dimensions; 54 mm x 86 mm.

The color of the fractured surface of each sample was recorded using a rock-color chart issued by the Geological Society of America (GSA). Samples were described as sedimentary rocks instead of metamorphic, seeing that the metamorphic grade was low enough to preserve physical sedimentary structures. Using a binocular microscope, grain size and shape were recorded, with shape described in terms of roundness and sphericity. Sorting and maturity of the rock was then determined using this information, after standard methods recommended by (Pettijohn et al. 1987). Otherwise, physical, chemical, and biogenic structures were described and sketched. These data were then compiled into a Microsoft Excel™ spreadsheet along with each samples location.

Several maps of sample localities tied in with descriptive data were created using ESRI's ArcMap™ application. Base-map data, such as county roads and contour layers, were collected from the Atlanta Regional Commission website. The coordinate system of these map sets was North American Datum 1983 StatePlane Georgia West. The Excel table was then imported into the map as an event layer, a temporary feature class of XY data, and the coordinate system of the sampling points imported from the existing map. However, once the points were displayed on the map, they were positioned far to the southwest of the actual sampling area. This error was attributed to the GPS recording the points using the World Geodetic System (WGS) 84, thus the coordinate system for the points was changed from the projected StatePlane coordinate system to the non-projected WGS 84 system. Once this error was corrected and the points properly displayed on the map, each point was assigned a different symbol based on fields of the table to analyze the distribution of features across the sampling area. First, grain sizes were given a color-coding from silt to very coarse sand, and these colors plotted on the map. Each subsequent field was displayed in the same way to view the distribution of features and each map exported as a JPEG file.

Next, a thin section of the quartzite was obtained from Martin, which had been previously made by Crawford in 1996, but had never been analyzed quantitatively. The thin section was a longitudinal section of a suspected fossil burrow in the local quartzite obtained from Henderson Mountain. The slide was first viewed under cross-polarized light in a petrographic microscope to determine the general types of minerals composing the rock. A point count of 1,000 counts was taken of the slide using an automatic stage. Each mineral grain appearing under the microscope crosshairs was identified and its occurrence recorded. The thin section had suffered some damage, probably as a result of its age (about 15 years), and had small gaps where minerals had fallen out. These darker areas were not recorded and any presence under the microscope crosshairs was not included in the 1,000 counts. At the end of the count, the number of occurrences of each mineral was converted to a percent.

A sample of burrows collected by Martin and Crawford (1996) was then reexamined. Martin and Crawford (1996) had previously reported the size distribution of burrow diameters using a handheld ruler and compared those diameters with descriptions of *Palaeophycus*. The burrow diameters were re-measured using a pair of digital calipers and the diameters measured to the nearest 0.1 mm. After a number of preliminary measurements, it was apparent that each burrow size did not remain consistent. As a result, each burrow was measured at two points along its length to encompass a range of diameters within each. Both the inside diameter and outside diameter of each burrow was measured. A total of 70 outside measurements and 66 inside diameters were recorded. These measurements were compiled in a Microsoft Excel™ spreadsheet and the average burrow diameter, standard deviation, median diameter, and mode were calculated. The mean of the burrow diameters measured from the outside of the burrow was then compared to the mean found by Martin and Crawford (1996) by a Z-test to determine significant difference. These statistics, along with verbal descriptions, were then compared to descriptions of *Palaeophycus* by Pemberton and Frey (1982) and *Skolithos* by Alpert (1974).

Results

Many of the rocks at the sampling site contained darker spots, ranging in size from 3-4 mm to 10-12 mm in diameter. Within each sample, the size of these spots was relatively the same throughout and oriented in the same direction (Figure 2); however, spot sizes varied between individual rocks. Each spot was an ellipsoid structure that tapered along its sides into thin edges. These spots did not occur in the same samples as other physical structures, and occasionally co-occurred with iron staining (Figure 2). In many cases, the presence of these spots was in the form of negative relief where they had weathered out of the surrounding rock. Under a binocular microscope, the grains forming the spots were typically the same size as the surrounding grains and often more opaque, almost solid white in most instances. In between these larger white grains were very fine-grained minerals that were dark red to black.

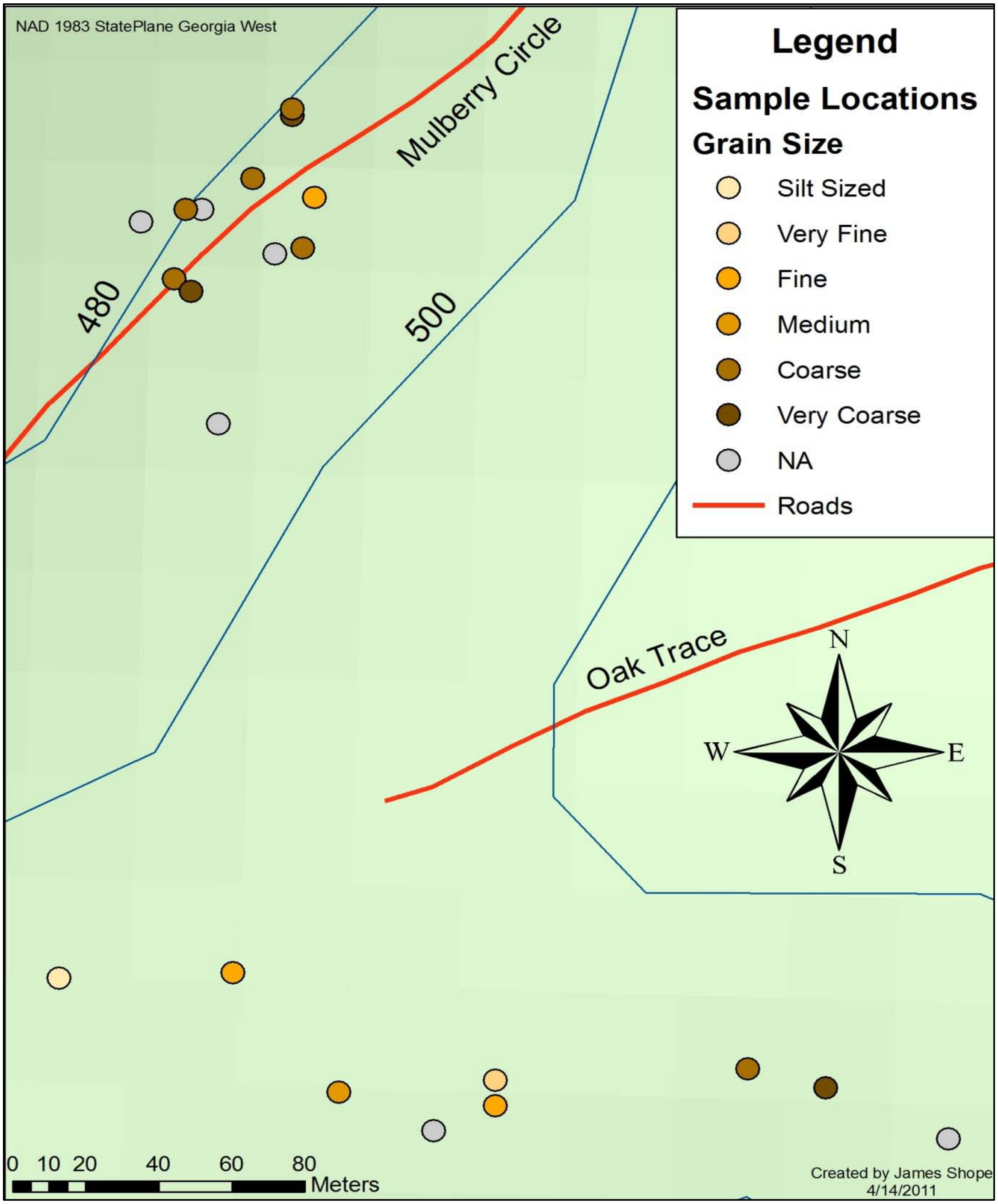

Figure 3. The distribution of grain sizes by sample location at Henderson Mountain, Pickens County, Georgia.

No discernable pattern was detected with respect to the distribution of rocks based on the grain size (Figure 3).

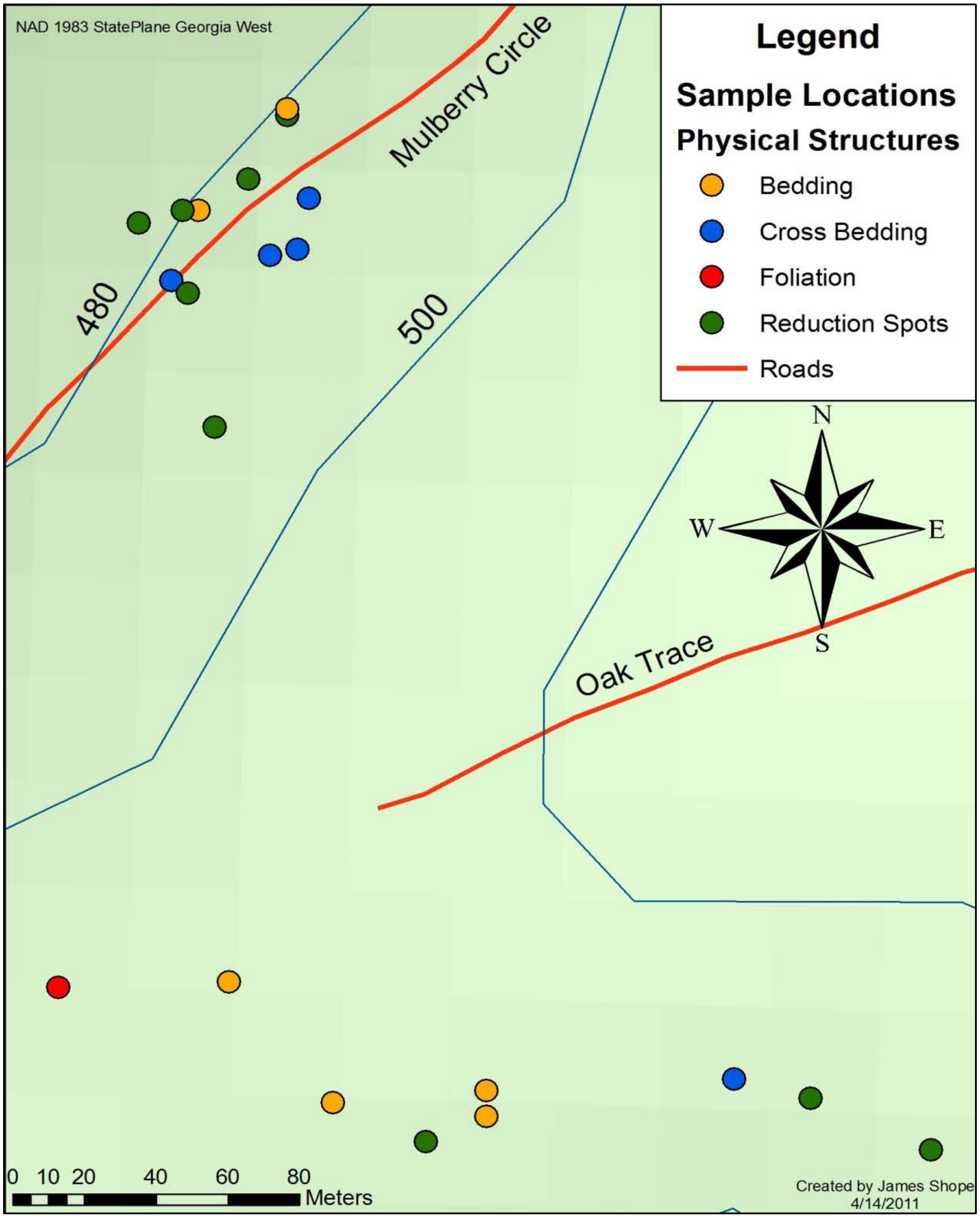

Figure 4. The distribution of physical structures observed by sample location at Henderson Mountain, Pickens County, Georgia.

The distribution of physical structures shows that spots and cross bedding were more common in the northern sampling site, whereas the southwestern portion of the sampling area was seemingly more metamorphosed (Figure 4). Again, no major trend was apparent in the distribution of physical structures.

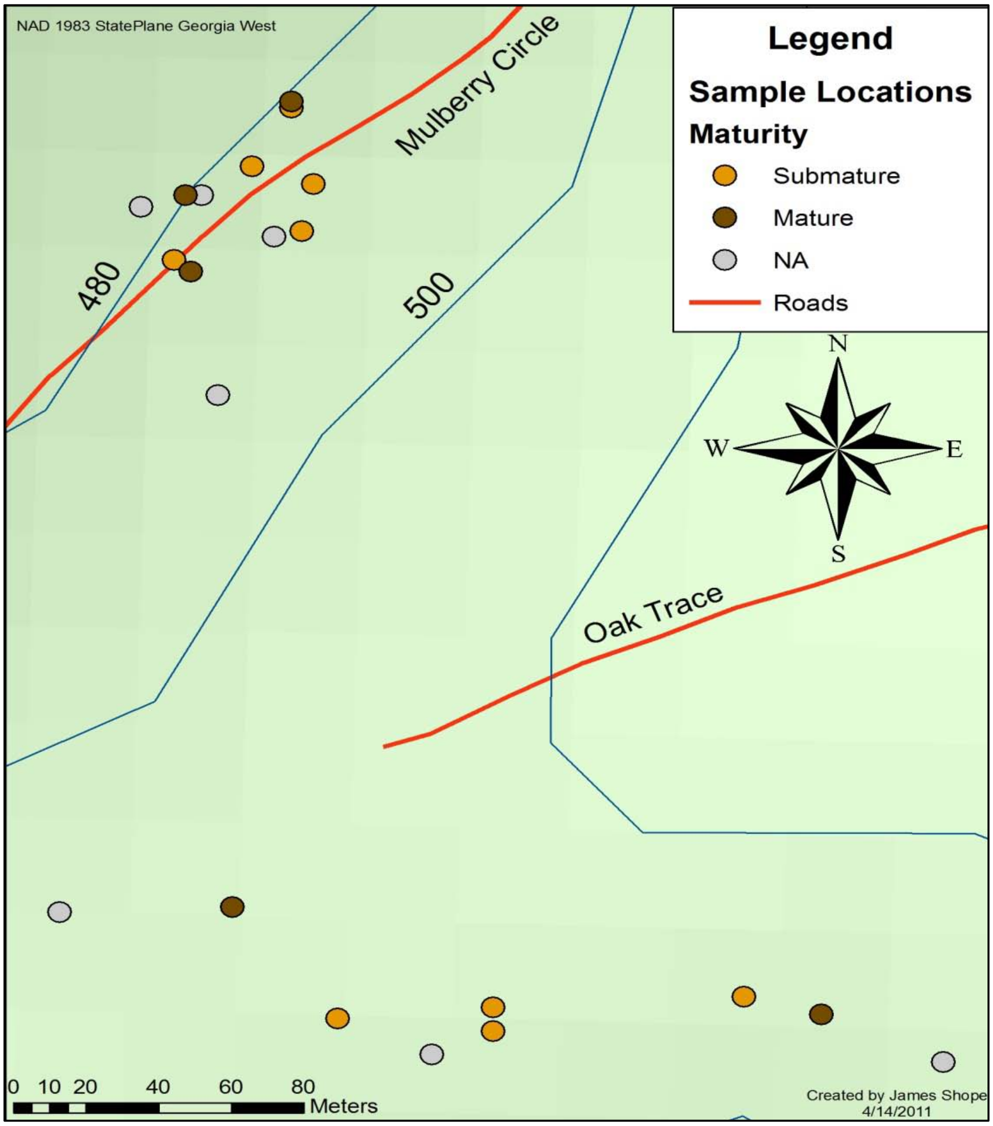

Figure 5. The distribution of maturity rocks by sample location, Henderson Mountain, Pickens County, Georgia.

The majority of samples were composed of submature grains to mature grains in places (Figure 5). In many samples, the maturity of the rock could not be determined, as significant weathering had distorted surface-grain characteristics. Other samples were metamorphosed to the extent that grains could not be adequately classified as mature or submature. Instead, these samples were classified as NA (not available).

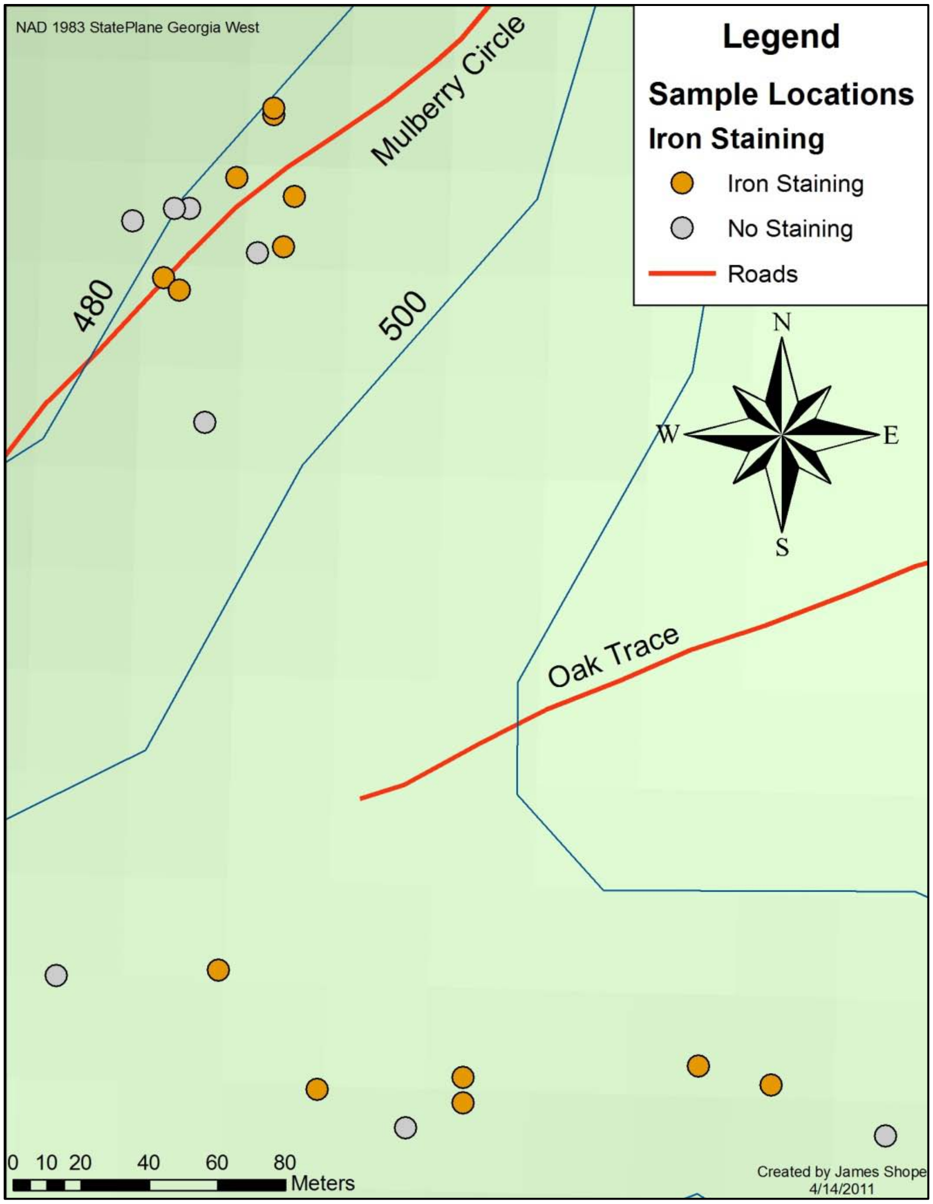

Figure 6. Distribution of iron staining in rocks by sample location, Henderson Mountain, Pickens County, Georgia.

The majority of the quartzite rocks in the Henderson Mountain sampling area had iron staining throughout (Figure 6). In many instances, the staining only penetrated a few centimeters into the rock or occurred in bands within the rock.

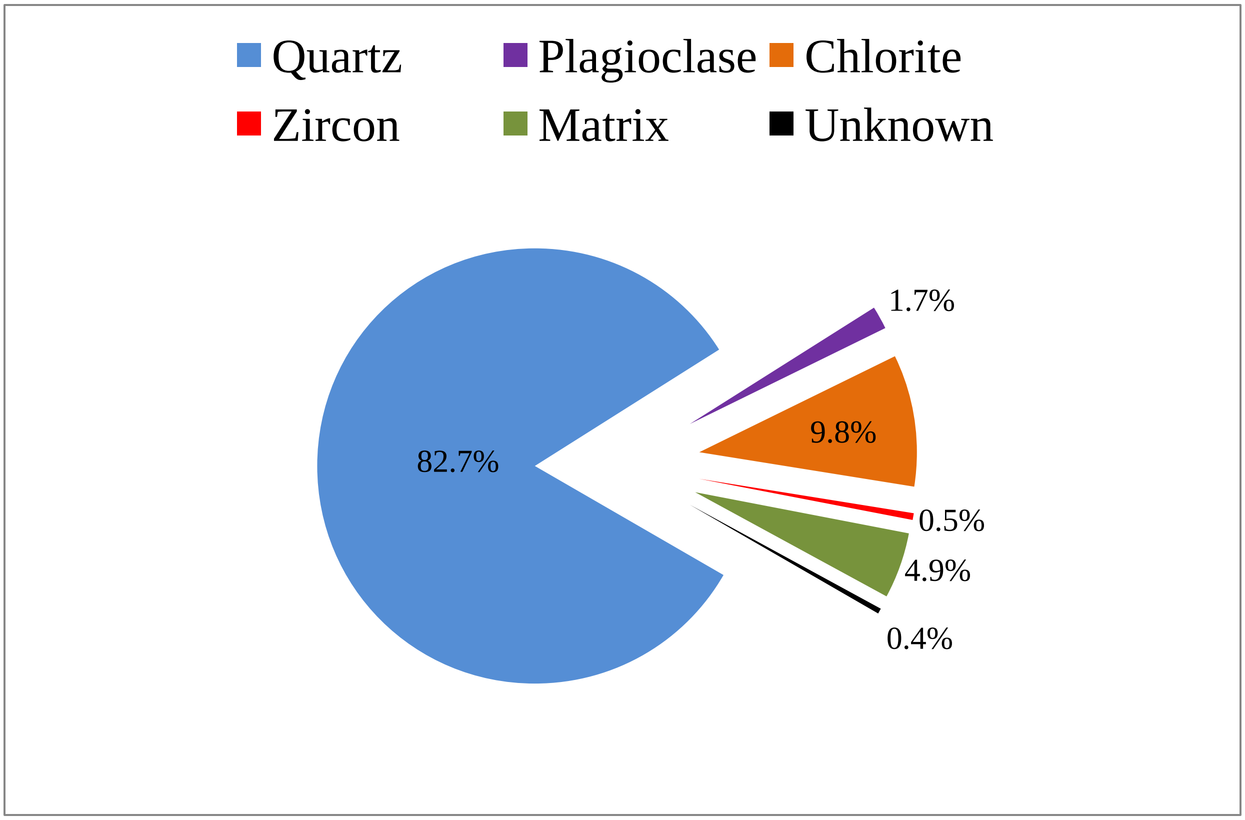

Figure 7. Mineral composition of the Henderson Mountain quartzite determined by point count (n = 1000)

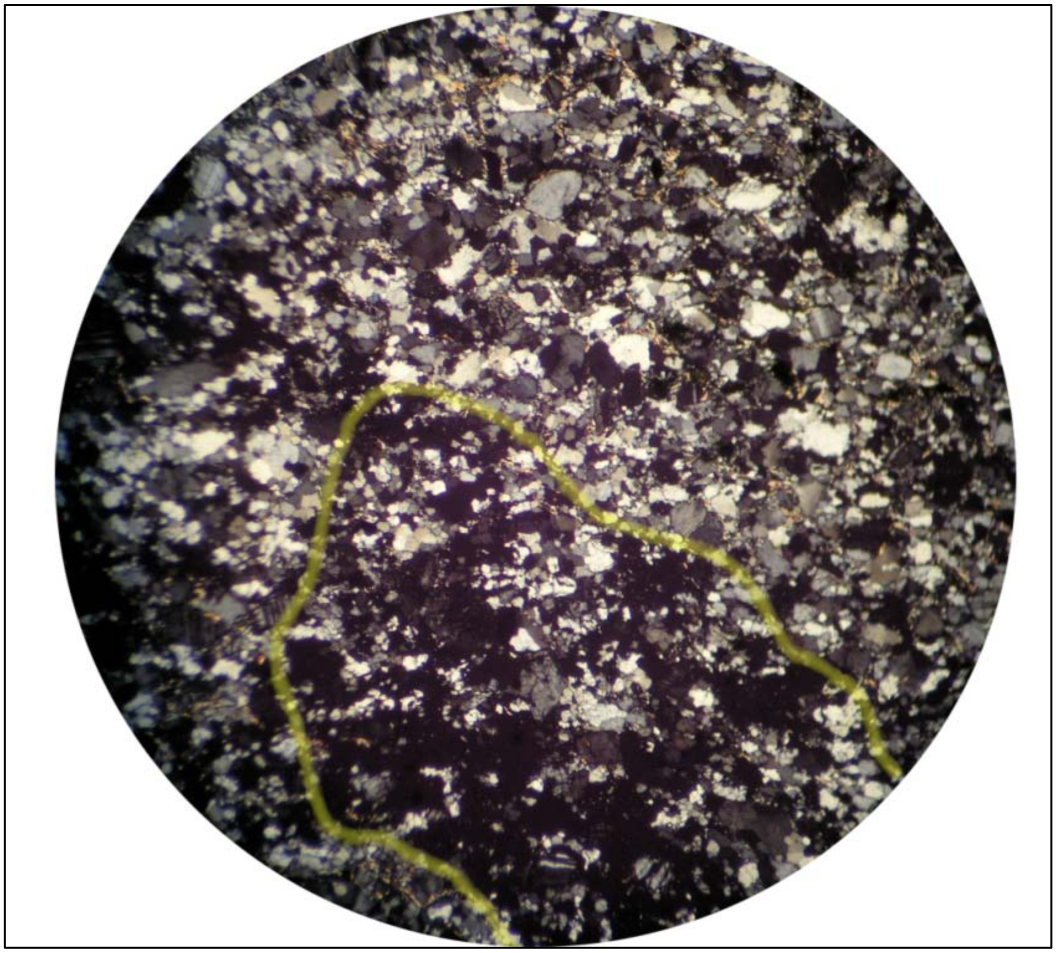

Figure 8. Photomicrograph of the Henderson Mountain quartzite. Yellow line delineates a burrow wall, composed of the darker minerals.

The thin-section sample was overwhelmingly composed of quartz (82.7 %), with chlorite as the next most abundant mineral at 9.8 %. Aside from the chlorite, the minerals were evenly distributed throughout the sample. The chlorite was located primarily in the walls of the burrow. There was no difference between the composition inside the burrow and in the surrounding rock. As a photomicrograph of the sample indicates (Figure 8), larger quartz grains are interlocking and somewhat angular, a product of recrystallization of the quartz grains. The darker band of minerals represents the boundary of the burrow, and is primarily composed of aggregates of very fine chlorite crystals. These could be alterations of clay minerals that originally formed a lining on the burrow; linings are common traits of modern burrows and are apparent in some trace fossils (Jensen et al. 2006, Potter et al. 2005, Ruppert and Fox 1988).

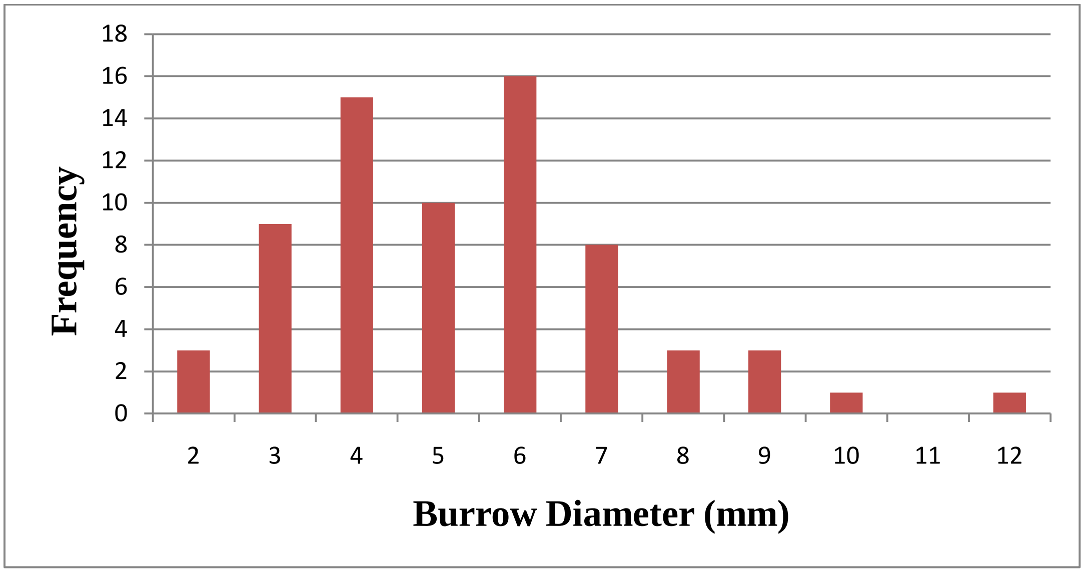

Figure 9. Size-frequency distribution of *Palaeophycus* diameters, Pinelog Formation, Pickens County, Georgia (n = 70 specimens).

Table 1. Descriptive statistics for *Palaeophycus* from the Pinelog Formation, Pickens County, Georgia.

Burrow Diameters (n = 70 Specimens)	**Burrow Diameter Statistics Reported by Martin and Crawford (n = 121 Specimens)**
Mean = 5.7 mm Standard Deviation = ± 2.0 mm Median = 5.7 mm Mode = 6.0 mm	Mean = 5.8 mm Standard Deviation = ± 1.4 mm Median = 6.0 mm Mode = 5.0 mm

Table 2. Z-test for similarity between the means of observed burrow diameter and burrow diameter reported by Martin and Crawford (1996).

Z-Test
Null Hypothesis: $\mu = 5.8$
Test Statistic: $z = -0.41833$
Critical Value: $\pm$ 1.96
Conclusion: Fail to reject null hypothesis at 95% confidence

Burrow diameters were mostly 3-5 mm (Figure 9). The Z-test (Table 2) shows no significant difference between the re-measured sample mean and the mean of the population compared to those determined originally by Martin and Crawford (1996). This result is not statistically conclusive as the distribution of burrow diameters is not statistically normal; however, on a practical level, there is no difference.

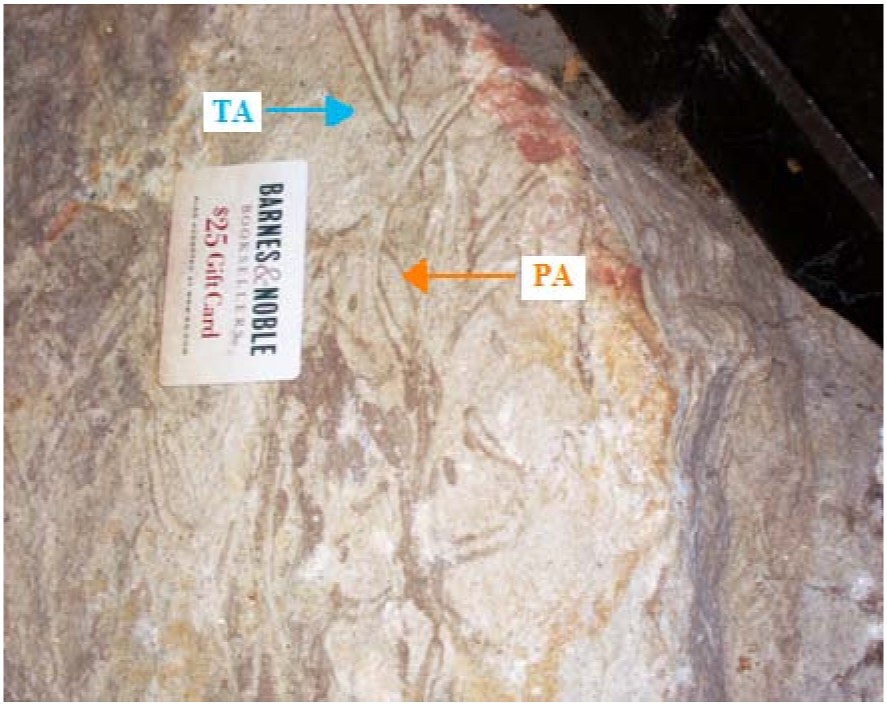

Figure 100. Example of *Palaeophycus* and possible *Taenidium* with meniscate (backfill) structure in quartzite, Pinelog Formation, Pickens County, Georgia. Card Dimensions: 54mm x 86 mm.

Figure 11. *Taenidium* ichnofossil with a meniscate (backfill) structure and possible branching (or intersecting) with another backfill structure.

Table 3.Comparison of features described by Pemberton and Frey (1982) for *Palaeophycus heberti*, features observed for structures in the Pinelog Formation, Pickens County, Georgia, and features described by Alpert (1974) for *Skolithos.*

P. heberti	**Observed**	***Skolithos***
Smooth, Unornamented Burrow	Smooth, Unornamented	May Have Limited Ornamentation
Cylindrical	Cylindrical	Cylindrical
Thickly Lined Burrow Wall	Thickly Line Burrow Wall (avg. = 1.15 mm)	Burrows Not Lined
Straight to Sinuous	Straight to Sinuous	Straight to Sinuous
Burrow Crossovers Common	Multiple Burrow Crossovers	Limited to No Crossovers
Hypichnial Ridges Present	Burrow Linings Display Levee Form	No Ridges Present
Branching Uncommon	No Branching, Possible in Places	No Branching
Oriented Oblique to Bedding	Oriented Horizontal to Oblique to Bedding	Vertical Tubes

Discussion

No trend in the distribution of grain sizes or physical structures can be determined cartographically. As Tull (2007) describes, the Pinelog Formation represents a fining-upwards sequence. Therefore, when exposed to weathering, the grain sizes of an exposed rock should be similar to those around it, as the stratigraphic column is grouped into distinct layers of similar grain sizes. However, the mix of grain sizes in close proximity to one another is most likely due to human influence. The site had been previously disturbed by bulldozing and construction activity. As a result, these rocks were fragmented and disordered.

The maturity of the grains is by and large submature to mature (Figure 5), suggesting a moderate amount of transport. As the Pinelog Formation lies uncomfortably on top of the local Grenvillian basement massifs, sediments forming the Pinelog are probably directly derived from the erosion of these massifs (Li and Tull 1998). As the Pinelog represents a fluvial to near-shore depositional sequence, these grains were probably transported a moderate distance and deposited readily in shallow waters without much rounding due to wave action. A possible cause for the lack of rounding could be that the sediments were buried relatively quickly under newer sediments. Although the entire formation is composed of metamorphic rocks, the samples collected from the other areas of Henderson Mountain had easily recognizable grains with limited recrystallization. However, the rocks in the southwest portion of the sampling area were completely recrystallized metamorphic rocks. Few of these rocks were collected, as no physical structures could be observed.

The distribution of physical structures also did not reveal much information. The dark spots (Figure 2) never occurred in a sample of quartzite that had either bedding or cross-bedding (Figure 4), suggesting that they formed either during or after metamorphism. There have been many theories for the formation of reduction spots. Broadly, the formation of reduction spots can be attributed to diagenesis before sedimentary lithification and subsequent metamorphism (Wood and Oertal 1980). Reduction spots may form during diagenesis if the sediment has a somewhat large amount of iron-bearing minerals. Most of the rocks within the sample area have large amounts of iron staining (Figure 6), and fulfill this requirement. The process of reducing the iron is accomplished by bacteria that rely on organic material as an energy source to drive the reaction (Weibel 1998). These spots can then be used as strain indicators as they orient themselves perpendicular to stress (Wood and Oertal 1980). Initially, they would appear spherical, and then deformation would result in ellipsoidal areas oriented in the same direction, as previously seen on Henderson Mountain (Wood and Oertal 1980). However, the preservation of these spots would be inconsistent with the erasure of other physical structures. Because reduction spots did not occur alongside any other physical structure in any sample, it is unlikely that the processes, metamorphic or otherwise, that removed bedding planes and other structures would have left the spots relatively undamaged. Additionally, a review of the literature has yielded no examples of reduction spots occurring in quartzites, just in shales and slates. These inconsistencies would need to be resolved before claiming that these structures are indeed reduction spots.

An alternative explanation is that, given enough bioturbation in these areas, physical sedimentary structures would have been removed, and the organic material left behind by the bioturbating organisms could have been used by bacteria to fuel the reduction process. However, no direct evidence was found to support this hypothesis, hence future research should continue to ascertain the genesis of these features.

Measurements of burrow diameters by Martin and Crawford (1996) with a handheld ruler were shown to be significantly similar to the measurements of the burrows in the sample measured with digital calipers (Table 2). Comparisons with observed features with examples of *Skolithos* and *Palaeophycus heberti* show that the structures observed more closely resemble *Palaeophycus heberti* (Table 3). Further evidence that these burrows are indeed *P. herberti* is from chlorite composing the lining of the burrow walls (Figure 8). *Palaeophycus* burrow walls are composed of agglutinated sediment that may be coarser grained than the surrounding rock (Pemberton and Frey 1982). In this instance, the presence of chlorite in the wall of the burrow would indicate that the chlorite had formed from finer-grained clays lining the walls of the burrows, most probably placed there by a burrowing organism as a byproduct of feeding or for structural support. The range of burrow diameters also compares favorably to previous examples of *P. heberti*. The range of sample burrow diameters is from 2.4 mm to 12.4, whereas previous research of *P. heberti* by Frey and Howard (1985) indicated burrow diameters ranging from 1.5 to 8 mm. Although no statistical test was undertaken to compare the two means, the range of the burrow diameters overlaps enough to provide further evidence that these structures are consistent with *P. heberti*.

Palaeophycus can be used as a limited index fossil for the Cambrian Period and younger rocks (Martin and Crawford 1996). Although there is limited evidence for the presence of *Palaeophycus* in the latest Precambrian (Martin and Crawford 1996, Babcock et al. 2005, Jensen et al. 2006), it is unlikely that these rocks are Precambrian. Further evidence that the rock is at least Cambrian is the presence of the ichnogenus *Taenidium* among the *Palaeophycus* in the sample. *Taenidium* is an ichnogenus present in Cambrian and younger rocks and is denoted primarily by meniscate structures, indicating the burrowing organism backfilled the burrow (Figure 11; Jensen et al. 2006). There have been previous reports of *Taenidium* in Ediacaran rocks, but these have since been identified as body fossils (Jensen et al. 2006).

Tull (2007) cites the relatively low ratio of K-feldspar to plagioclase feldspar as a major feature of the Pinelog Formation, making it lithologically more similar to the Snowbird Group (Ocoee Supergroup). In contrast, the Chilhowee Group tends to have a higher ratio of K-feldspar to plagioclase, and the sandstone facies tend to be arkosic to subarkosic sandstones (Cudzil and

Driese 1987). The quartzite analyzed at Henderson Mountain is fairly pure. The proportion of other minerals aside from chlorite to quartz is extremely small, suggesting that the protolith was probably a quartz arenite and not an arkosic sandstone. The relatively high percentage of chlorite can be downplayed when relating it to the overall lithology of the Pinelog, as this mineral was concentrated in the burrow linings of the sample (Figure 8). In addition, the proportion of K-feldspar to plagioclase is non-existent, as no K-feldspar was identified in the sample (Figure 6). Even assuming the unknown category is all K-feldspar, the proportion of K-spar to plagioclase would still be very small and not large enough to consider the protolith to have been arkosic. Additionally, Tull (2007) states that the Pinelog Formation is characterized by low grain support, being composed of ~37% matrix. However, the thin section analyzed was composed of ~4.9% matrix, indicating high grain support (Figure 7). Comparing the two descriptions of the Snowbird Group and the lower part of the Chilhowee Group to the analysis of the thin section collected by Martin and Crawford (1996), the Middle Pinelog Formation rocks at Henderson Mountain did not seem lithologically more similar to either group. However, this conclusion is based solely on one thin section of the Middle Pinelog and the description of hand samples collected from the study area (Appendix B), and thus does not capture the entirety of the Pinelog Formation.

Conclusions

The distribution of grain sizes and physical structures did not show a pattern in the physical distribution of samples, probably because rocks of different ages were mixed together by human activity, such as leveling of the area for development. The maturity of the rocks indicates a moderate amount of sediment transport to a marine environment without much further rounding due to wave action.

The observed spots on many of the rocks in the Henderson Mountain cannot be definitively classified as reduction spots. However, conditions indicate that the reduction of iron-bearing minerals in the sediment before lithification of the protolith is probable. One piece of evidence contrary to this hypothesis is that physical structures seem to have been erased while the spots have persisted. Future research must be undertaken to find either a sample containing physical structures and “reduction spots,” or evidence of bioturbation that could have erased bedding planes before the spots formed during diagenesis. Otherwise, there is not enough evidence to conclude that these features are indeed reduction spots.

Martin and Crawford’s (1996) hypothesis that the observed burrow structures are trace fossils, and specifically *Palaeophycus*, was supported by the presence of chlorite composing the burrow wall, suggesting the presence of agglutinated clay minerals and organic material in the walls of the burrow before metamorphism (Potter et al 2005). Further research on burrow morphology has tentatively classified these specimens as *Palaeophycus heberti* with one example of *Taenidium*. The presence of *P. heberti* along with *Taenidium* suggests an age of Cambrian or younger for the Pinelog Formation. Petrographic analysis of a thin section of the Middle Pinelog was inconclusive, and the similarity of the formation to either the Chilhowee or Snowbird Groups unresolved. However, the Pinelog is at least Cambrian, which suggests that it belongs to the Chilhowee Group.

References Cited

Alpert, S.P. (1974). Systematic Review of the Genus *Skolithos. Journal of Paleontology*, 48(4), 661-669.

The Atlanta Regional Commission. GIS data. (2003-2009). Retrieved from http://www.atlantaregional.com/info-center/gis-data-maps/gis-data

Babcock, L.E. (2005). *Interpretation of Biological and Environmental Changes Across the Neoproterozoic-Cambrian Boundary*. San Diego, CA: Elsevier.

Crawford, T.J., Higgins, M.W., Crawford, R.F., Atkins, R.L., Medlin, J.H., and Stern, T.W. (1999). Revision of stratigraphic nomenclature in the Atlanta, Athens, and Cartersville 30 –x 60-minute quadrangles, Georgia. *Georgia Geologic Survey Bulletin*, 130, 45.

Cudzil, M.R. and Driese, S.G. (1987). Fluvial, tidal and storm sedimentation in the Chilhowee Group (Lower Cambrian), northeastern Tennessee, U.S.A. *Sedimentology*, 34, 861-883.

Frey, R.W., and Howard, J.D. (1986). Trace Fossils from the Panther Member, Star Point Formation (Upper Cretaceous), Coal Creek Canyon, Utah. *Journal of Paleontology*, 59(2), 370-404.Georgia GIS Clearinghouse. Map Data and Aerial Photography. http://data.georgiaspatial.org/index.asp

Gibson, G.G. (1989). Trace Fossils from Late Precambrian Carolina Slate Belt, South-Central North Carolina. *Journal of Paleontology*, 63(1), 1-10.

Jensen, S., Droser, M.L., and Gheling, J.G. (2006). A Critical Look at the Ediacaran Trace Fossil Record. In Shuhai Xiao and Alan Jay Kaufman (Eds.), *Neoproterozoic Geobiology and Paleobiology*. Dordrecht, The Netherlands: Springer.

Li, L., and Tull, James F. (1998). Cover Stratigraphy and Structure of the Southernmost External Basement Massifs in the Appalachian Blue Ridge: Evidence for a Two Stage Late Proterozoic Rifting. *American Journal of Science*, 298, 829-867.

Mack, G.H. (1980). Stratigraphy and Depositional Environments of the Chilhowee Group (Cambrian) in Georgia and Alabama. *American Journal of Science*, 208, 497-517.

Martin, A.J., and Crawford, R.F. (1996). Trace Fossils in the Pinelog Formation, Piedmont-Blue Ridge, Georgia, and Their Application to Sedimentology, stratigraphy, and Structural Geology. *Georgia Geological Society Handbook*, 16, 89-96.

Potter, P.E., Maynard, J.B., Depetris, P.J. (2005). *Mud and Mudstones: Introduction and Overview*. Berlin, Germany: Springer-Verlag Berlin Heidelberg.

Pemberton, S.G., and Frey, R.W. (1982). Trace Fossil Nomenclature and the *Planolites-Palaeophycus* Dilemma. *Journal of Paleontology*, 56(4), 843-881.

Pettijohn, F. J., Potter, P. E., Siever, R. (1987). *Sad and Sandstone* (2nd ed.)New York, NY: Springer-Verlag New York Inc.

Rogers, J.J.W. (1996). A History of Continents in the past Three Billion Years. *The Journal of Geology*, 104(1), 91-107.Ruppert, E.E. and Fox, R.S. (1988) *Seashore Animals of the Southeast: a Guide to Common Shallow-Water Invertebrates of the Southeastern Atlantic Coast*. Columbia, SC: University of South Carolina Press.

Tacker, R.C., Martin, A.J., Weaver, P.G., and Lawver, D.R. 2010. Trace fossils versus body fossils: Oldhamia recta revisited. *Precambrian Research*, 178: 43-50.Tull, J.F. (2007). Rifted margin architecture, cover stratigraphy, and structure of basement culminations, frontal Appalachian Blue Ridge, Georgia, USA. *Memoir - Geological Society of America*, 200, 567-594.

Weibel, R. (1998). Diagenesis in oxidizing and locally reducing conditions — an example from the Triassic Skagerrak Formation, Denmark. *Sedimentary Geology*, 121, 259-276.

Wood, D.S. and Oertel, G. (1980). Deformation in the Cambrian Slate Belt of Wales. *The Journal of Geology*, 88(3), 309-326.

Appendix A

Table 4. Coordinate and Sample Analysis Data

ID	Lat	Long	Color	Color #	Size	Roundness	Sphericity	Maturity/Grade	Sorting	Physical Structures	Chemical Structures	Biogenic Structures	Primary Mineral	Rock Name
M1	34.40556	84.54558	Yellowish Gray	5Y 8/1	Coarse	Sub Angular	Spherical	Submature	Well	Cross Bedding	Iron Staining	NA	Quartz	Quartzite
M2	34.40553	84.54553	Very Pale Orange	10 YR 8/2	Very Fine	Sub Angular	Sub Prismoidal	Mature	Moderate	Reduction Spots	Iron staining	NA	Quartz	Quartzite
M3	34.40518	84.54545	NA	NA	NA	NA	NA	NA	NA	Reduction Spots	NA	NA	Quartz	Quartzite
M4	34.40563	84.54528	NA	NA	NA	NA	NA	NA	NA	Cross Bedding	NA	NA	Quartz	Quartzite
M5	34.40565	84.54520	Pale Yellowish Orange	10YR 8/6	Coarse	Sub Angular	Spherical	Submature	Moderate	Cross Bedding	Iron Staining	NA	Quartz	Quartzite
M6	34.40600	84.54523	Yellowish Gray	5Y 8/1	Very Coarse	Sub Angular	Sub Prismoidal	Submature	Poor	Reduction Spots	Iron Staining	NA	Quartz	Quartzite
M7	34.40575	84.54523	NA	NA	NA	NA	NA	NA	NA	Bedding	NA	NA	QUartz	Quartzite
M8	34.40578	84.54516	Yellowish Gray	5Y 8/1	Fine	Sub Angular	Sub Discoidal	Submature	Moderate	Cross Bedding	Iron Staining	NA	Quartz	Quartzite
M9	34.40571	84.54568	NA	NA	NA	NA	NA	NA	NA	Reduction Spots	NA	NA	Quartz	Quartzite
M10	34.40575	84.54555	Yellowish Gray	5Y 7/2	Coarse	Sub Angular	Spherical	Mature	Moderate	Reduction Spots	NA	Fungal Colony	Quartz	Quartzite
M11	34.40583	84.54535	Pale Yellowish Brown	10YR 6/2	Coarse	Sub Rounded	Spherical	Submature	Moderate	Reduction Spots	Iron Staining	NA	Quartz	Quartzite
M12	34.40601	84.54523	Yellowish Gray	5Y 7/2	Coarse	Sub Angular	Spherical	Mature	Moderate	Bedding	Iron Staining	NA	Quartz	Quartzite
O1	34.40341	84.54508	Pale Yellowish Orange	10YR 8/6	Medium	Sub Rounded	Spherical	Submature	Moderate	Bedding	Iron Staining	NA	Quartz	Quartzite
O2	34.40645	84.54461	Yellowish Gray	5Y 8/1	Very Fine	Sub Angular	Spherical	Submature	Moderate	Bedding	Iron Staining	NA	Quartz	Phyllite
O3	34.40406	84.54540	Light Olive Gray	5Y 6/1	Fine	Sub Angular	Spherical	Mature	Well	Bedding	Iron Staining	NA	Quartz	Quartzite
O4	34.40372	84.54592	Medium Dark Gray	N4	Silt Sized	NA	NA	Low Grade	NA	Foliation	NA	NA	NA	Phyllite
O5	34.40332	84.54480	NA	NA	NA	NA	NA	NA	NA	Reduction Spots	NA	NA	Quartz	Quartzite
O6	34.40338	84.54462	Medium Gray	N8	Fine	Sub Angular	Sub Prismoidal	Submature	Moderate	Bedding	Iron Staining	NA	Quartz	Quartzite
O7	34.40348	84.54386	Grayish Orange	10YR 7/4	Coarse	Sub Rounded	Spherical	Submature	Poor	Burrow, Cross Bedding	Iron Staining	NA	Quartz	Quartzite
O8	34.40343	84.54363	Very Pale Orange	10YR 8/2	Very Coarse	Sub Rounded	Spherical	Mature	Well	Reduction Spots	Iron Staining	NA	Quartz	Meta Conglomerate
O9	34.40330	84.54326	NA	NA	NA	NA	NA	NA	NA	Reduction Spots	NA	NA	Quartz	Quartzite
M1	NA	NA	Light Olive Gray	5Y 6/1	Coarse	Sub Angular	Sub Prismoidal	Submature	Moderate	Cross Bedding	NA	Burrows	Quartz	Quartzite
XX1	NA	NA	Light Bluish Gray	5B7/1	Very Fine	NA	NA	Low Grade	NA	Foliation	Iron Staining	NA	NA	Phyllite
XX2	NA	NA	Yellowish Gray	5Y 8/1	Coarse	Sub Rounded	Sub Prismoidal	Mature	Well	Cross Bedding	Iron Staining	NA	Quartz	Quartzite
XX3	NA	NA	Yellowish Gray	5Y 7/2	Medium	Sub Angular	Spherical	Mature	Well	NA	Iron Staining	Burrows	Quartz	Quartzite
XX4	NA	NA	Very Pale Orange	10YR 8/2	Coarse	Sub Rounded	Spherical	Mature	Well	Large Dark Marks	NA	NA	Quartz	Quartzite
XX5	NA	NA	Yellowish Gray	5Y 7/2	Medium	Sub Angular	Spherical	Submature	Moderate	Reduction Spots	Iron Staining	NA	Quartz	Quartzite

Appendix B. In-Depth Sample Descriptions

Mulberry Circle Site

M1)

Color: Yellowish Gray 5Y 8/1. The bedding planes are Grayish Brown 5YR 3/2

Size: Coarse grains ranging from 3/4 - 1 mm. Sizes are relatively the same throughout. Minerals composing the supposed bedding lines are about medium sized – 1/3 mm at the smallest measured grain.

Shape: Most of the grains are somewhat misshapen due to metamorphism. Overgrowth of quartz crystals on most grains. They are roughly spherical and subangular. Some of the subangular shape may be attributed to the quartz overgrowth on the grains.

Maturity: Moderate sorting. Hard to estimate maturity because of metamorphism. The best description is submature.

Physical Structures: Examples of bedding. Minerals making up the bedding planes appear to be of a different mineral composition from the surrounding rock. Could possibly be trough cross-bedding as the planes are not parallel to one another. The bottom of the sample has two main bedding planes that intersect as they cross the sample and continue along the remainder of the sample as apparently one plane.

Biogenic Structures: None observed.

Chemical Structures: Mostly iron staining inn various areas throughout the sample.

Mineral Composition: Mainly Quartz

M2)

Color: The largest portion of the sample is Very Pale Orange 10 YR 8/2 with patches of Pale Yellowish Brown 10 YR 6/2. The darker spots on the surface are Dark Gray N3.

Size: Two main sizes. Mostly very fine sand grains between 1/16 and 1/8 mm. The surrounding grains are smaller, probably silt sized. The darker spots do not seem to show a difference in size.

Shape: Most grains are subangular in roundness and subprismoidal in sphericity. The darker grains are angular and subprismoidal.

Maturity: The rock is probably mature as it is also fairly well sorted.

Physical Structures: There are darker spots throughout the sample that could potentially be reduction spots. They are all oriented in the same direction and ellipsoid in shape.

Chemical Structures: Iron staining throughout with more of the sample being stained than not. There is a boarder of staining around the breakage surface.

Biogenic Structures: None observed

Mineral Composition: Mostly Quartz

M3 & 4 Were not collected

Physical Structures: M3 has “reduction spots” and M4 shows evidence of cross-bedding

M5)

Color: Pale Yellowish Orange 10YR 8/6

Size: Coarse and grains with a mix of medium sized grains

Shape: Subangular and spherical

Maturity: Difficult to discern sorting because of metamorphism.

Physical Structures: Looks like bedding; darker layers could have been deposited in a trough or on a slope. These layers could potentially be the markings of burrow walls, but that is the only burrow like characteristic of the feature. More than likely, this feature is cross-bedding.

Chemical Structures: Iron staining throughout

Biogenic Structures: None observed

Mineral Composition: Mostly quartz

M6)

Color: Yellowish Gray 5y 8/1 and the darker spots present are Dark Greenish Gray SG 4/1

Size: Two main sizes. There are very coarse quartz grains that seem to be in a matrix of very fine sand grains. The smaller grains are very distorted and irregular in shape and may be the product of metamorphic activity. There is not a size difference between the darker spots and the surrounding rock, but there are some very fine sand sized reddish colored grains intermittently throughout the spots.

Shape: The larger visible grains are subangular in roundness and subprismoidal in sphericity. The smaller dark grains are angular and spherical.

Maturity: There is poor sorting throughout though it appears to be heterogeneous. Probably submature.

Physical Structures: The only distinguishing features are the darker spots (possibly reduction spots). They are darker than the surrounding rock and many evident as negative relief, where the filling grains have been weathered out. All of these spots are oriented in the same direction and are ellipsoid in shape.

Chemical Structures: There is some iron staining on the surface.

Biogenic Structures: None visible.

Mineral Composition: Mostly quartz. The small darker minerals may be a type of tourmaline.

M7 was not collected

Physical Structures: Bedding

M8)

Color: Yellowish gray 5Y 8/1

Size: Fine grain with some coarse grains throughout

Shape: Subangular grains and many are subdiscoidal

Maturity: Fairly homogeneous throughout and moderately well sorted. Probably submature.

Physical Structures: There is evidence of bedding and cross bedding. There are two major areas of bedding planes and it is probably cross-bedding.

Chemical Structures: Some iron staining on the surface (possibly just old dust), but there is none in the interior of the sample.

Biogenic Structures: None Observed

Mineral Composition: Mostly Quartz

M9 was not collected

Physical Structures: “Reduction spots”

M10)

Color: Yellowish Gray 5Y 7/2

Size: Coarse sand grains with very fine grains in between; same for “reduction spot”

Shape: Subangular and spherical

Maturity: Moderately sorting and mature

Physical Structures: "Reduction spots" throughout the sample. Some have weathered out while others remain intact. The spots are all oriented in the same direction, probably due to stress.

Chemical Structures: None observed

Biogenic Structures: None observed

Mineral Composition: Mostly quartz

M11)

Color: Pale Yellowish Brown 10YR 6/2. Darker spots are a mix of previous color with Medium Gray N5.

Size: Coarser grains intermittently throughout the remainder of the sample which is mainly fine sand grains. The size of the grains in the spots is fine to very fine.

Shape: Subrounded and spherical in general. In the spots, the grains are subangular and spherical.

Maturity: Probably submature seeing as it is moderately well sorted.

Physical Structures: Darker spots throughout. Look more weathered than the surrounding rock, and are almost negative relief.

Chemical Structures: Very little iron staining

Biogenic Structures: None observed

Mineral Composition: Mostly Quartz

M12)

Color: Yellowish Gray 5Y 7/2

Size: Coarse sand with a matrix of very fine or smaller grains. Would assume that the matrix is due to metamorphism.

Shape: Mainly subangular and spherical

Maturity: Moderately well sorted so probably mature

Physical Structures: There is a potential bedding plane, and represents trough cross bedding if this is so. Otherwise, it could be a burrow, with the two darker lines of the area representing the levee structures from a burrow wall. The inside is a different color from the surrounding rock. This structure is about 8 mm in diameter.

Chemical Structures: Iron staining banding that has infiltrated into the rock

Biogenic Structures: None observed unless the structure is a burrow

Mineral Composition: Mostly quartz

Oak Trace Site

O1)

Color: Pale Yellowish Orange 10YR 8/6

Size: Larger medium and grains with some smaller very fine grains. Some coarse grains very intermittently.

Shape: Subrounded grains that are approximately spherical

Maturity: The rock is submature, but seems slightly more mature than previously examined specimens.

Physical Structures: No distinguishable bedding marks, but it breaks easily along layers. This breaking could be attributed to foliation, but the breaking is being interpreted as occurring along bedding planes, as the rest of the rock does not seem metamorphic. In fact, it is the least metamorphic-looking sample collected.

Chemical Structures: Iron staining along the edges, tends to be pretty pervasive.

Biogenic Structures: None observed

Mineral Composition: Mostly quartz

O2)

Color: Yellowish Gray 5Y 8/1

Size: Very fine grains, almost too small to see

Shape: Hard to tell, but probably subangular and spherical

Maturity: Moderate sorting and submature

Physical Structures: Alternating band of light and dark colors that probably represents bedding, again this looks like it could be gneissic banding without magnification. There are also areas of smoother planes (slippage planes?). The rock also breaks along certain more easily and these planes are perpendicular to the bedding.

Chemical Structures: Iron staining throughout

Biogenic Structures: None observed

Mineral Composition: Mostly quartz

O3)

Color: Light Olive Gray 5Y 6/1 on the weathered surface

Size: Main size is fine sand grains; there are smaller grains but very intermittently.

Shape: Subangular and more or less spherical

Maturity: Well-sorted grains that lead to the classification of mature.

Physical Structures: There is bedding throughout the sample. These darker bedding planes are in between what appear to almost be foliation layers. The grain size of these layers does not differ from surrounding layers.

Chemical Structures: Iron staining throughout

Biogenic Structures: None observed

Mineral Composition: Mostly quartz

O4)

Color: Medium Dark Gray N4

Size: Seems to be completely metamorphic but not quartzite. Crystal size is smaller than 1/16 mm, so silt sized.

Shape: Cannot be ascertained, as grains are too small. Overall, the rock shows much deformation.

Maturity: As it seems to be more metamorphosed than the quartzite, maturity would not be possible to ascertain. Still a low-grade metamorphic rock, but more metamorphosed than the surrounding rocks.

Physical Structures: Can see deformation on the surface and evidence of foliation.

Chemical Structures: None observed

Biogenic Structures: None observed

Mineral Composition: Cannot be determined, but the rock itself is either a phyllite or a schist

O5 was not collected

Physical Features: “Reduction spots”

O6)

Color: Bands of Very Light Gray N8 that alternate with thin bands of Medium Gray N5 and terminates in a very thick layer of Medium Gray.

Size: Fine and grain

Shape: Subangular and subprismoidal (somewhat hard to tell because of deformation)

Maturity: Moderately well sorted and submature

Physical Structures: Definite bedding of alternating lighter and darker layers that are about the same thickness. At first, seems that it could be gneissic banding, but the area is too low-grade and it is clear that these are low-grade grains under the microscope.

Chemical Structures: Slight iron staining

Biogenic Structures: None observed

Mineral Composition: Mostly quartz

O7)

Color: Grayish Orange 10 YR 7/4

Size: Range from medium sized sand to very coarse sand. The "bottom" of the sample is composed of very coarse grains with almost a matrix of medium sized grains with overgrowths. The top has mostly coarse sand grains with a few medium sized grains.

Shape: Visible grains close to spherical and are subrounded in shape. Most overgrowth on the grains is not bad enough to obscure the shape of the original grains.

Maturity: Seems to be submature as it is poorly sorted.

Physical Structures: On the surface is a light colored streak of quartz that progresses across the surface, though there does not appear to be a sedimentological reason for it. There are also two depressions on the surface. One extends about 77 mm from the edge with small levee structures on the sides that help demark it. It has a generally cylindrical shape and ranges from approximately 17 mm at its widest. The depression tapers off until it terminates. The second depression is not marked by levees but has a distinct shape. It extends perfectly straight and is about 50 mm long and 5 mm across. It terminates in a larger circular depression that is 15 mm in diameter.

There is evidence on the breakage surface. There are four separate darker layers that are slightly bowed, suggesting deposition in a trough.

Biogenic Structures: None observed, unless the described depressions can be interpreted as burrow structures.

Chemical Structures: Iron staining on the surface of the rock. Once fractured, there is a ring of iron staining along the outside rim of the breakage surface. Within the sample, there are alternating bands of iron staining.

Mineral Composition: Primarily quartz.

O8)

Color: Very Pale Orange 10YR 8/2

Size: Most grains are very coarse sand with fine grains in between.

Shape: Subrounded spherical grains

Maturity: Well sorted and probably mature

Physical Structures: There are larger negative relief marks where something has weathered out of the rock. The leftover grains tend to be smaller than the surrounding rock and of a darker hue. Larger than the other spots observed.

Chemical Structures: Iron staining penetrating the rock

Biogenic Structures: None observed

Mineral Composition: Mostly quartz

O9 was not collected

Physical Structures: "Reduction spots"

Samples without coordinates – Preliminary samples

XX1)

Color: Light Bluish Gray 5B 7/1

Size: Crystalline rock mostly. Size ranges from very fine to silt sized crystals.

Shape: Cannot be determined

Maturity: Maturity of the protolith would be harder to obtain as it is more metamorphosed than surrounding rocks, probably a schist of some sort.

Physical Structures: Definite foliation and deformation of the rock. There are small holes in the rock that look as though crystals had occupied them and had been weathered out.

Chemical Structures: The surface is a reddish color, but a deeper red than is typically associated with iron staining. Probably some other mineral forming on the surface, would need a thin section to ascertain.

Biogenic Structures: None observed

Mineral Composition: Cannot ascertain, but the rock is a type of schist

XX2)

Color: Yellowish Gray 5Y 8/1

Size: Coarse sand grains with fine and grains in between.

Shape: Subrounded and subprismoidal

Maturity: Well sorted so probably mature

Physical Structures: Definite cross-bedding in this sample that can be seen from both the “front” and “back” of the sample. Besides being darker in hue, there isn’t anything that distinguishes the grains making up the bedding planes form the surrounding rock. Could potentially be trough cross-bedding.

Chemical Structures: Iron staining throughout the rock

Biogenic Structures: None Observed

Mineral Composition: Mostly Quartz

XX3)

Color: Yellowish Gray 5Y 7/2

Size: Mostly medium sand grains

Shape: Subangular and spherical

Maturity: Well sorted as most of the grains are all about the same size, so probably mature

Physical Structures: There is a potential burrow in this rock. It’s about 11 mm in diameter and about 8 mm in the smallest diameter. There are darker streak marks on the edge of the structure, which are raised like levees. The length is much longer than other observed burrows, larger than 170 mm in length. The wall also tends to undulate a large amount, which could be due to deformation by metamorphism. It could be two deformed bedding planes, but it looks more like a burrow.

Chemical Structures: Iron Staining

Biogenic Structures: None observed

Mineral Composition: Mostly quartz

XX4)

Color: Very Pale Orange 10YR 8/2

Size: Coarse sand grains with some very coarse sand grains intermittently throughout

Shape: Subrounded and spherical

Maturity: fairly well sorted and most of the grains are pretty round, so mature

Physical Structures: There are 2 darker patches in the rock. The grains in these patches are a light pale blue gray color. They are 10 and 13 mm in diameter and do not appear to resemble any burrows or "reduction spots." Could be places where graphite has been wearing out of the rock.

Chemical Structures: None observed

Biogenic Structures: None observed

Mineral Composition: Mostly quartz

XX5)

Color: Moderate Gray Pink 5R 7/2

Size: Mainly medium sized sand grains with some coarser grains intermittently throughout

Shape: Subangular and spherical

Maturity: Moderate sorting throughout, probably submature

Physical Structures: "Reduction spots" again that are partially weathered down, so there isn't any positive or negative relief. No difference between these grains and the ones composing the surrounding rock besides color. 8-13 mm long and 3-5 mm in diameter at the thickest point. They are all oriented in the same direction.

Chemical Structures: Iron staining throughout. Very deep coloration around the surface of the fractures.

Biogenic Structures: None observed

Mineral Composition: Mostly quartz

Appendix C –

Table 5. Burrow Diameter Measurements and Statistics

Number	Diameter 1 (mm)	Number	Diameter 1 (mm)
1	2.5	38	5.8
2	2.9	39	6.0
3	2.9	40	6.0
4	3.2	41	6.1
5	3.2	42	6.2
6	3.4	43	6.2
7	3.5	44	6.3
8	3.5	45	6.4
9	3.5	46	6.4
10	3.5	47	6.4
11	3.7	48	6.6
12	3.7	49	6.7
13	3.8	50	6.7
14	4.0	51	6.7
15	4.1	52	6.9
16	4.1	53	6.9
17	4.2	54	6.9
18	4.2	55	7.1
19	4.3	56	7.2
20	4.3	57	7.3
21	4.3	58	7.3
22	4.4	59	7.3
23	4.4	60	7.4
24	4.5	61	7.7
25	4.5	62	7.9
26	4.7	63	8.1
27	4.8	64	8.1
28	4.8	65	8.4
29	5.0	66	9.1
30	5.1	67	9.5
31	5.2	68	9.9
32	5.2	69	10.3
33	5.4	70	12.4
34	5.5	Mean	5.7
35	5.5	Median	5.7
36	5.8	Mode	3.45

37	**5.8**	**Standard Dev.**	**2.0**