North Carolina Department of Environmental Quality (DEQ)
Division of Energy, Mineral and Land Resources (DEMLR)
Kenneth B. Taylor, State Geologist

North Carolina Geological Survey
Open File Report 2019-03

Lithic material identification guide –
Carolina terrane, North Carolina

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Recommended Citation:
Hanna, H.D. and Bradley, P.J., 2019, Lithic material identification guide – Carolina terrane, North Carolina: North Carolina Geological Survey Open-file Report 2019-03.

Information About this Lithic Identification Guide

The North Carolina Geological Survey (NCGS) conducts detailed geologic mapping within the Orange and Chatham county portions of the Carolina terrane, and often examines rock material from the Uwharries area. Fine-grained volcanogenic rock is frequently encountered during routine field mapping and an impromptu "best attempt" at identification must be made. The resulting field observations, ground truthed with geochemical analysis when possible, have led to informal logic-trees for initial field identifications. This guide summarizes the field geologist's thought processes (logic-trees) to identify fresh rock material. It is the authors' hope that archaeologists will use the guide and provide feedback for improvement.

The guide consists of two flow charts ("Tuff, Lava, or Sedimentary Rock?" (Page 23) and "Composition of Lavas and Tuffs" (Page 24)); a "Frequently Asked Questions" section to answer questions that may arise while using the flow charts; a "Less Common Textures" section to cover textures not mentioned in the flow charts; a "Glossary of Terms" to define geologic terminology, a worksheet to document thought processes while using the guide, and examples with which to practice the guide. The two flow charts are meant to be used in a particular order. The "Tuff, Lava, or Sedimentary Rock?" flow chart should be used first. If the resulting rock is a lava or tuff, the second flow chart, "Composition of Lavas and Tuffs", can be used to estimate if the sample is basaltic, andesitic, dacitic, or rhyodacitic. Important notes about each the flow chart are included in a gray box on the right hand side of the flow chart's page. The "Frequently Asked Questions" section (Pages 2-14) contains photographs and detailed descriptions of the textures and features used by the flow charts to identify rock types. The "Less Common Textures" section (Pages 15-18) contains photographs and detailed descriptions of textures that are not represented in the flow chart but may be seen in lithic material. Both of these sections should be read before using the guide for the first time. The "Glossary of Terms" (Pages 20-22) provides brief, non-technical definitions of terms in **bolded** text used in the guide. The worksheet documents the decisions made while using the flow charts to identify a sample. Two people may arrive at different end results for the sample depending on how they answered the questions in the flow charts. If the thought process used is documented, the differences can be discussed and a consensus possibly reached. It is recommended that the user read the "Frequently Asked Questions," "Less Common Textures," and "Glossary of Terms" sections and work through the examples before using the flow charts for the first time.

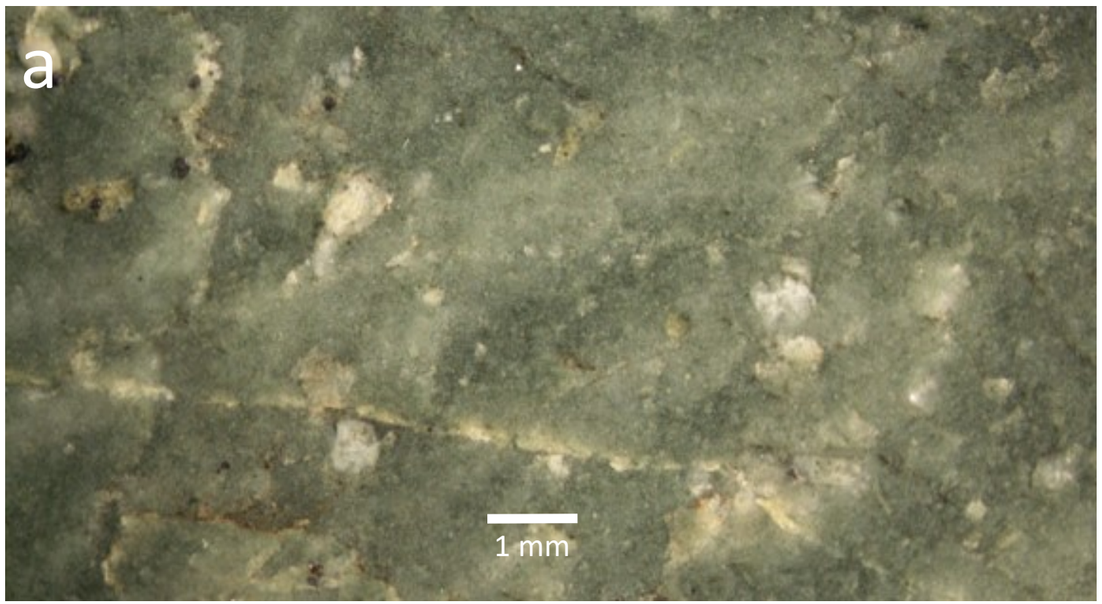
Some features, particularly **flow banding**, **welding**, bedding, and **soft sediment deformation**, can be difficult to tell apart. It is recommended to use these features in conjunction with other clues – such as the presence (if applicable) of **amygdules**, **fiamme-shaped clasts**, a **hyaloclastic** texture, or **spherulites** – to help determine the final rock identification.

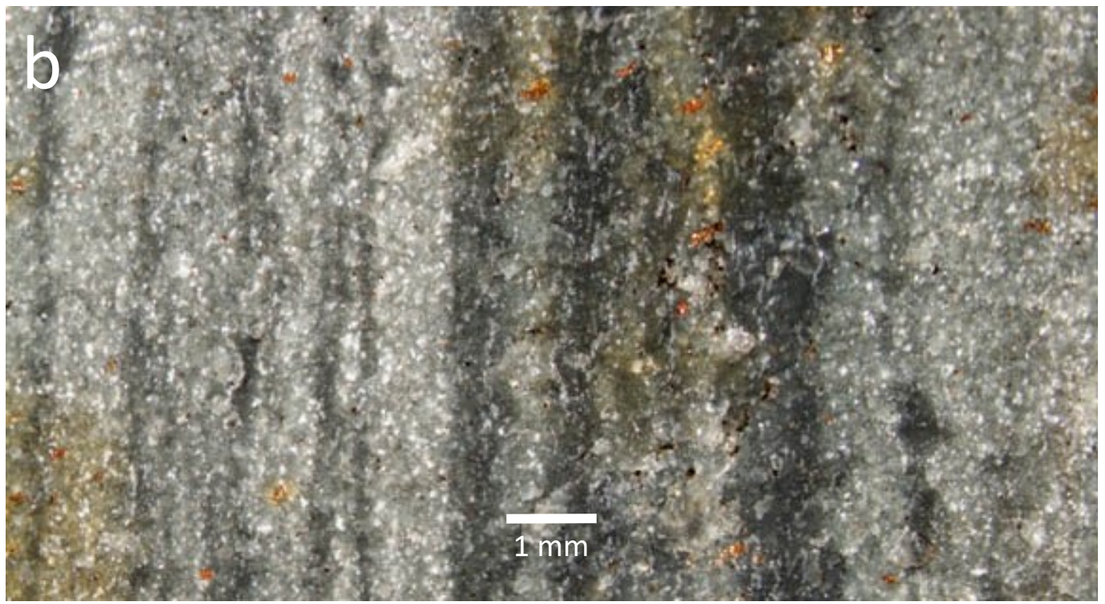
Note: this guide covers identification of fresh rock material. Although weathered surfaces may convey some information, a fresh surface is usually necessary for lithic identification beyond general "metavolcanic" and/or "metasedimentary" labels. Therefore, the destruction of the artifact may be necessary for proper identification.

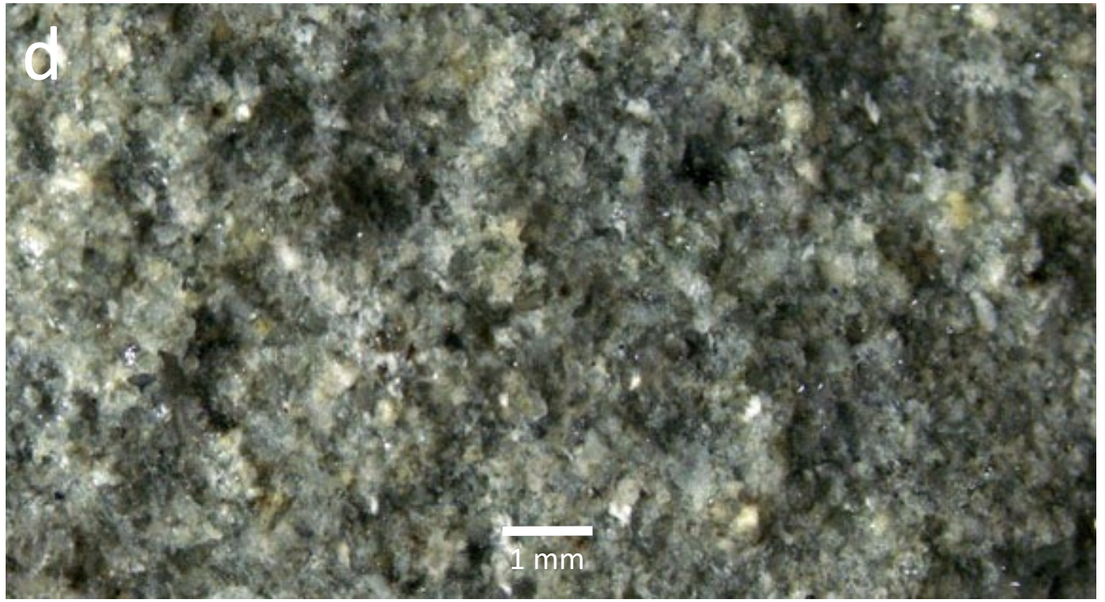
This is not intended as a geologic rock identification guide. It was written specifically for identification of lithic material and therefore does not encompass the entire range of textures and rock types observed in the Carolina terrane.

Frequently Asked Questions

Is the matrix of my sample aphanitic or granular?







An aphanitic matrix looks fairly smooth, as if it is one coherent piece of material. A granular matrix looks like it is made of little pieces of other rocks or minerals that are touching each other.

The photographs above were taken of wet samples under a microscope at 10x magnification to simulate how they would look under a handheld 10x magnifier. The samples with an **aphanitic** matrix are on the left (a & c) and the samples with a granular matrix are on the right (b & d). Notice the **aphanitic** matrix looks relatively smooth, whereas the granular matrix looks like it is made up of tiny pieces.

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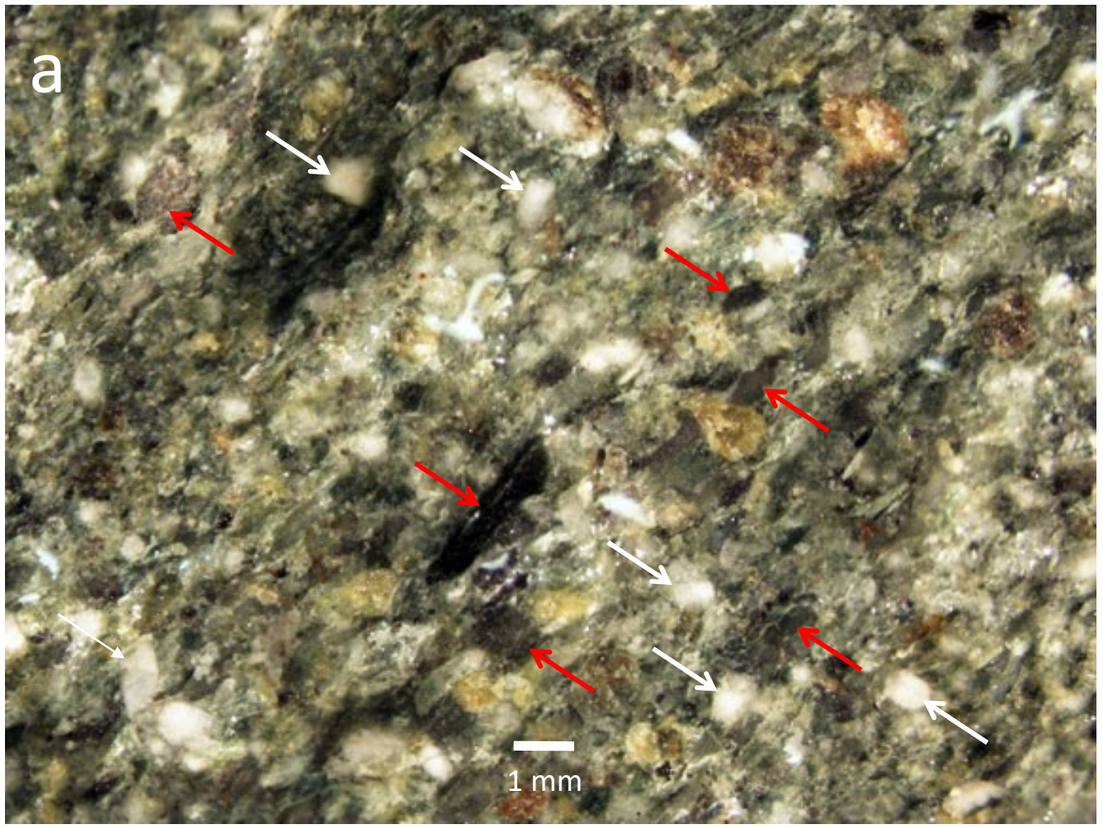
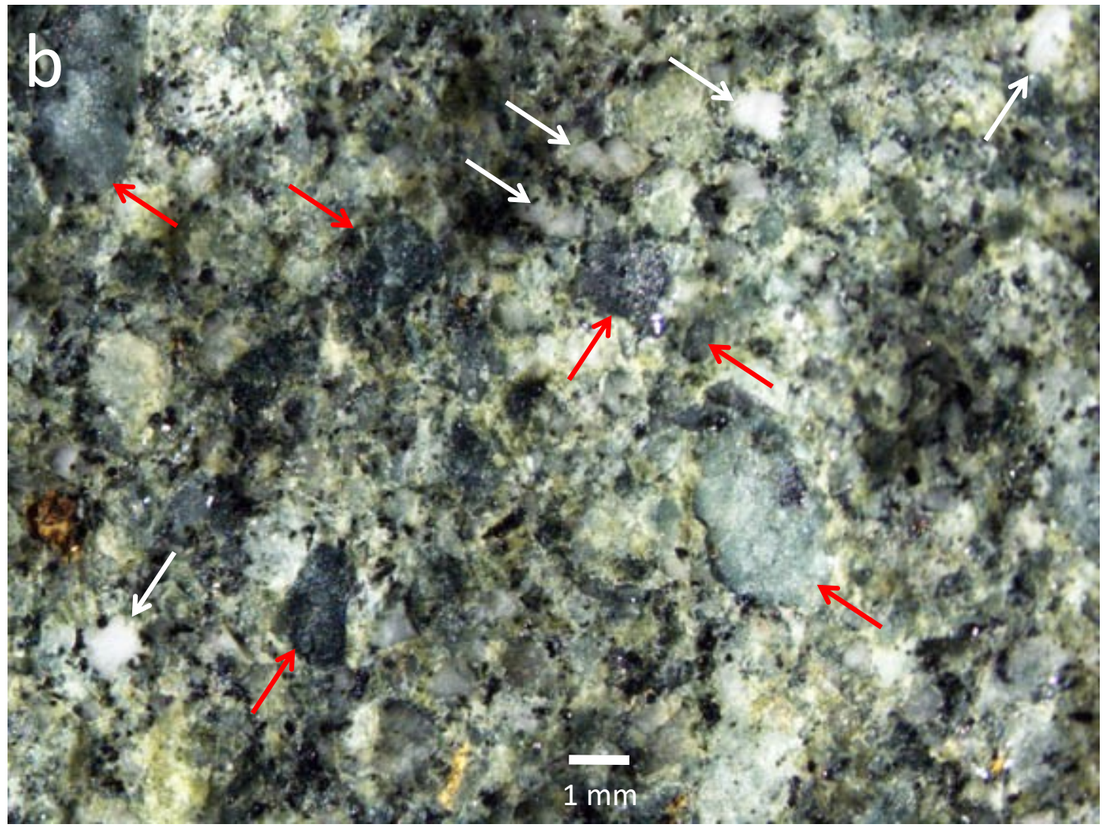
How can someone tell clasts from crystals in a sample?





Clasts are fragments of rock
Crystals are mineral grains

The photographs above were taken of wet, fresh surfaces of geologic samples under a microscope at 10x magnification to simulate how they would look under a handheld 10x magnifier. Examples of crystals are noted by white arrows whereas examples of clasts are indicated with red arrows. The color difference between the crystals and clasts may be the first thing someone notices about the photographs above. However, color differences are not diagnostic. While crystals in the above photographs are white in color, some crystals can also be gray (quartz), black (amphibole\pyroxene) or pink (potassium feldspar). The clasts in the photographs are mostly gray or black in color, however clasts can weather to be any number of colors including white, which can make them resemble crystals. When determining if a feature is a clast or crystal, it can help to examine a broken surface: rock fragments may display “frosted flakes” (see page 12), whereas a minerals may show cleavage planes or conchoidal fracture. Luster, or how a mineral reflects light, can also be useful since minerals generally have a different luster than rock fragments. While clasts often show up on the fresh surface, sometimes they are best seen on the weathered surface so it is best to check both surfaces when looking for clasts.

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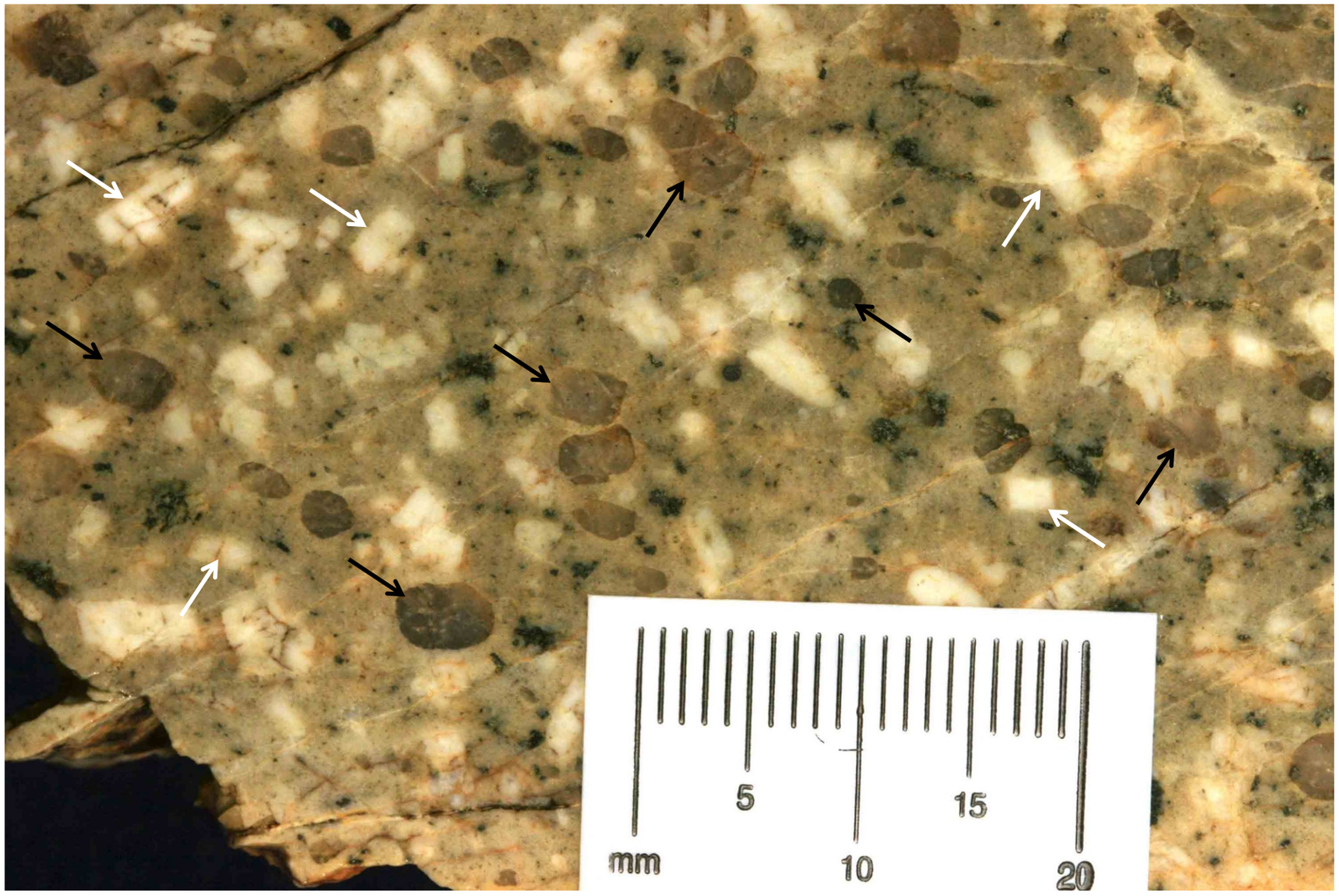
How can someone tell feldspar from quartz in a sample?



Quartz and feldspar are common minerals in North Carolina Piedmont rocks.

The photograph above was taken with an SLR camera and shows the wet, fresh surface of a geologic hand sample of a quartz and feldspar porphyritic rock. In this sample, quartz looks grey whereas feldspar looks white. While this color difference can be useful, it is best to look for conchoidal (bowl-shaped) fracture in a broken piece of quartz as confirmation. Feldspars do not fracture conchoidally. The color of feldspar can be useful for field determinations of which type it is: if a feldspar is white, it is generally called plagioclase, whereas a pink-colored feldspar is usually orthoclase. Examples of feldspar are noted by white arrows whereas examples of quartz are indicated with black arrows. A smaller black mineral, possibly amphibole or biotite, is also present in the photograph but is not indicated by arrows.

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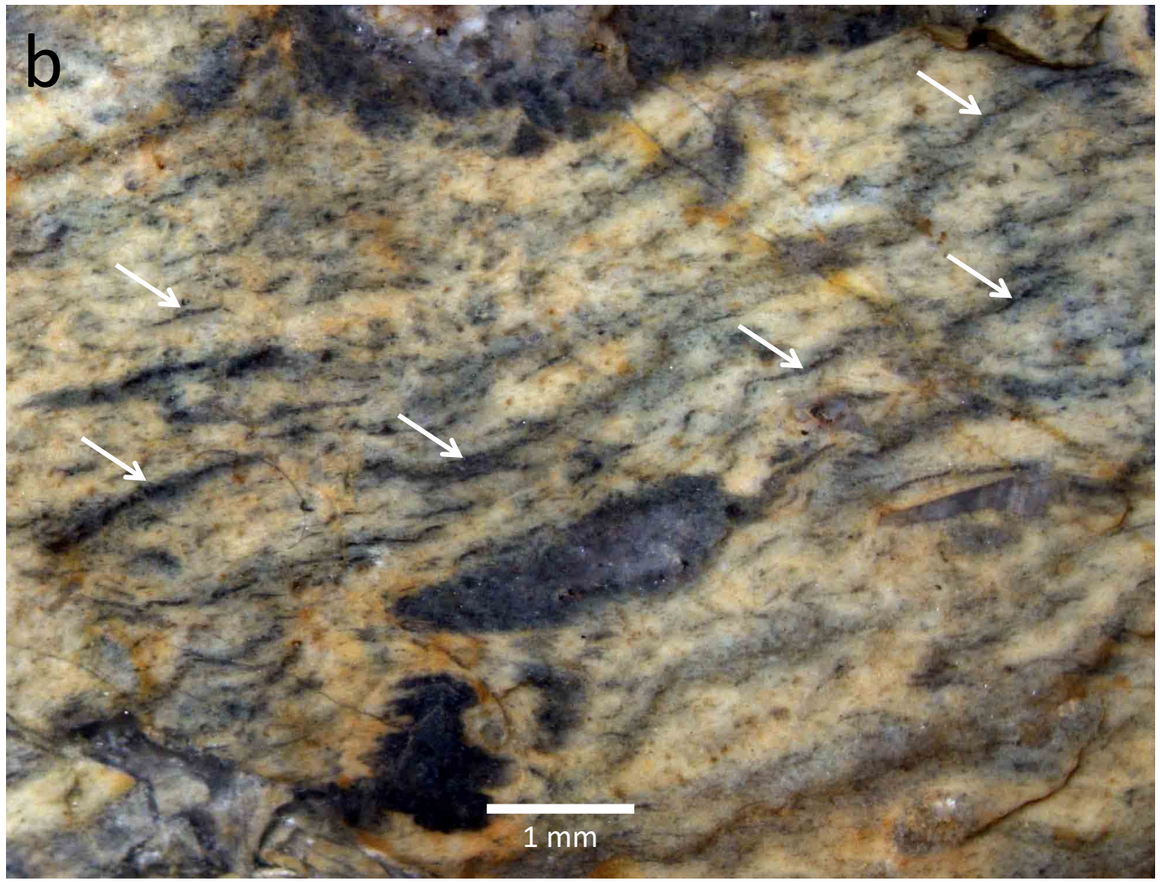
What are fiamme-shaped clasts?



Fiamme (fee-ah-may) are flame-shaped clasts of flattened pumice that are characteristic of a welded tuff.

Photograph “a” above was taken with an SLR camera and shows the dry, weathered surface of a small (~1.5” long), lightly weathered rock fragment. This rock fragment contains abundant **fiamme**-shaped clasts of different sizes and simulates how **fiamme** may look on some lithic flakes. Photograph “b” shows the same rock fragment under a microscope at 10x magnification, and was taken while the sample was wet. This is analogous to how **fiamme** may look under a hand held 10x magnifier. In both photographs, examples of the **fiamme** are noted with arrows. While clasts often show up on the fresh surface, sometimes they are best seen on the weathered surface so it is best to check both surfaces when looking for clasts.

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What does a “hyaloclastic” texture look like?

A hyaloclastic texture means some clasts display a “jigsaw fit.”

The photograph above was taken with an SLR camera and shows the dry, fresh surface of a geologic hand sample. This rock exhibits a **hyaloclastic** texture. Note the arrows, which point to examples where clasts look like they could fit back together like puzzle pieces. **Hyaloclastic** textures form due to differences in cooling rate between the outside and inside of a lava flow or magma intrusion. While clasts often show up on the fresh surface, sometimes they are best seen on the weathered surface so it is best to check both surfaces when looking for clasts.

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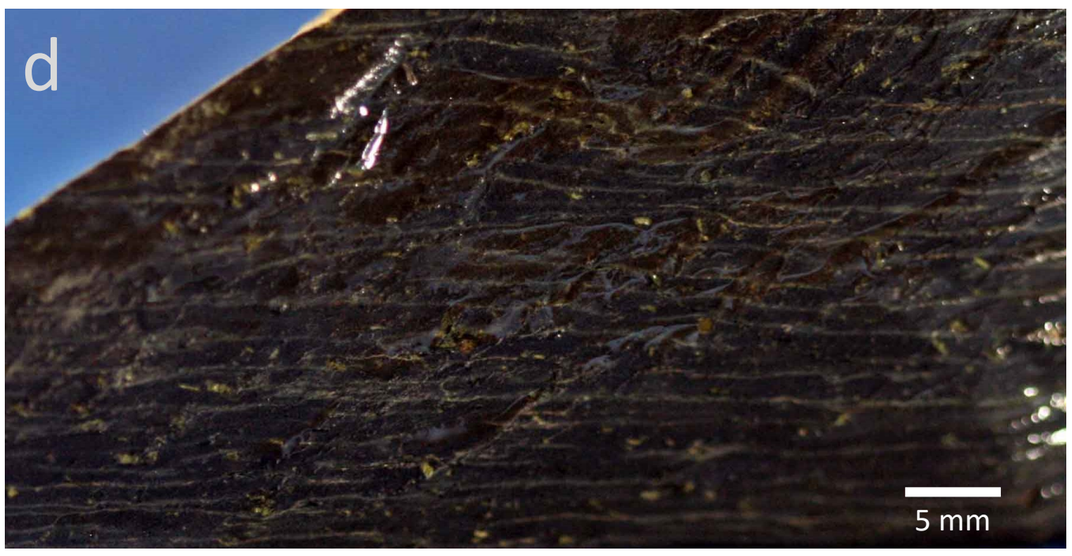
What does “flow banding” look like?



Flow banding looks like streaks or lines on the weathered surface, but may be less noticeable on the fresh surface.

The photographs above were taken with an SLR camera. Photograph “a” and shows the dry, weathered surface of a piece of cultural debris from Morrow Mountain; photograph “b” shows the dry, weathered surface of a geologic hand sample; photograph “c” and shows the dry, lightly weathered surface of a piece of cultural debris; and photograph “d” shows the wet, fresh surface of a geologic hand sample. The samples above exhibit **flow banding**, which often appears as roughly parallel lines (e.g. photograph “a”), though can have a “squiggly” appearance like in photographs “b” and “c”. This feature is often easily visible as stripes on the weathered surface (a, b, & c), though may be more subtle on the fresh surface (d). **Flow banding** forms in lavas due to friction between a flowing lava and solid rock. Flow banding can be difficult to tell from bedding in hand sample and is best interpreted in the context of other clues. For example, the presence of **amygdules** or tight folds favor **flow banding** over bedding. (See soft sediment deformation in “Less Common Textures” section for an exception to tight folds favoring **flow banding**.)

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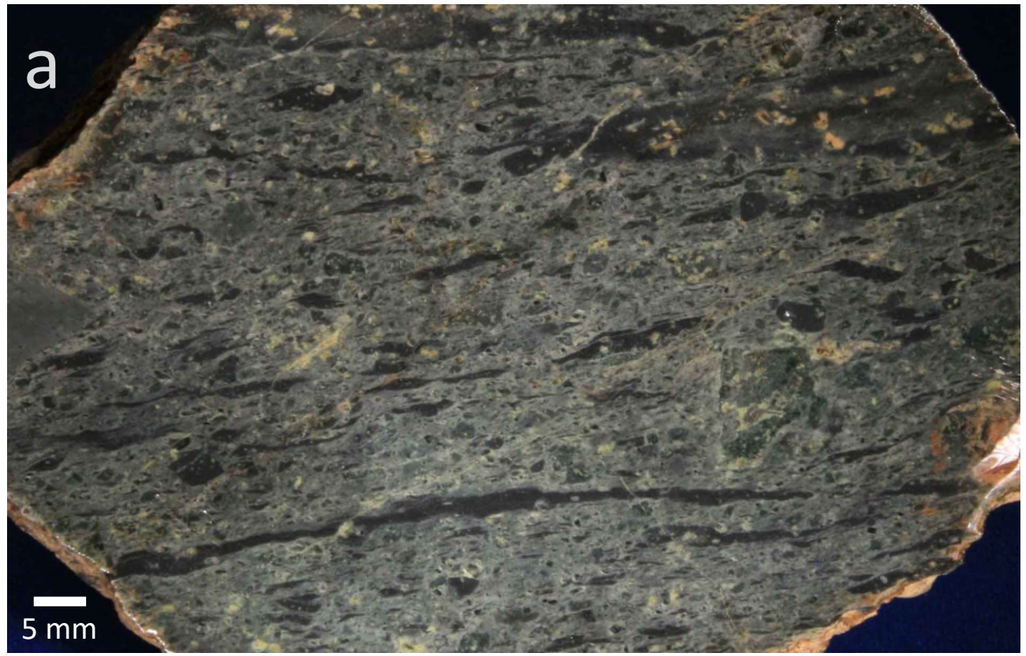

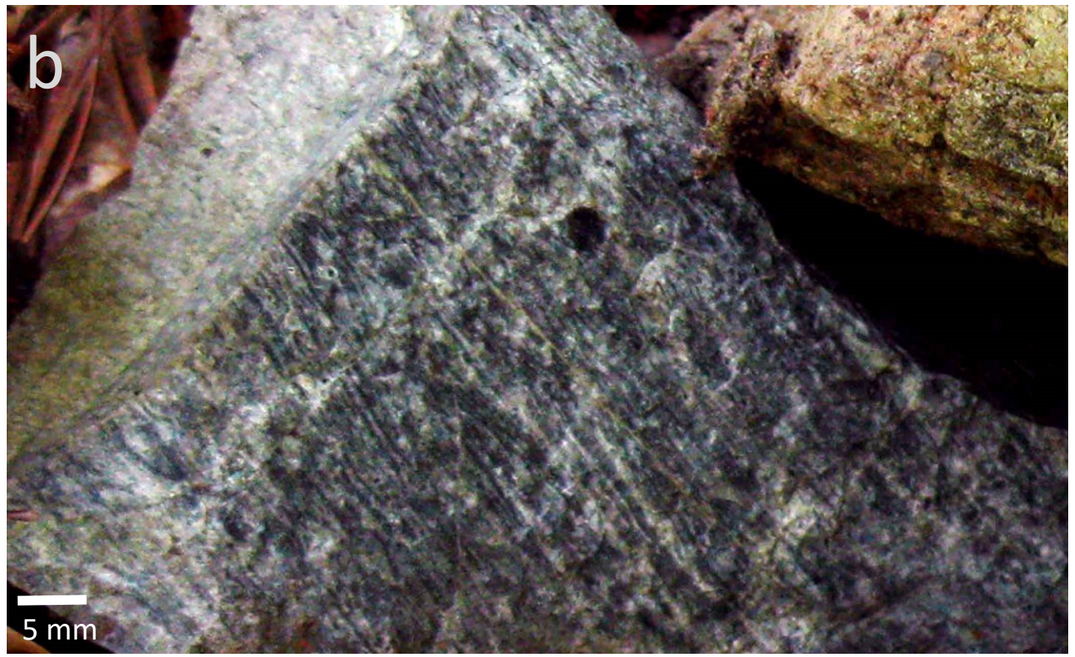

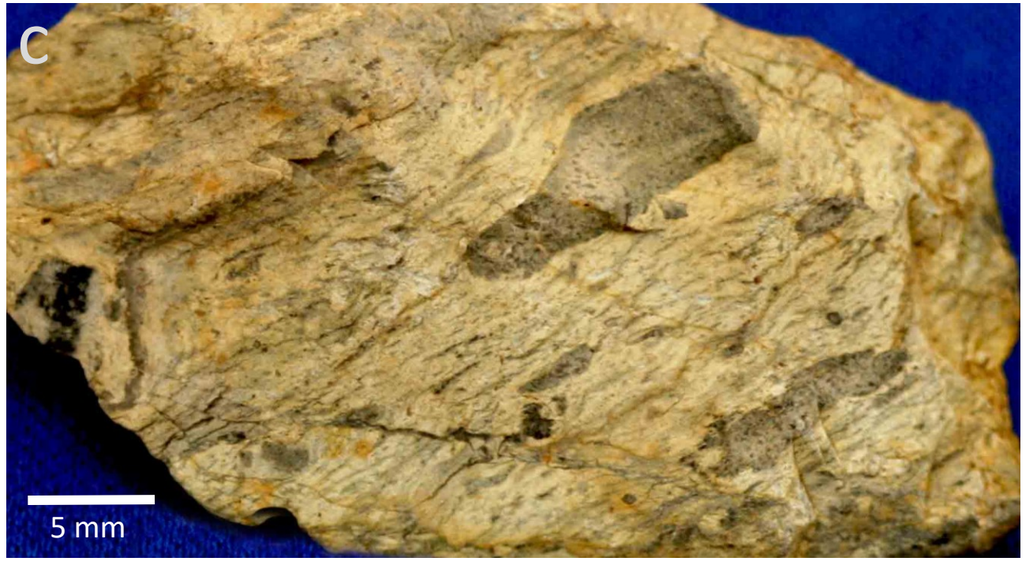

Welding can appear as thin lines on the fresh or weathered surface of the rock and is often accompanied by fiamme-shaped clasts. It is characteristic of a type of tuff.

The photographs above were taken with an SLR camera. Photographs “a” and “b” show the wet, fresh surface of a geologic hand sample; photograph “c” shows the dry, lightly weathered surface of a rock fragment; and photograph “d” shows the dry, highly weathered surface of a geologic hand sample. On fresh (a and b) and lightly weathered (c) surfaces, welding may appear as thin, roughly parallel to somewhat disjointed lines and may be defined by **fiamme-shaped clasts** (a and c). On highly weathered surfaces, welding can appear as “record grooves”, though less weathered surfaces - such as those on cultural debris – are less likely to develop grooves. Welding occurs in tuffs that were hot enough at the time of deposition for the ash to weld together.

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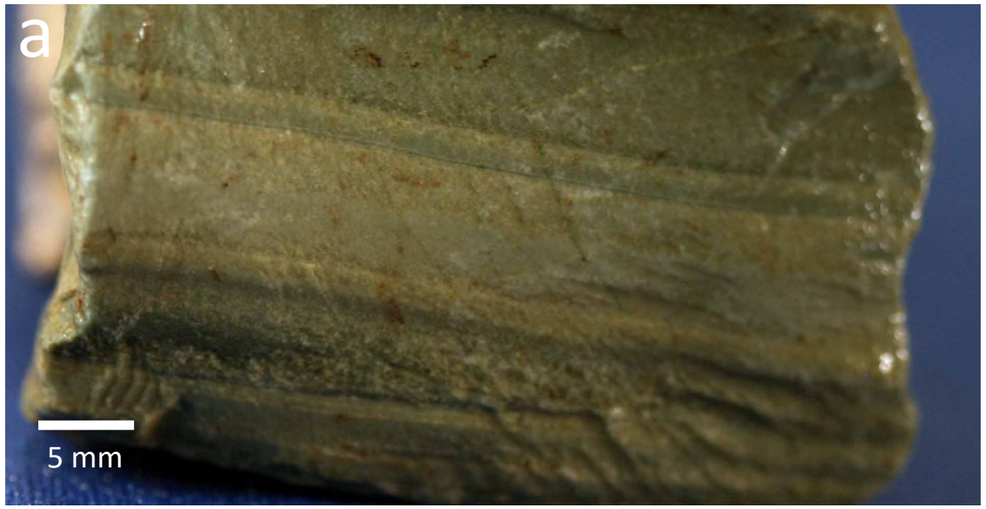
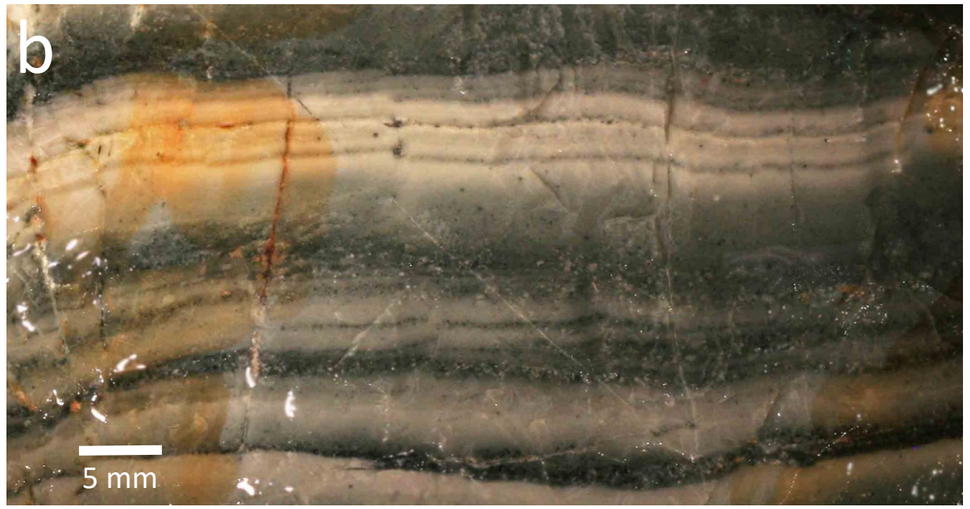
What does “bedding” look like?





Bedding is a sedimentary feature that can appear as roughly parallel lines of differing thickness. It can be found in tuffs and epiclastic rocks (sandstones and siltstones).

Photographs “a” through “c” were taken with an SLR camera. Photographs “a” and “b” show bedding on the wet, fresh surface of a geologic sample; photograph “c” shows the dry, lightly weathered surface of a piece of cultural debris. Photograph “d” shows the same sample as “c”, but was taken under a microscope at 10x magnification to show how small-scale bedding may look under a hand held 10x magnifier. In all samples bedding appears as relatively parallel lines of differing colors and thicknesses. Bedding is often apparent on both the fresh (a & b) and weathered (c & d) surfaces. On well weathered surfaces, differences in relief can also form due to differences in how quickly layers weather.

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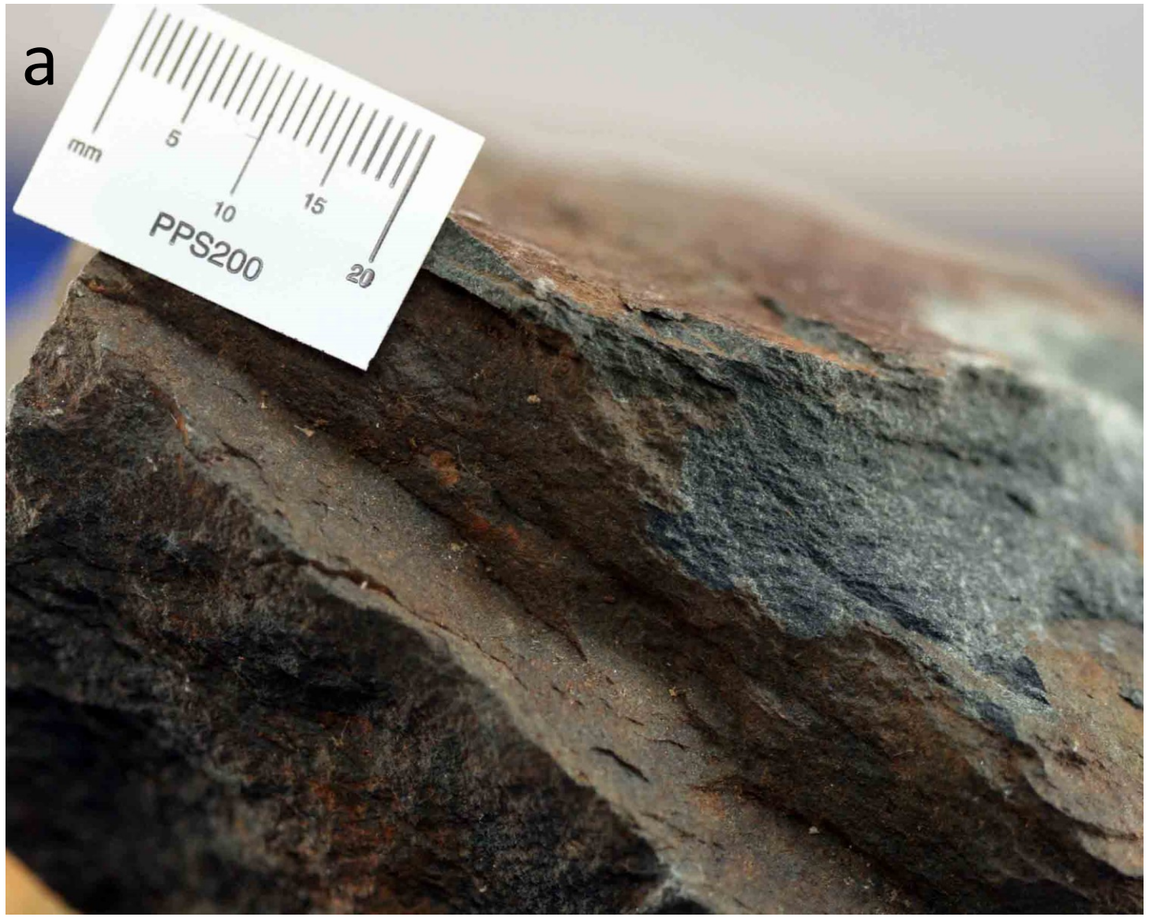
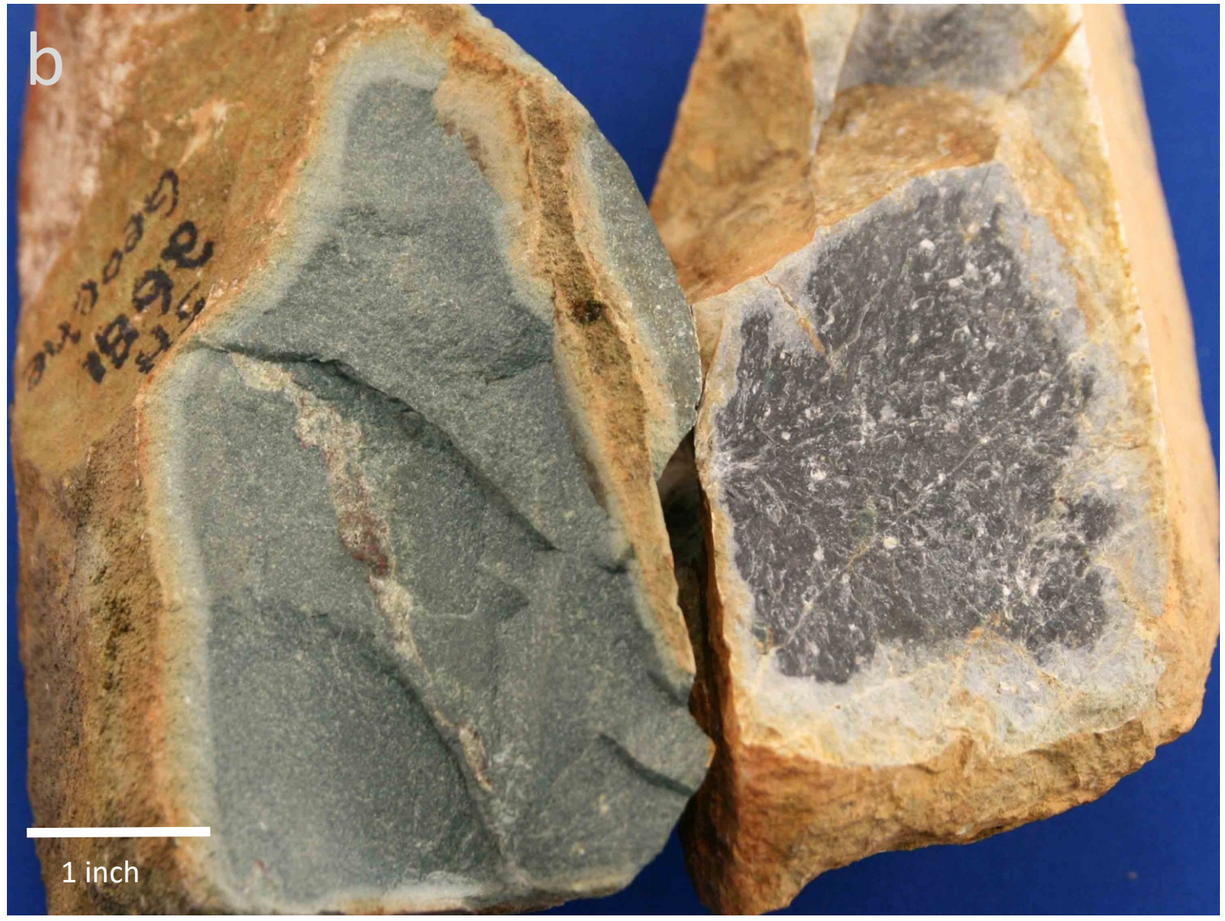
Weathering rinds (cortex): mafic, intermediate, or felsic?





Weathering rinds (cortex) are the outer portions of rocks that have been chemically altered through weathering.

The photographs above were taken with an SLR camera and show both the dry weathered and dry fresh surfaces of geologic hand samples. Weathering rinds (cortex) yield valuable information about chemical composition of the rock; however it can sometimes take practice to train one's eye to see the differences. Since these differences are most obvious in a geologic hand sample, this guide will start there then take a look at weathering on cultural debris. Photograph "a" shows a mafic weathering rind, such as what would be seen on a basalt. Notice the rind is dark brown, and there is not a lighter weathering rind between the fresh surface and the brown weathering. Photograph "a" corresponds to the "weathering rind is dark brown" option in flow chart 2. Photograph "b" shows an intermediate weathering rind, such as what would form on an andesite, on the left and a felsic weathering rind, such as what would form on a dacite to rhyodacite, on the right. While both weathering rinds have a brown exterior and a lighter interior, there are differences in the color of each. The intermediate sample has more grey or green tones to the light portion of the weathering rind, and the brown is a darker, more olive-brown shade than the felsic weathering rind on the right. The sample on the left corresponds to the "weathering rind is olive brown and may have a lighter greenish-gray inner layer" option on flow chart 2, whereas the sample on the right corresponds to the "Weathering is primarily light gray to cream colored and may have brown patches" option in flow chart 2. A Munsell color chart may be useful for deciphering the subtle color differences between the intermediate and felsic weathering rinds.

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How would intermediate and felsic weathering rinds/patina look on cultural debris?

Weathering rinds can provide insight into the general composition of the rock.

The photographs “a” and “b” were taken with an SLR camera and show both the dry weathered and dry fresh surfaces of cultural debris. The fresh surfaces for both are indicated with arrows. In photograph “a”, the brown patina is against the fresh surface without an intervening lighter rind. The color of the patina is a drab olive brown, like the intermediate sample on the previous page, though not as dark brown as the mafic samples. This corresponds to the “weathering rind is an olive brown and may have a lighter greenish-gray inner layer” option on flow chart 2. Photograph “b” shows a well developed light weathering rind and with some lighter brown areas on the outside. Note the color of the light and brown portions of the rind are similar to the felsic rind on the hand sample on the previous page. Photograph “b” corresponds to the “Weathering is primarily light gray to cream colored and may have brown patches” option in flow chart 2.

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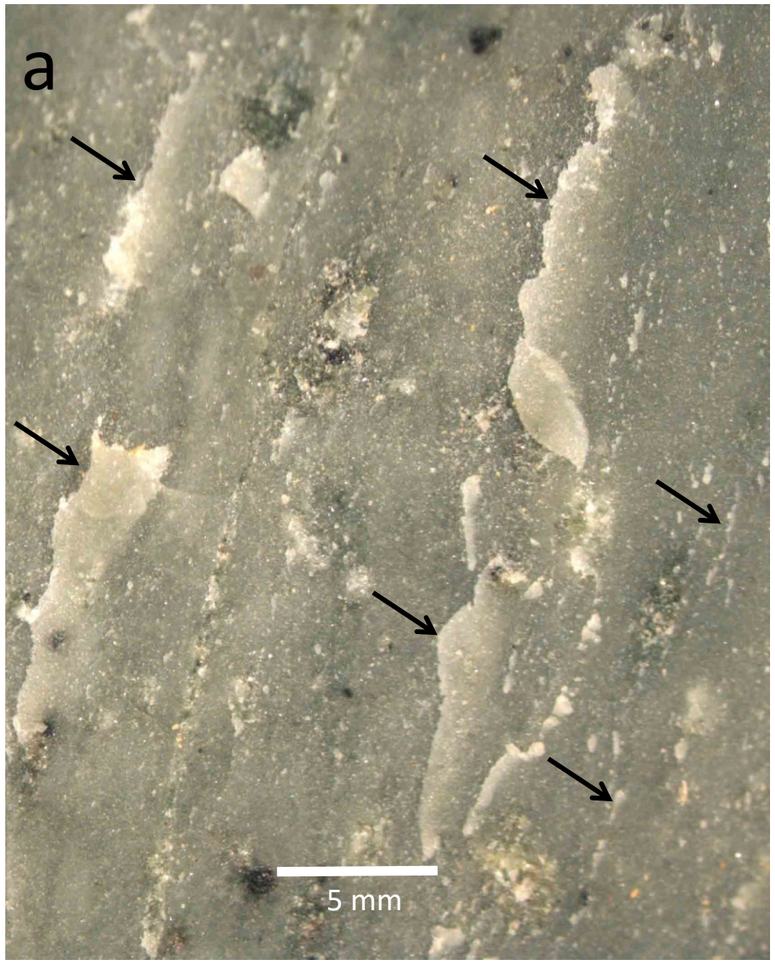
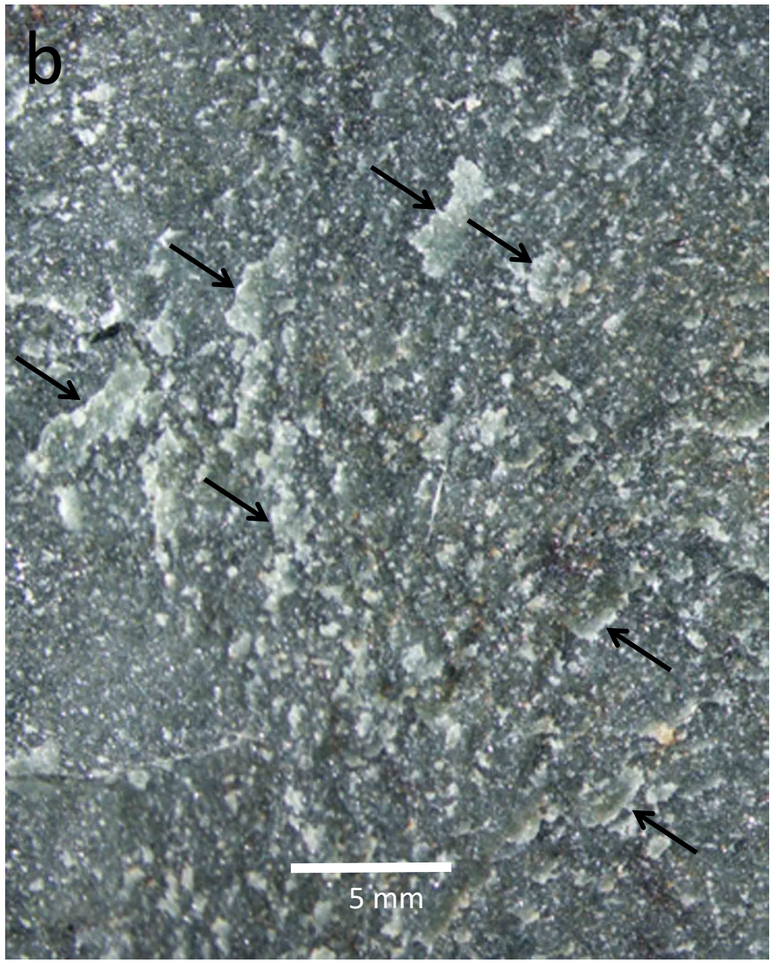
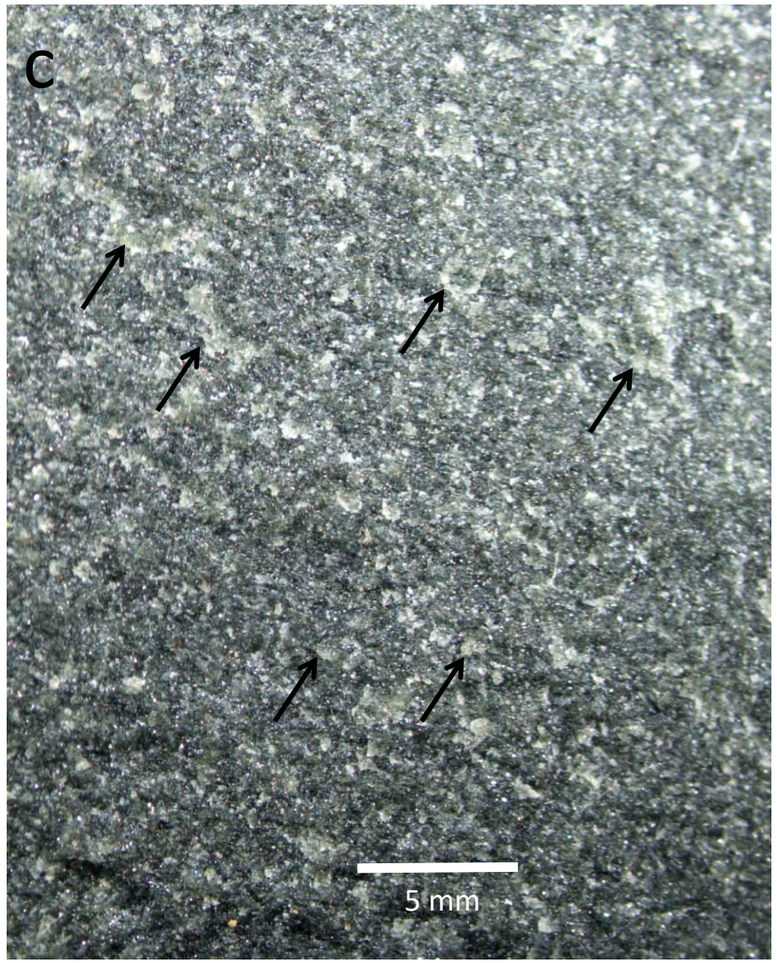
What do “frosted flakes” look like and how can I tell how vitric something is?







“Frosted flakes” are the translucent flakes that form on the fresh surface when intermediate to felsic rocks are broken. The presence and nature of frosted flakes yield valuable information about the composition of a sample.

The photographs above were taken of the dry, fresh surface of geologic hand samples under a microscope at 10x magnification to simulate how they would look under a handheld 10x magnifier. Checking for “frosted flakes” should always be done on a fresh, dry surface. Photograph “a” shows a strongly vitric rock, such as a rhyodacite. Note that the “frosted flakes” (some of which are identified with arrows) are easily visible. Photograph “b” shows a sample that is vitric, but less vitric than the one in photograph “a”. This sample is a dacite. Photograph “c”, an andesite, still has frosted flakes, but they are not as well developed as they are on the samples in photographs “a” and “b”. When using the “composition of lavas” flow chart, photographs “a” and “b” correspond to the option “I can easily see frosted flakes with a 10x magnifier or can see them without a magnifier”; photograph “c” corresponds to “I can see some frosted flakes with a 10x magnifier”.

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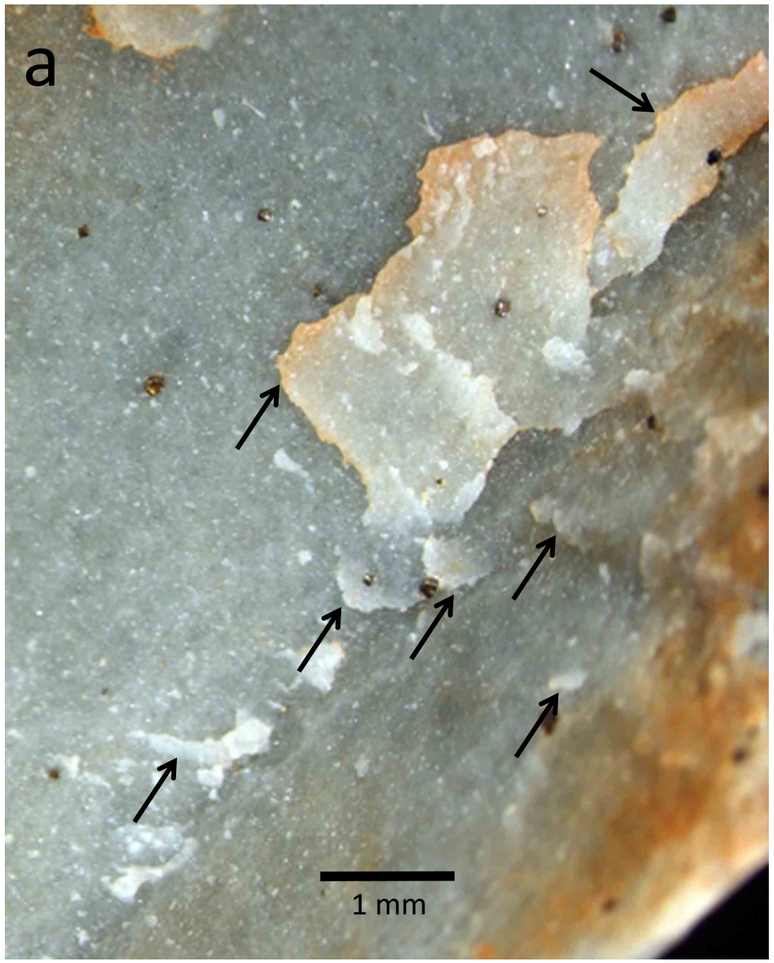
What would “frosted flakes” look like on broken surfaces of cultural debris?



“Frosted flakes” are the translucent flakes that form on the fresh surface when intermediate to felsic rocks are broken. The presence and nature of frosted flakes yield valuable information about the composition of a sample.

Photographs “a-c” show broken areas on cultural debris, and were taken at 10x under a microscope to simulate how they might look with a 10x hand held magnifier. Note that frosted flakes are easily visible in photographs “a” and “b”. These would be an example of the “I can easily see frosted flakes with a 10x magnifier or can see them without a magnifier“ option on flow chart #2. The fresh surface in photograph “c” shows a few frosted flakes, but they are not as well developed as in photographs “a” and “b”. Photograph “c” is an example of the “I can see some frosted flakes with a 10x magnifier“ option in flow chart #2.

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When do I wet the sample and when do I look at it dry?

Use a dry sample when you:

- Are examining the weathered surface to determine:
    - if flow banding, bedding, or welding are present
    - if fiamme-shaped clasts are present
    - the color of the weathering rind/patina
- Are examining the fresh surface to determine:
    - how vitric a sample is.

Use a wet sample when you:

- Are looking at the fresh surface to determine whether:
    - the groundmass is aphanitic or granular
    - clasts and/or crystals are present
    - flow banding, bedding, or welding are present

How can I tell a tuff from a lava?

Tuffs and lavas can be difficult to tell apart. Here are some additional tips that may help:

- If you are looking at the outcrop, note its shape. Lavas tend to have blocky outcrops with joints (repeated fractures in the rock). Tuffs tend to have fin-shaped outcrops with cleavage or foliation present.
- If you are looking at an unmodified cobble or boulder note its shape. A lava will be blocky whereas a tuff is generally more flagstone shaped.

How can I contact the authors?

Heather Hanna can be contacted at the following email address: nclithicsguide@gmail.com
Phil Bradley (NCGS) email: pbradley@ncdenr.gov

Where can I find more information?

The following reference is an in-depth guide to volcanic textures, and was consulted in the making of this lithic identification guide:
McPhie, J., Doyle, M., and Allen, R., 1993, Volcanic Textures, Tasmanian Government Printing Office, Tasmania, 198 p.

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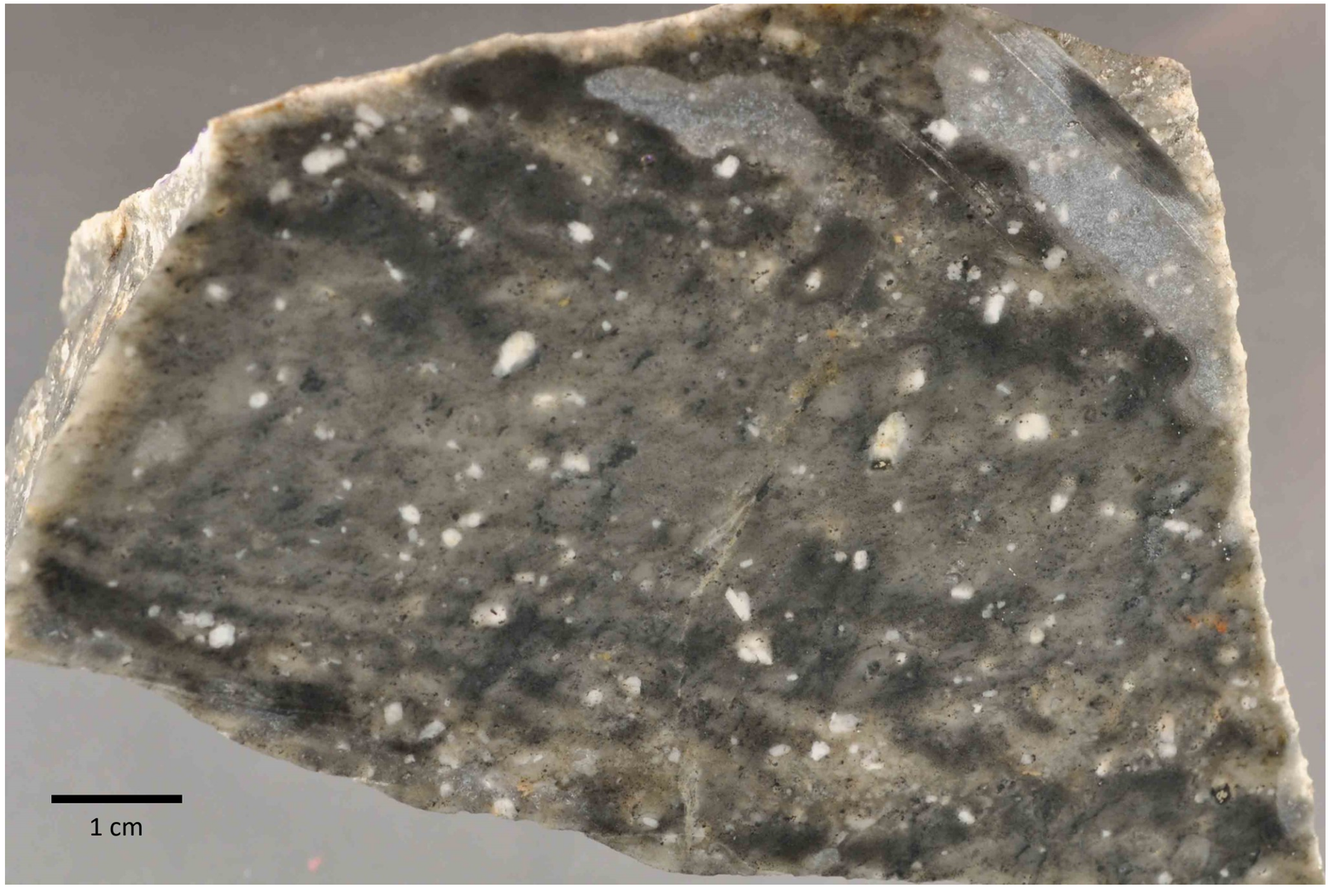
Less Common Textures

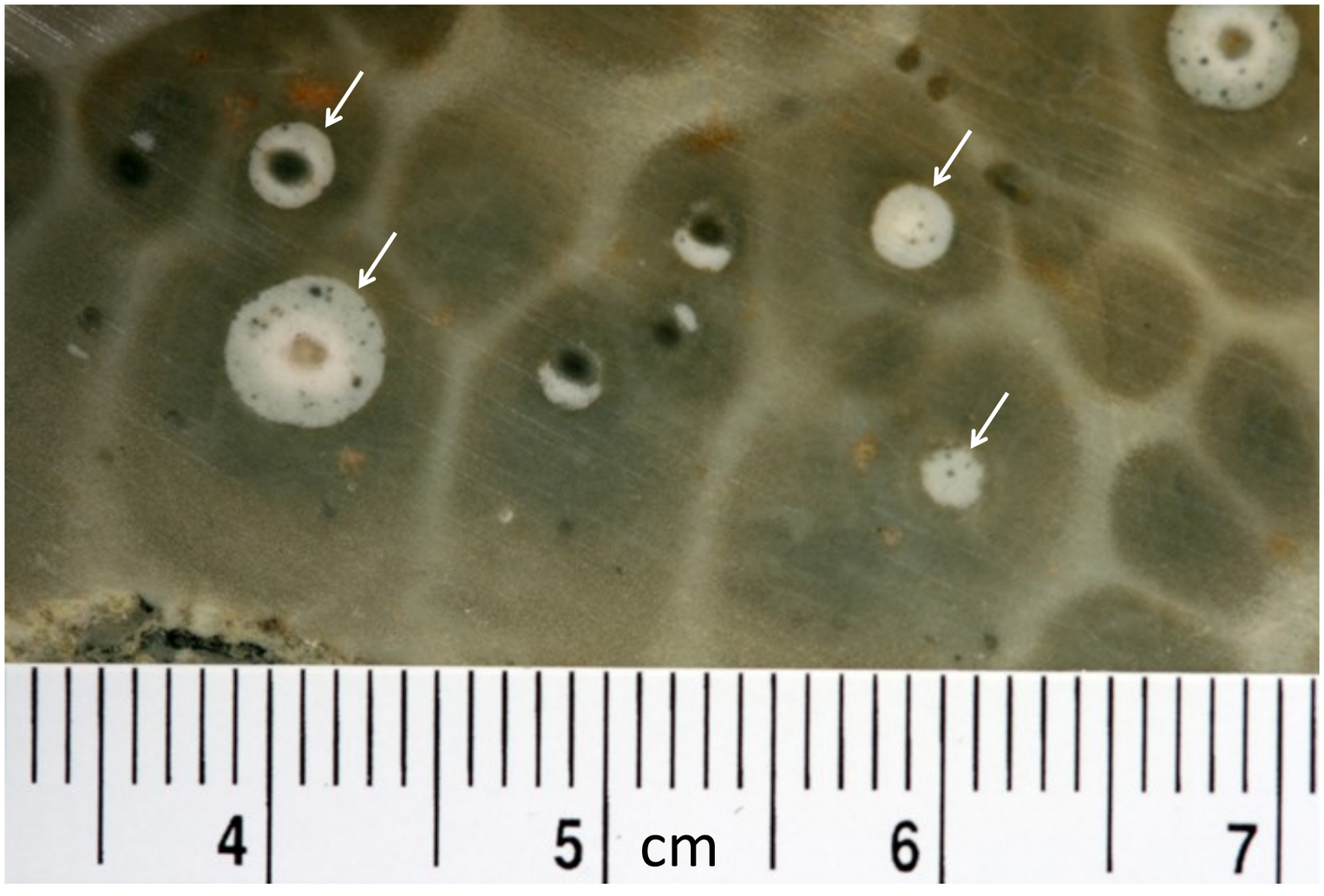
Devitrification of an aphanitic matrix



The splotchy look of the matrix in the above sample is due to devitrification, which occurs when thermodynamically-unstable volcanic glass grows very tiny crystals.

The photograph above was taken with an SLR camera and shows the wet, fresh surface of a geologic hand sample. When this sample formed the matrix was composed of volcanic glass, meaning the matrix cooled too quickly for crystals to grow. Volcanic glass is not stable over long geologic time scales and under certain conditions, causing the matrix to grow tiny crystals at lower temperatures in a process called **devitrification**. The growth of tiny crystals during **devitrification** caused the splotchy look of the matrix in the above picture. **Devitrification** features can be present in felsic lavas and tuffs, and the siltstones and sandstones derived from them.

Spherulites



Spherulites are small, radiating groups of crystals that are commonly round in shape. They form by devitrification of volcanic glass.

The photograph above was taken with an SLR camera and shows the wet, fresh surface of geologic hand sample that displays a type of **devitrification** feature called **spherulites**. Examples of **spherulites** are noted with white arrows. This sample was originally composed of volcanic glass, meaning it cooled too quickly for crystals to grow. Volcanic glass is not stable over long geologic time scales and under certain conditions, causing crystals to grow at lower temperatures in a process called **devitrification**. Sometimes that crystal growth can produce radiating groups of crystals called **spherulites**. The scale at the bottom of the photograph is in centimeters.

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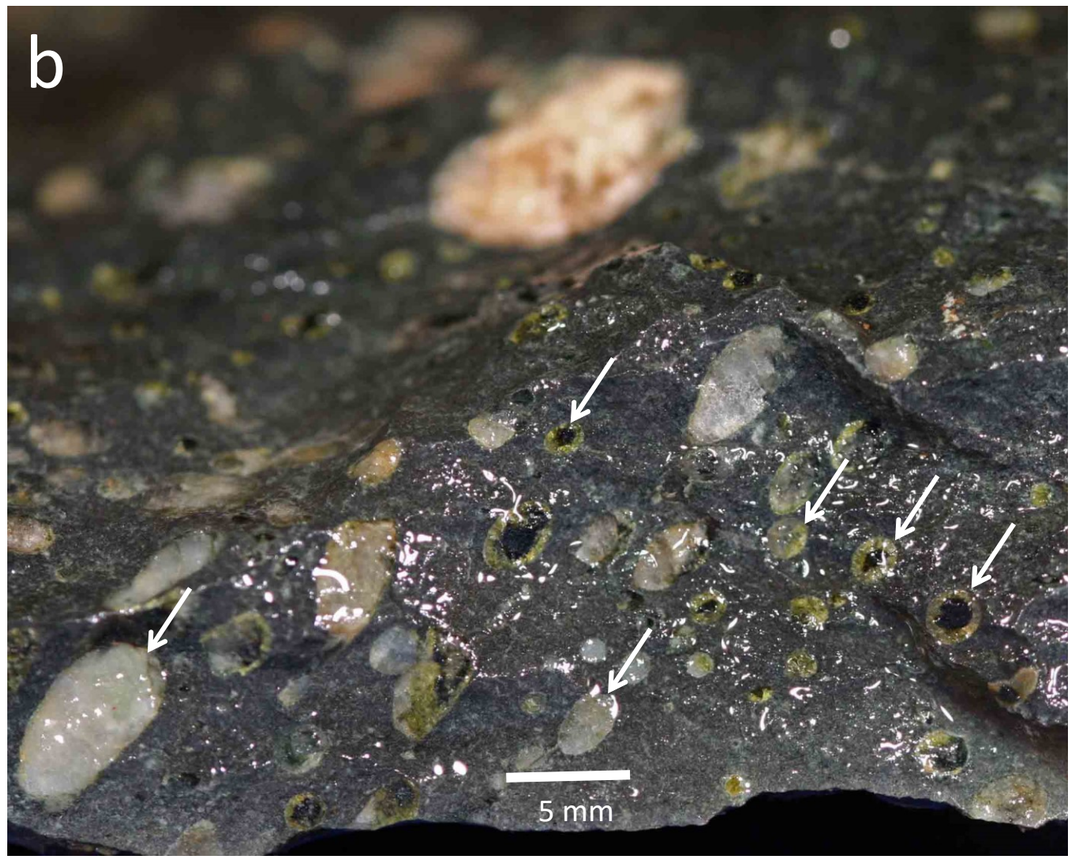
Vugs and Amygdules



Vugs are holes left by trapped gases in magma or lava.
Amygdules are vugs that are partially or completely filled by mineral growth.

The photographs above were taken with an SLR camera and show the dry, weathered (a) and wet, fresh (b) surfaces of geologic hand samples. Note the arrows, which point to examples of **amygdules**. Photograph "a" shows an amygdule where the cavity is partially filled with crystals, while photograph "b" shows amygdules that are completely filled by mineral growth. **Vugs** and **amygdules** can vary in shape, though most are rounded in appearance. Amygdules can also vary in the type of mineral or minerals filling the cavity. Both **vugs** and **amygdules** are indicative of a lava rock.

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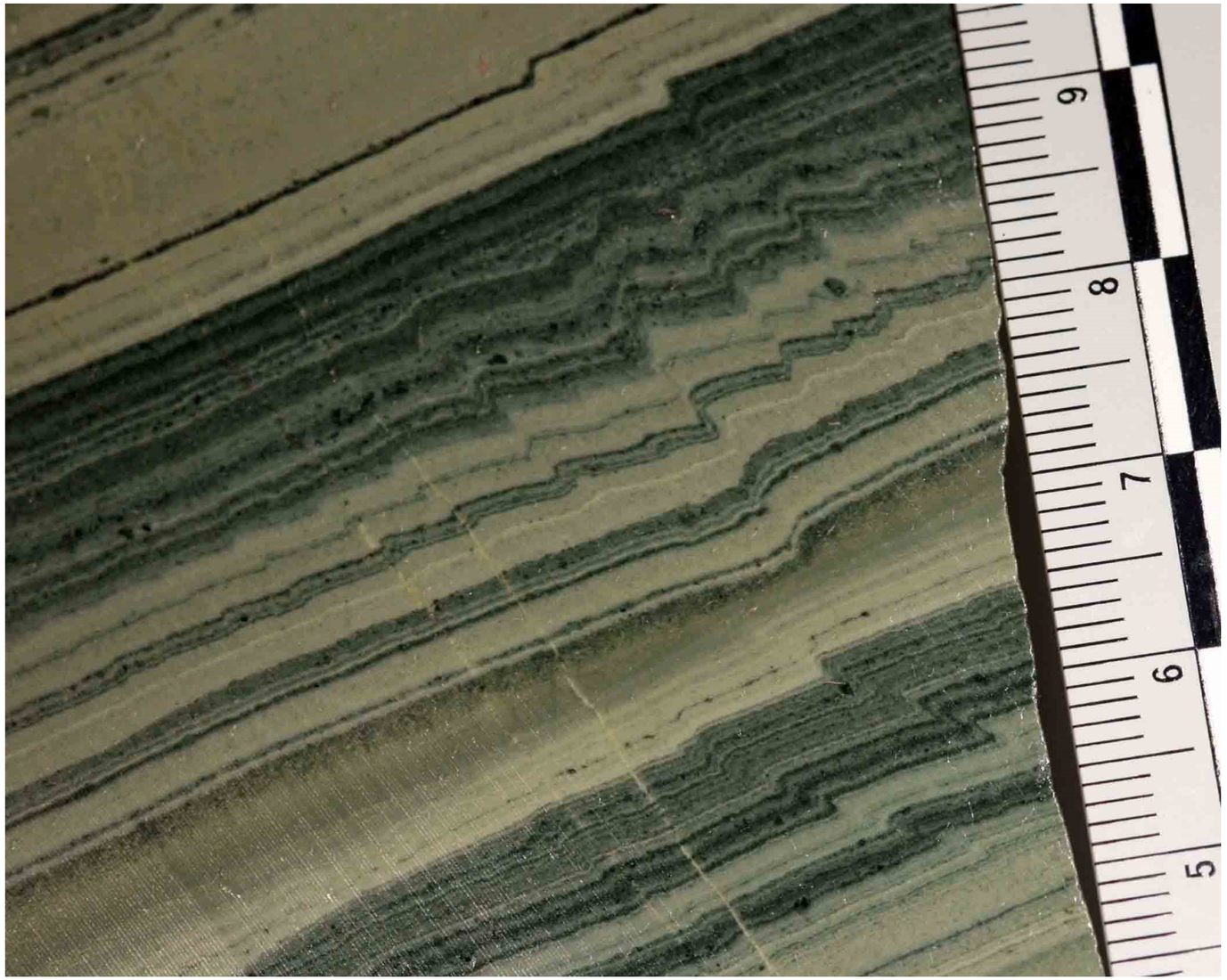
Soft sediment deformation



Soft sediment deformation features form before sediment is cemented into a rock.

The photograph above was taken with an SLR camera and shows the wet, fresh surface of geologic hand sample. The convoluted bedding in the picture is a common example of **soft sediment deformation**, which forms before the sediment was cemented into a rock. The presence of **soft sediment deformation** is suggestive of a **siltstone** or fine-grained **sandstone**.

Acknowledgements

This guide represents a collaboration between members of the North Carolina archaeology community and geologists from the North Carolina Geological Survey. Without the significant contributions of the following individuals, this guide would not be possible:

- Lea Abbott, Office of State Archaeology
- Susan Bamann, Coastal Carolina Research
- Randy Daniel, Department of Anthropology, East Carolina University
- Steve Davis, Research Laboratories of Archaeology, UNC Chapel Hill
- John Mintz, Office of State Archaeology
- Brian Overton, North Carolina Department of Transportation
- Anna Katerina Pascht, North Carolina Geological Survey
- Brandon T. Peach, North Carolina Geological Survey
- Shane Peterson, North Carolina Department of Transportation
- Amanda Keeny Stamper, Coastal Carolina Research

Preliminary Glossary of Terms

The "Glossary of Terms" provides brief, non-technical definitions written specifically for rock types appropriate for use as lithic material. To make the guide more useable and less jargon-laden, the use of geologic terms was kept to a minimum. It is our hope to incorporate more terminology used by archaeologists as the document evolves.

Amygdules: Holes left by trapped gasses in magmas or lavas that are partially or completely filled by mineral growth.

Andesite: A lava rock of intermediate composition. Andesite samples tend to be weakly vitric on the fresh surface and have particular weathering rind/patina color(s) as discussed in the "Frequently Asked Questions" section.

Aphanitic: Matrix looks fairly smooth, as if it is one coherent piece of material. It does not look "bumpy" like it is made of little pieces of other rocks or minerals. See photographs in "Frequently Asked Questions" section for examples.

Basalt: A lava rock rich in iron and magnesium but low in silica. These lavas are not usually vitric on the fresh surface and tend to form brown weathering rinds.

Clast: A rock fragment contained in a rock. Clasts can occur in lavas, tuffs, and epiclastic rocks, and can be angular to rounded in shape and dark grey to light gray or white in color. Some clasts, such as fiamme-shaped or hyaloclastic clasts, can be diagnostic of a particular rock type.

Cleavage: A planar feature in a rock that can act as a plane of weakness when the rock is broken. Cleavage is very similar to foliation. To tell the difference, think of a book: the covers of the book would be cleavage and the pages would be foliation.

Crystal-lithic tuff: A tuff that contains both crystals and clasts. If the sample contains more crystals than clasts, it is called a crystal-lithic tuff. If it contains more clasts than crystals, it is called a lithic-crystal tuff.

Crystal tuff: A tuff that contains crystals.

Dacite: A felsic lava rich in silica. These lavas are vitric on the fresh surface and have a light colored weathering rind/patina. The weathering rind can also have medium to light brown areas as discussed in the "Frequently Asked Questions" section.

Devitrification: A process which occurs when thermodynamically-unstable volcanic glass grows tiny crystals. Devitrification can produce a variety of textures including spherulites and a splotchy matrix.

Epiclastic: A rock formed from preexisting rock fragments

Felsic: Felsic is a term used in geology to refer to magma or rocks formed from magma enriched in silica, aluminum, sodium and potassium. Rocks formed from felsic magmas typically contain the minerals quartz, and sodium and potassium feldspars. The word is derived by combining the words *feldspar* and *silica*. Older literature often uses the synonym *acid* or *acidic* when referring to a felsic magma or rock.

Fiamme-shaped clasts: Clasts that have a flame shape. Fiamme are formed by the compaction of pumice and are characteristic of welded tuffs.

The "Glossary of Terms" provides brief, non-technical definitions written specifically for rock types appropriate for use as lithic material. To make the guide more useable and less jargon-laden, the use of geologic terms was kept to a minimum. It is our hope to incorporate more terminology used by archaeologists as the document evolves.

Foliation: A planar feature in a rock that can act as a plane of weakness when the rock is broken. Cleavage is very similar to foliation. To tell the difference, think of a book: the covers of the book would be cleavage and the pages would be foliation.

Flow banding: A feature that forms in lavas due to friction between a flowing lava and solid rock. Flow banding often looks like streaks or lines on the weathered surface. See "Frequently Asked Questions" section for photographs of examples.

Hyaloclastic: Some clasts have a jigsaw fit (i.e. look like they could fit back together like a puzzle). This texture forms as the surface of flowing lavas cools and breaks apart.

Lava: Traditionally, lava is molten rock that has been expelled from a volcano. Due to ambiguity in samples and for ease of use, "lava" as used in this guide may also include shallowly intruded magma.

Lithic-crystal tuff: A tuff that contains both clasts and crystals. If the sample contains more crystals than clasts, it is called a crystal-lithic tuff. If it contains more clasts than crystals, it is called a lithic-crystal tuff.

Lithic tuff: A tuff that contains clasts.

Mafic: Mafic is a term used in geology to refer to magma or rocks formed from magma enriched in magnesium and iron. Rocks formed from mafic magmas typically contain dark colored minerals like pyroxene, amphibole and olivine. Mafic rocks may also contain calcium-rich plagioclase feldspar. The word is derived by combining the words *magnesium* and *ferric* (iron-containing). Older literature often uses the synonym *basic* when referring to a mafic magma or rock.

Porphyritic: Noticeably larger crystals in a fine-grained or aphanitic groundmass. This term applies to lavas.

Phyric: Noticeably larger crystals in fine-grained or aphanitic groundmass. Phyric is a synonym for "porphyritic".

Pumice: A porous form of solidified magma. Pumice contains abundant air pockets that are called vesicles. The air pockets cause the pumice to be less dense than typical rock. Pumice may float on water if the air pockets are sufficiently abundant. Because of the air pockets pumice can be easily flattened.

Rhyodacite: A felsic lava very rich in silica. These lavas are very vitric on the fresh surface and have light colored to white weathering. Morrow Mountain rocks are an example of rhyodacite.

Sandstone: A sedimentary rock composed mostly of sand-sized mineral grains and/or rock fragments.

Siltstone: A sedimentary rock composed mostly of silt-sized mineral grains and/or rock fragments

Soft sediment deformation: features, such as convoluted bedding, that form before sediment is cemented into a rock.

The "Glossary of Terms" provides brief, non-technical definitions written specifically for rock types appropriate for use as lithic material. To make the guide more useable and less jargon-laden, the use of geologic terms was kept to a minimum. It is our hope to incorporate more terminology used by archaeologists as the document evolves.

Spherulites: Small, radiating groups of crystals that are commonly round in shape. They form by devitrification of volcanic glass.

Tuff: A rock formed by volcanic ash. Some tuffs are entirely aphanitic while others have clasts and/or crystals.

Vitric: Rock has a "glassy" characteristic and shows "frosted flakes" on broken surface. Frosted flakes can be observed in tuffs, some lavas, and tuffaceous siltstones and sandstones.

Volcanic glass: Forms when lava or tuffs cool too quickly for crystals to grow.

Volcaniclastic: A rock composed of clasts of volcanic material. Volcaniclastic rocks can include tuffs, hyaloclastic lavas, sandstones, and siltstones.

Vugs: Holes left by trapped gases in magma or lava.

Welded tuff: A tuff formed by particles hot enough to weld together. Clasts in a welded tuff may be compressed and flattened See "Frequently Asked Questions" section for more information.

Lithic Material Identification Guide

For more information see noted page of guide ex. Page 5

1. Tuff, Lava, or Sedimentary Rock?

There may be outliers that do not fit into the flow chart. In these cases, use the flow chart to the extent each sample allows and consult the "Less Common Textures" section for features not covered in the chart. Outliers may still exist when all sources of information have been used.

START HERE: LOOK AT YOUR WET SAMPLE WITH A 10X MAGNIFIER. WHICH OF THE FOLLOWING DESCRIBES THE MATRIX?

- Matrix is made of tiny bits or looks grainy under 10x magnifications. *(epiclastic rock)* → Page 2
  - Yes → ***Are visible clasts or crystals part of the matrix?*** Page 3
    - Yes → ***Are there stripes on the weathered or fresh surface?*** Page 9
      - Yes → Rock is probably a bedded tuffaceous sandstone.
      - No → Rock is probably a tuffaceous sandstone.
    - No → ***Are there stripes on the weathered or fresh surface?*** Pages 7-9
      - Yes → Rock is probably a bedded tuffaceous siltstone.
      - No → Rock is probably a tuffaceous siltstone.
- Matrix is aphanitic. *(metavolcanic rock.)* → Page 2
  - ***Are there clasts or crystals in the matrix?*** Page 3
    - Clasts *(lava with clasts or lithic tuff)*
      - ***Are clasts fiamme-shaped?*** Page 5
        - Yes → Rock is probably a welded tuff.
        - No → ***Do clasts fit together like jigsaw puzzle pieces?*** Page 6
          - Yes → ***Are there stripes on the weathered or fresh surface?*** Pages 7 and 9
            - Yes → Rock is probably a bedded crystal-lithic/lithic-crystal tuff, but could also be a flow banded lava.***
            - No → Rock is probably a crystal-lithic/lithic-crystal tuff, but could also be a lava***
          - No → ***Are there stripes on the weathered or fresh surface?*** Page 7
            - Yes → Rock is probably a flow banded, porphyritic, hyaloclastic lava.
            - No → Rock is probably a porphyritic, hyaloclastic lava.
    - Crystals and clasts (porphyritic lava with clasts or crystal lithic tuff)
      - ***Are clasts fiamme-shaped?*** Page 5
        - Yes → Rock is probably a welded tuff with crystals.
        - No → ***Do clasts fit together like jigsaw puzzle pieces?*** Page 6
          - No → ***Are there stripes on the weathered or fresh surface?*** Pages 7 and 9
            - Yes → Rock is probably a bedded crystal-lithic/lithic-crystal tuff, but could also be a flow banded lava.***
            - No → Rock is probably a crystal-lithic/lithic-crystal tuff, but could also be a lava***
          - Yes → ***Are there stripes on the weathered or fresh surface?*** Page 7
            - Yes → Rock is probably a flow banded, porphyritic, hyaloclastic lava.
            - No → Rock is probably a porphyritic, hyaloclastic lava.
    - Something other than/in addition to crystals or clasts is present in or as part of the matrix
      - Use appropriate choice for clasts/crystals to identify rock type on flow chart, and consult "Less Common Textures" section to identify unusual feature(s).
    - Neither are present (tuff, lava, or siltstone)
      - ***Are there stripes on the weathered or fresh surface?***
        - Yes → Rock is probably a flow banded lava, bedded/welded tuff or bedded tuffaceous siltstone.
        - No → Rock is probably a lava, tuff, or tuffaceous siltstone
    - Crystals (porphyritic lava or crystal tuff)
      - ***Are there stripes on the weathered or fresh surface?***
        - Yes → Rock is probably a flow banded porphyritic lava or bedded crystal tuff.***
        - No → Rock is probably a porphyritic lava or crystal tuff.***

- Rock is probably a hyaloclastic lava.
  - No → ***Are there stripes on the weathered or fresh surface?*** Page 7
    - Yes → Rock is probably a flow banded, hyaloclastic lava.
    - No → Rock is probably a hyaloclastic lava.
- Rock is probably a lithic tuff, but could also be a lava.***
  - No → ***Are there stripes on the weathered or fresh surface?*** Pages 7 and 9
    - Yes → Rock is probably a bedded lithic tuff, but could also be a flow banded lava.***
    - No → Rock is probably a lithic tuff, but could also be a lava.***

***Tuffs and lavas can be difficult to tell apart. See Frequently Asked Questions section of guide for more information. Pages 2-13

Note: all rocks have been metamorphosed and therefore should have "meta" in front of the rock name (example: metatuff). The "meta" prefix has been dropped for simplicity in this table, but is still implied.

2. Composition of Lavas and Tuffs

Lithic Material Identification Guide

For more information see noted page of guide ex. Page 10

START HERE: LOOK AT THE DRY, FRESH SURFACE WITH A 10X MAGNIFIER. DO YOU SEE "FROSTED FLAKES"?

Pages 12 and 13

I can easily see frosted flakes with a 10x magnifier or can see them without a magnifier (likely felsic lava or tuff)

What color is the weathering rind?

Pages 10 and 11

- Weathering adjacent to the fresh surface is primarily light gray to cream colored → Your rock is probably felsic lava or tuff (rhyodacitic to dacitic)
- Weathering adjacent to the fresh surface is olive brown → Your rock is probably a felsic to intermediate lava or tuff (dacitic to andesitic)
- Weathering rind is dark brown → This is a less common scenario, and the weathering rind may be misleading. The rock is probably a felsic to intermediate lava or tuff (dacitic to andesitic)

I can see sparse frosted flakes with a 10x magnifier (likely intermediate lava or tuff)

What color is the weathering rind?

Pages 10 and 11

- Weathering adjacent to the fresh surface is primarily light gray to cream colored → Your rock is probably an intermediate to felsic lava or tuff (andesitic to dacitic)
- Weathering adjacent to the fresh surface is olive brown and may have a lighter greenish-gray inner layer → Your rock is probably an intermediate lava or tuff (andesitic)
- Weathering rind is dark brown → This is a less common scenario, and the weathering rind may be misleading. The rock is probably an intermediate lava or tuff (andesitic)

I do not see frosted flakes with a 10x magnifier (likely mafic lava or tuff, but could be intermediate lava or tuff)

What color is the weathering rind?

- Weathering is primarily light gray to cream colored and may have brown patches → This is a less common scenario, and the weathering rind may be misleading. The rock is probably an intermediate lava or tuff (andesitic)
- Weathering rind is dark brown → Your rock is probably a mafic lava or tuff (basaltic)
- Weathering rind is olive brown and may have a lighter greenish-gray inner layer → Your rock is probably a mafic to intermediate lava or tuff (basaltic to andesitic)

The color of the weathering rind can be useful in determining the composition of a lava or tuff. However, color differences between intermediate and felsic weathering can be difficult to see and can lead to potentially incorrect conclusions. Therefore, how vitric a sample is (i.e. how easily "frosted flakes" can be seen) should be given more weight than the weathering rind color.

Note: all rocks have been metamorphosed and therefore should have "meta" in front of the rock name (example: metabasalt). The meta prefix has been dropped for simplicity in this table, but is still implied.

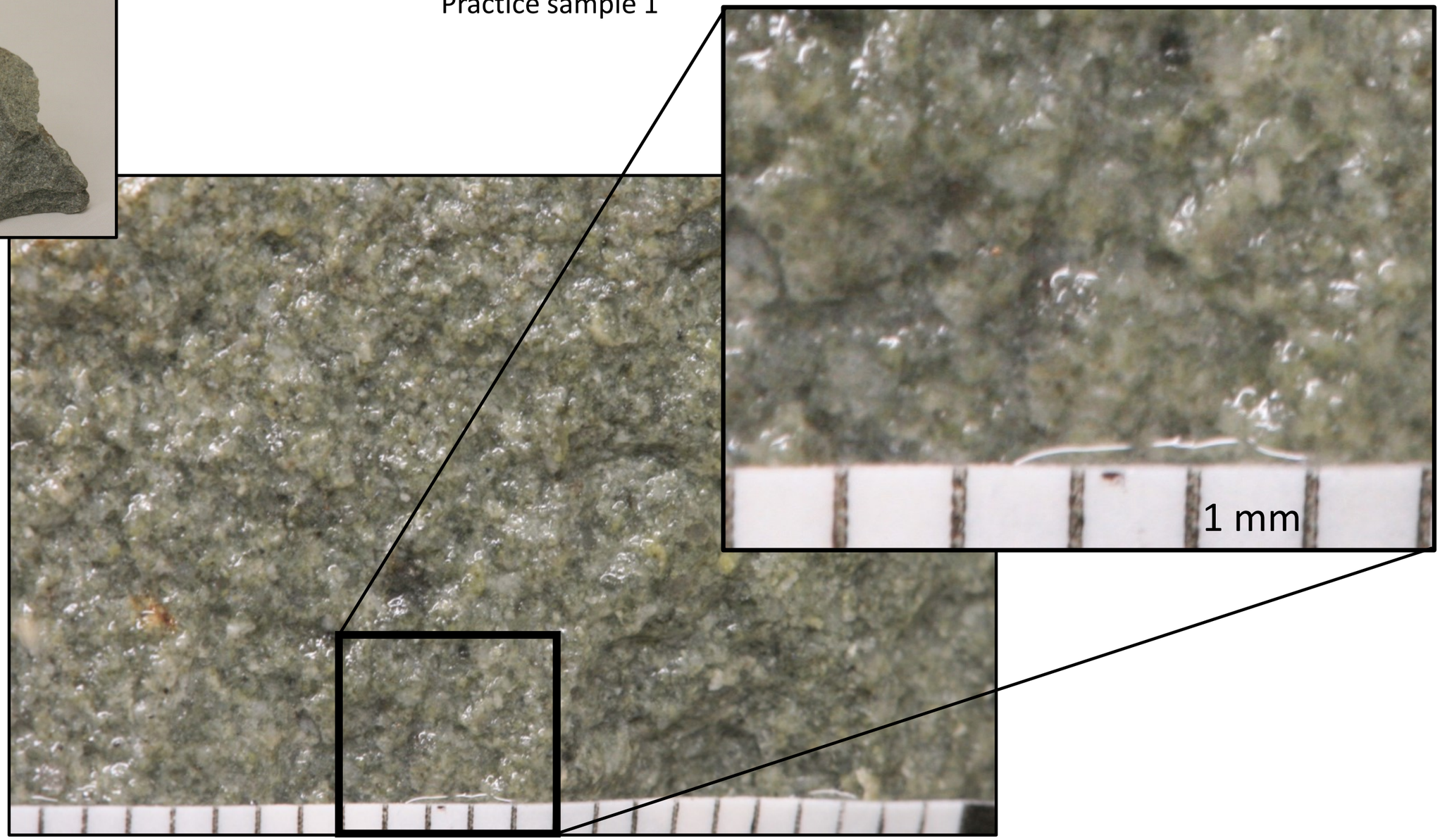
Note: It is recommended to input finalized data into excel format for potential use in GIS

Lithic Material Identification Guide

Sample number	Is matrix granular or aphanitic?	Are clasts and/or crystals present in the matrix, as part of the matrix, or not at all?	**For aphanitic matrix only:** If clasts are present, are they fiamme-shaped, jigsaw-fit (hyaloclastic), or neither?	Are stripes present on the weathered or fresh surface? If yes, are they likely bedding, welding, flow banding, or unknown?	What rock type was identified by the flow chart?	If rock type is lava or tuff, is it felsic, intermediate, or mafic? (See Composition of Lavas and Tuffs flow chart if applicable)	If crystals are present, are they quartz, feldspar, or something else? (See Frequently Asked Questions Section)	Were any textures identified using the "Less Common Textures" section? If so, list here.

Practice Samples

Practice sample 1

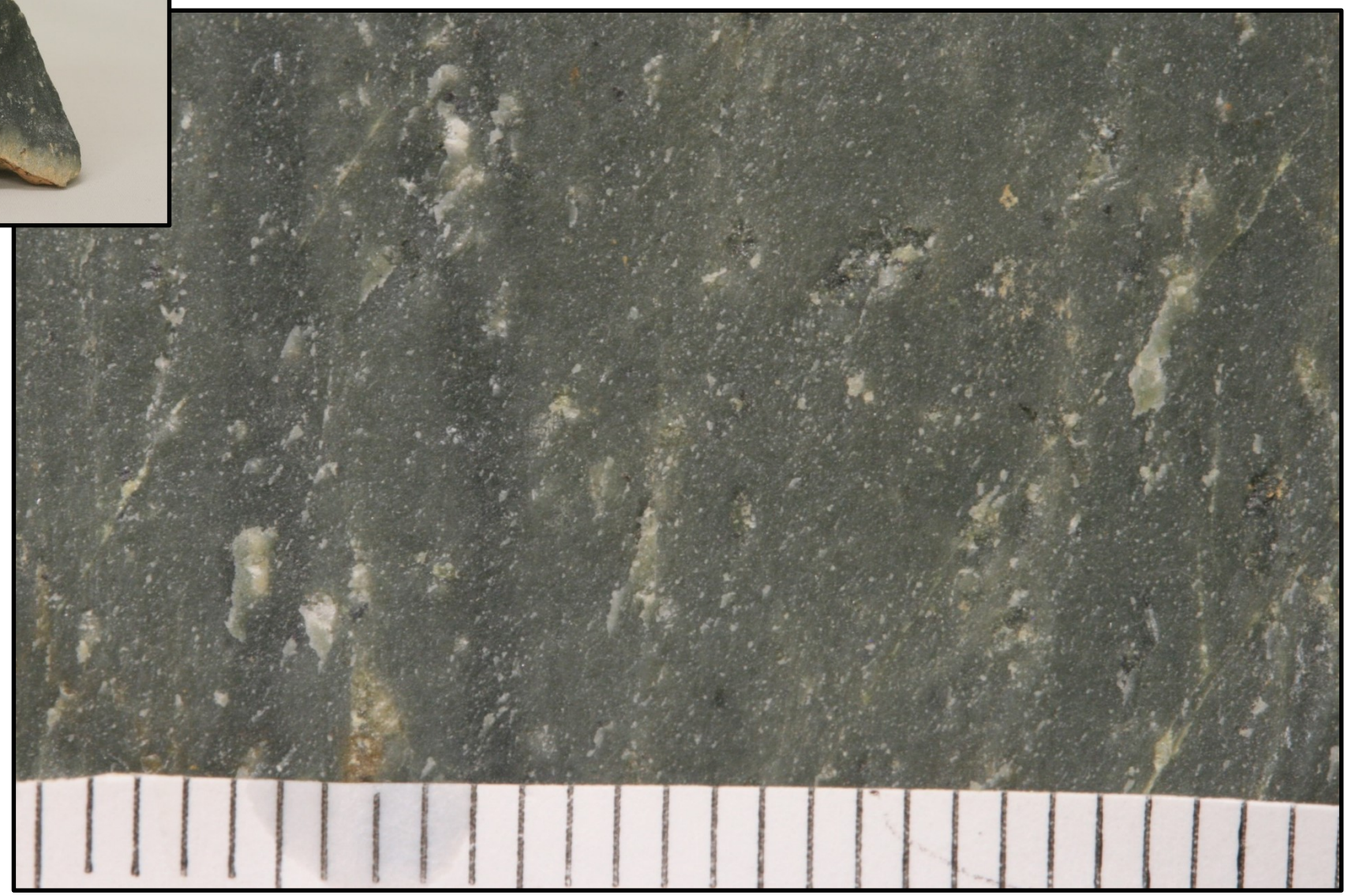


Use the “Tuff, Lava, or Sedimentary Rock?” flow chart and, if applicable, the “Composition of Lavas and Tuffs” to identify the sample in the photograph above. Use the worksheet on the previous page to record each decision you make while using the flow chart(s). When exercise is complete, compare your answers to the answer key at the end of the guide.

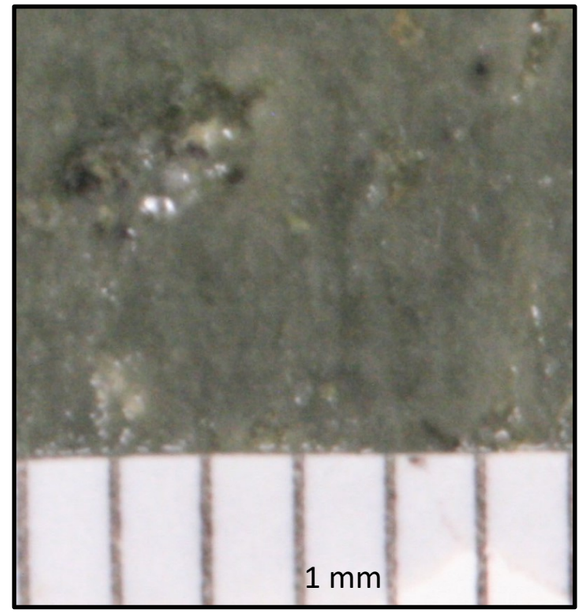
Note: This is not intended as a geologic rock identification guide. It was written specifically for identification of lithic material and therefore does not encompass the entire range of textures and rock types observed in the Carolina terrane.

Practice Samples

Practice sample 2



Dry surface.



Wet surface.

Use the “Tuff, Lava, or Sedimentary Rock?” flow chart and, if applicable, the “Composition of Lavas and Tuffs” to identify the sample in the photograph above. Use the worksheet on the previous page to record each decision you make while using the flow chart(s). When exercise is complete, compare your answers to the answer key at the end of the guide.

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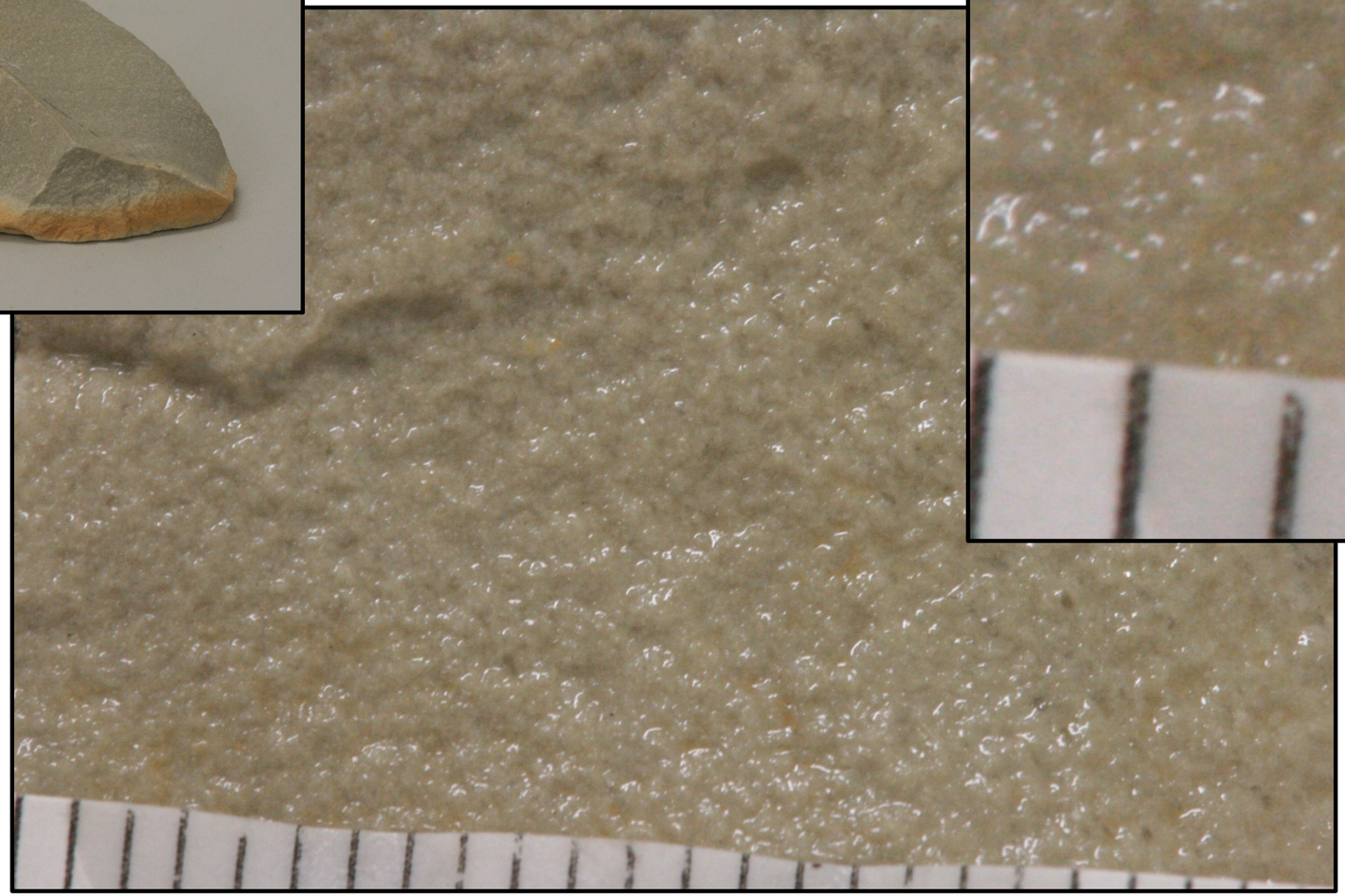
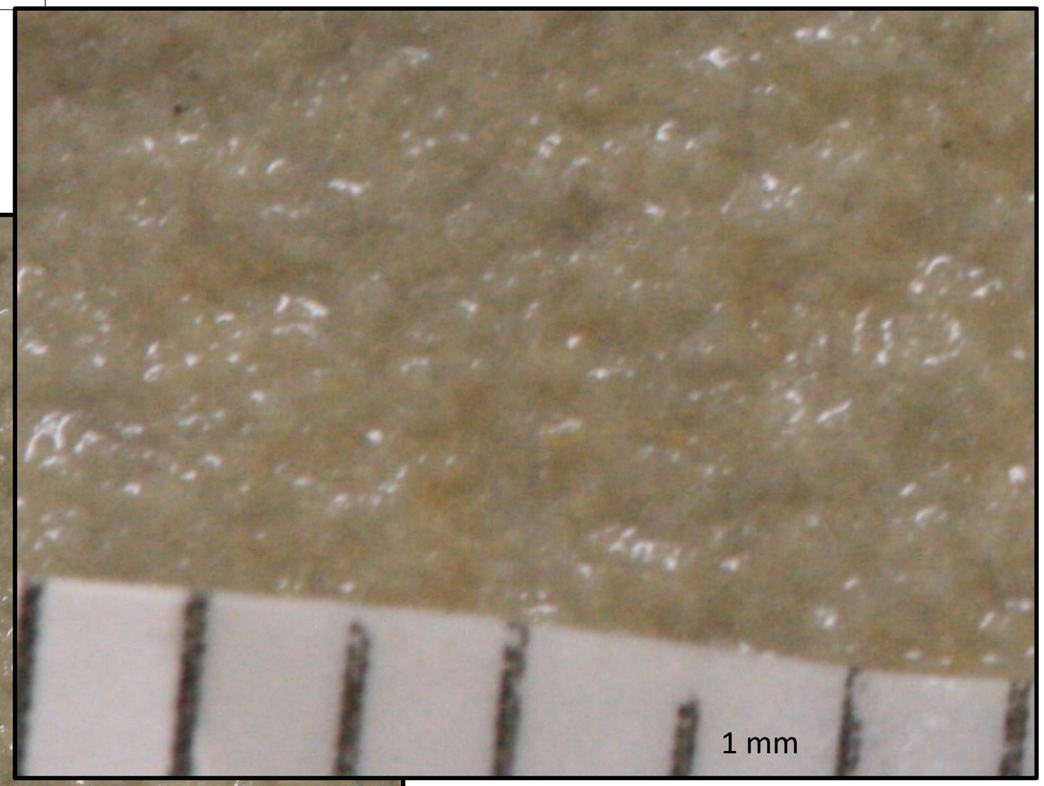
Practice Samples

Practice sample 3





Use the “Tuff, Lava, or Sedimentary Rock?” flow chart and, if applicable, the “Composition of Lavas and Tuffs” to identify the sample in the photograph above. Use the worksheet on the previous page to record each decision you make while using the flow chart(s). When exercise is complete, compare your answers to the answer key at the end of the guide.

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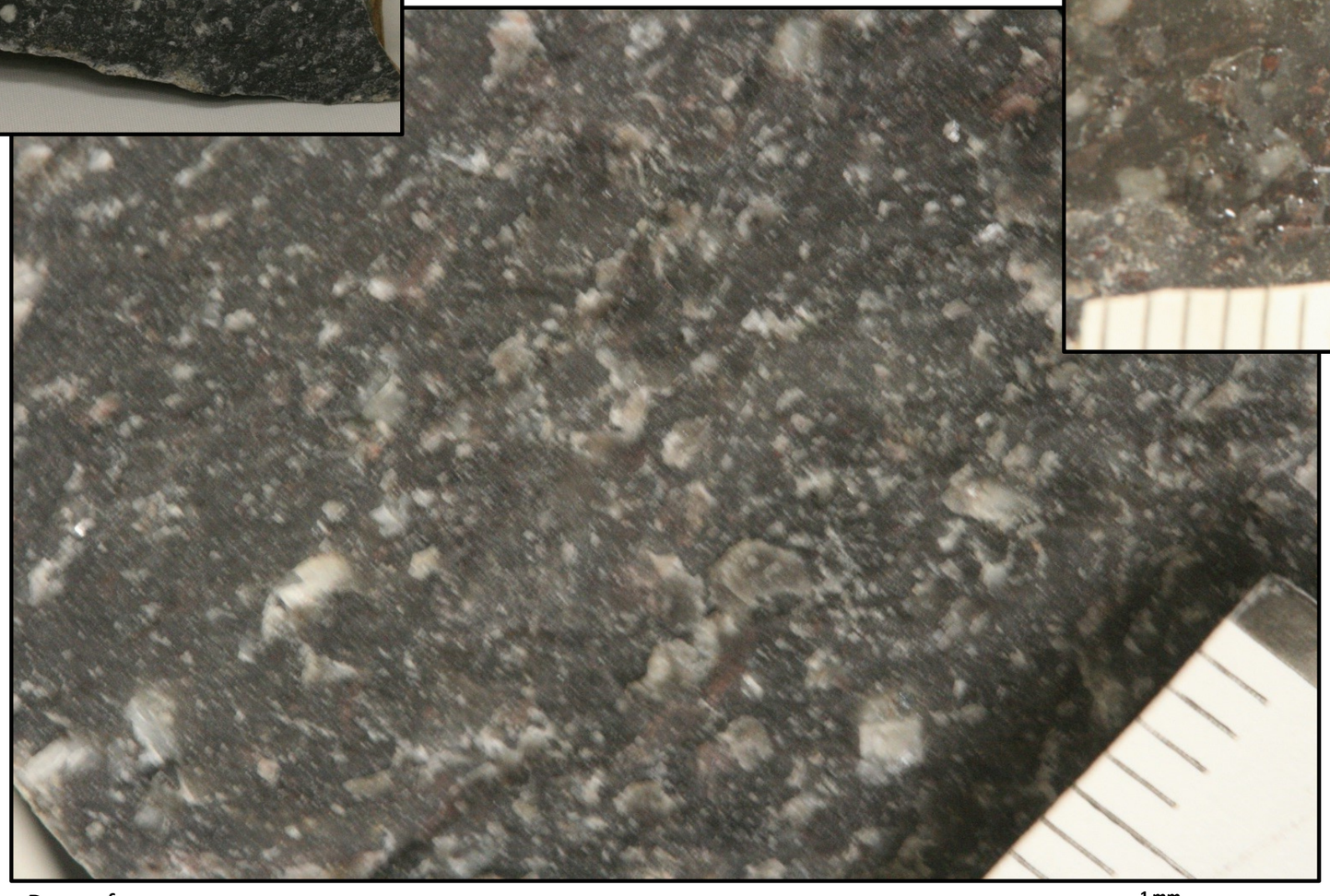
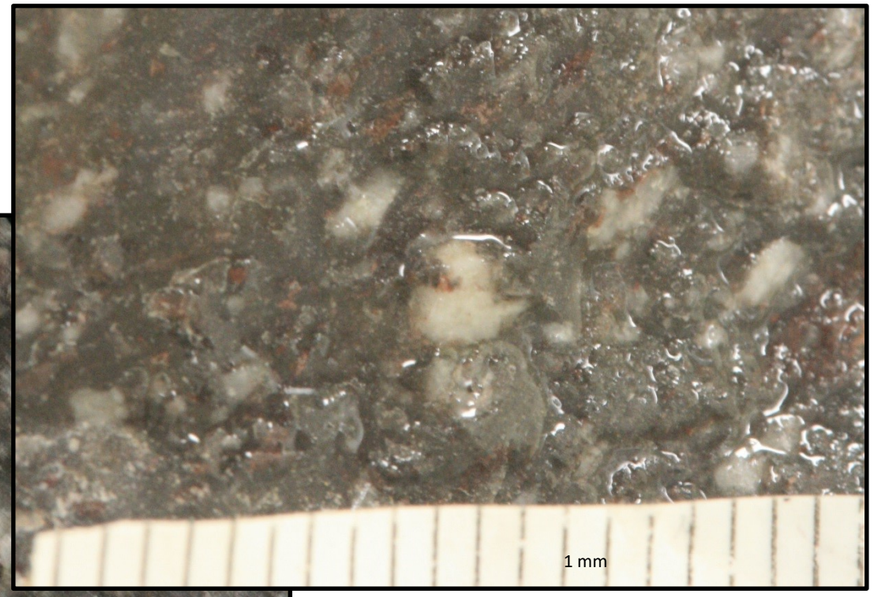
Practice Samples

Practice sample 4



Dry surface.



Wet surface.

1 mm

Use the “Tuff, Lava, or Sedimentary Rock?” flow chart and, if applicable, the “Composition of Lavas and Tuffs” to identify the sample in the photograph above. Use the worksheet on the previous page to record each decision you make while using the flow chart(s). When exercise is complete, compare your answers to the answer key at the end of the guide.

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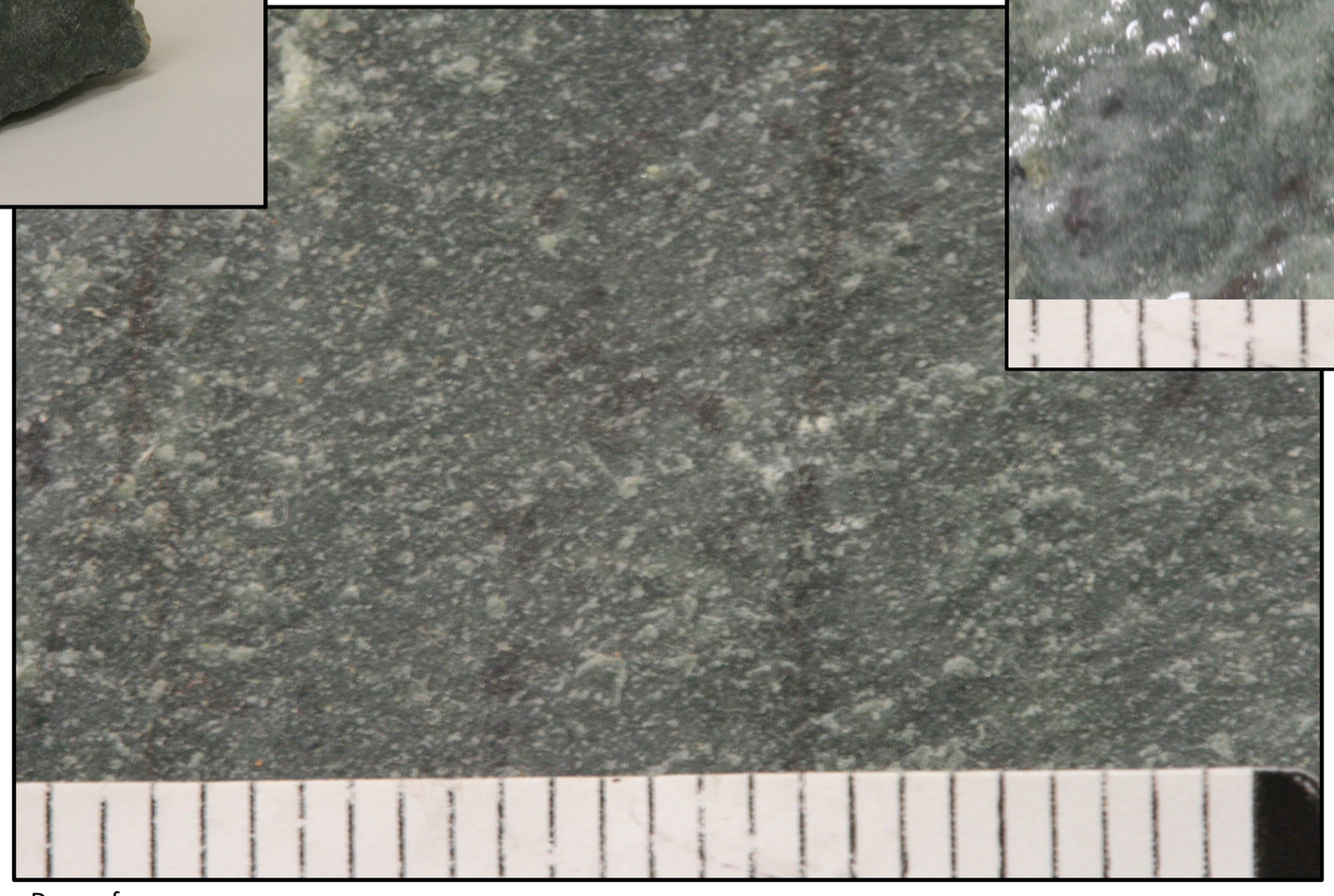
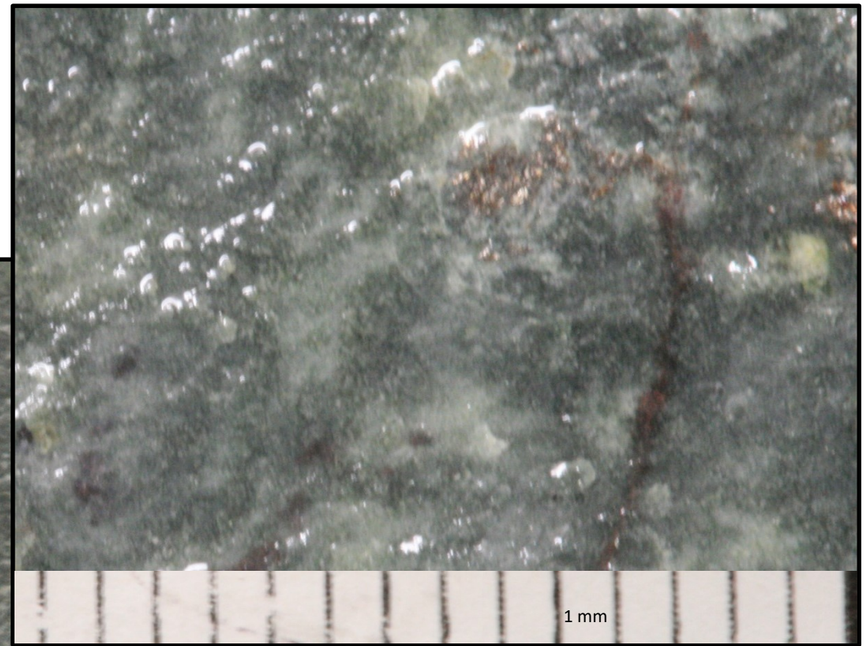
Practice Samples

Practice sample 5



Dry surface.

1 mm



Wet surface.

Use the “Tuff, Lava, or Sedimentary Rock?” flow chart and, if applicable, the “Composition of Lavas and Tuffs” to identify the sample in the photograph above. Use the worksheet on the previous page to record each decision you make while using the flow chart(s). When exercise is complete, compare your answers to the answer key at the end of the guide.

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Practice Samples Answer Key

Lithic Material Identification Guide

Sample number	Is matrix granular or aphanitic?	Are clasts and/or crystals present in the matrix, as part of the matrix, or not at all?	**For aphanitic matrix only:** If clasts are present, are they fiamme-shaped, jigsaw-fit (hyaloclastic), or neither?	Are stripes present on the weathered or fresh surface? If yes, are they likely bedding, welding, flow banding, or unknown?	What rock type was identified by the flow chart?	If rock type is lava or tuff, is it felsic, intermediate, or mafic? (See Composition of Lavas and Tuffs flow chart if applicable)	If crystals are present, are they quartz, feldspar, or something else? (See Frequently Asked Questions Section)	Were any textures identified using the "Less Common Textures" section? If so, list here.
1	Granular	Clasts and crystals are present as part of the matrix	N/A	No	Tuffaceous sandstone	N/A	Feldspar (Plagioclase)	No

Sample 1

- The matrix looks like it is made up of small particles, which means it is granular (grainy). You want to go up (toward epiclastic rock) on the flow chart.
- Clasts and crystals are visible as part of the matrix, so choose “yes” on the flow chart. Note that they are not floating in a more fine-grained matrix, but rather make up the matrix itself. If there were a few scattered in a more fine-grained matrix you would choose “no.” (In this sample crystals are more abundant than clasts.)
- There are not visible stripes on the weathered or fresh surface, so choose “no.”
- Following these steps should yield a final answer of “tuffaceous sandstone.”
- Because the answer is not tuff or lava, the Composition of Lavas and Tuffs flow chart is not applicable.
- The clasts are sparse and very small, so if you miss them amongst the crystals, that is okay and will not change your end result in this example. If you can find them, they are dark-colored.
- The crystals are plagioclase. The Frequently Asked Questions section discusses distinguishing plagioclase from quartz.
- There is nothing present in this sample that would require consulting the Less Common Textures section.

Practice Samples Answer Key

Sample number	Is matrix granular or aphanitic?	Are clasts and/or crystals present in the matrix, as part of the matrix, or not at all?	**For aphanitic matrix only:** If clasts are present, are they fiamme-shaped, jigsaw-fit (hyaloclastic), or neither?	Are stripes present on the weathered or fresh surface? If yes, are they likely bedding, welding, flow banding, or unknown?	What rock type was identified by the flow chart?	If rock type is lava or tuff, is it felsic, intermediate, or mafic? (See Composition of Lavas and Tuffs flow chart if applicable)	If crystals are present, are they quartz, feldspar, or something else? (See Frequently Asked Questions Section)	Were any textures identified using the "Less Common Textures" section? If so, list here.
2	Aphanitic	Crystals are present in the matrix	N/A	No	crystal-lithic/lithic-crystal tuff or lava	Felsic lava or tuff (rhyodacitic to dacitic)	Plagioclase and an unknown black mineral	No

Sample 2

- There are obvious crystals present in this sample which may draw the eye. However, when you look at the space between the crystals, you will notice the matrix does not look like it is made of tiny bits of particles. This means it is aphanitic, so you want to go down (toward metavolcanic rock) on the flow chart.

- Next you are looking to determine if there are clasts, crystals, both, or neither present in the matrix; the white crystals are the most obvious feature, however if you look closely, there are also sparse small black crystals. These can be distinguished from clasts by their luster. (See Frequently Asked Questions section for more information on discerning crystals from clasts). Select the “crystals” option on the flow chart.

- The flow chart now asks if there are stripes on the fresh or weathered surface. There are very subtle stripes present but for this exercise, choose no.

- Following these steps should yield a final answer of “crystal-lithic/lithic-crystal tuff or lava.”

- Because the answer is a lava or tuff, use the Composition of Lavas and Tuffs flow chart to estimate composition.

- When you look at the fresh, dry surface of the sample, you can easily see frosted flakes without a 10x magnifier. It may take a minute to train your eye to see them, especially with the crystals. Select the “I can easily see frosted flakes with a 10x magnifier or can see them without a magnifier” option on the flow chart.

- The next question asks what color is the weathering rind. The weathering rind is primarily light colored weathering rind, so select “weathering is primarily light gray to cream colored and may have brown patches.” For a comparison of weathering rind colors, see the Frequently Asked Questions section.

- This should yield an answer of” felsic lava or tuff (rhyodacitic to dacitic).”

- The white crystals are plagioclase, whereas the black crystals are more difficult to identify. They may be a metamorphic mineral that grew after the rock formed. Note the presence of both minerals as shown in the table above. The Frequently Asked Questions section discusses distinguishing plagioclase from quartz, and the Less Common Textures Section.

Practice Samples Answer Key

Lithic Material Identification Guide

Sample number	Is matrix granular or aphanitic?	Are clasts and/or crystals present in the matrix, as part of the matrix, or not at all?	**For aphanitic matrix only:** If clasts are present, are they fiamme-shaped, jigsaw-fit (hyaloclastic), or neither?	Are stripes present on the weathered or fresh surface? If yes, are they likely bedding, welding, flow banding, or unknown?	What rock type was identified by the flow chart?	If rock type is lava or tuff, is it felsic, intermediate, or mafic? (See Composition of Lavas and Tuffs flow chart if applicable)	If crystals are present, are they quartz, feldspar, or something else? (See Frequently Asked Questions Section)	Were any textures identified using the "Less Common Textures" section? If so, list here.
3	Granular	No visible clasts or crystals present	N/A	Yes, bedding	Bedded tuffaceous siltstone	N/A	N/A	No

Sample 3

- The matrix looks like it is made up of small particles, which means it is granular (grainy). You want to go up (toward epiclastic rock) on the flow chart.
- There are no visible clasts or crystals in this sample, so choose “no.”
- An inspection of the hand sample reveals there are visible stripes on the fresh surface. This texture is not easily visible on the photographs. For the exercise, choose “yes.”
- Following these steps should yield a final answer of “bedded tuffaceous siltstone.”
- Because the answer is not tuff or lava, the Composition of Lavas and Tuffs flow chart is not applicable.
- There are no visible crystals to identify.
- There is nothing present in this sample that would require consulting the Less Common Textures section.

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4	Aphanitic	Clasts and crystals are present in the matrix	Fiame-shaped	N/A	Welded tuff with crystals	Felsic lava or tuff (rhyodacitic to dacitic)	Plagioclase	No

Sample 4

- There are obvious crystals and some less obvious clasts present on the weathered surface in this sample which may draw the eye. However, when you look at the space between the crystals and clasts on the fresh surface, you will notice the matrix does not look like it is made of tiny particles of other rocks or mineral grains. This means it is aphanitic, so you want to go down (toward metavolcanic rock) on the flow chart.

- The crystals are the most obvious feature since the clasts are a dark color that may blend in with the matrix. Clasts sometimes show up better on the weathered surface, so check both the fresh and weathered surfaces when looking for clasts. For this example, select the “crystals and clasts” option on the flow chart.

- The clasts are fiamme-shaped. This is difficult to see on the fresh surface, but easier on the weathered surface. Select yes on the flow chart.

- Note: The flow chart does not ask if there are stripes on the weathered surface because fiamme-shaped clasts are indicative of a welded tuff. Welding can be difficult to see without fiamme-shaped clasts.

- Following these steps should yield a final answer of “welded tuff with crystals.”

- Because the answer is a tuff, use the Composition of Lavas and Tuffs flow chart to estimate composition.

- When you look at the fresh, dry surface of the sample, you can easily see frosted flakes without a 10x magnifier. It may take a minute to train your eye to see them, especially with the crystals. Select the “I can easily see frosted flakes with a 10x magnifier or can see them without a magnifier” option on the flow chart.

- The next question asks what color is the weathering rind. This is a light colored weathering rind, so select “weathering is primarily light gray to cream colored and may have brown patches.” For a comparison of weathering rind colors, see the Frequently Asked Questions section.

- This should yield an answer of” felsic lava or tuff (rhyodacitic to dacitic).”

- The crystals are plagioclase. The Frequently Asked Questions section discusses distinguishing plagioclase from quartz.

- There is nothing present in this sample that would require consulting the Less Common Textures section.

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5	Aphanitic	No visible clasts or crystals present	N/A	Yes	From chart 1: a flow banded lava, bedded/welded tuff or bedded tuffaceous siltstone From chart 2: intermediate to felsic lava or tuff	Andesitic to dacitic	N/A	No

Sample 5

- With the naked eye and magnifier, you will notice the matrix does not look like it is made of tiny particles of other rocks or mineral grains. This means it is aphanitic, so you want to go down (toward metavolcanic rock) on the flow chart.
- There are no visible clasts or crystals in this sample, so choose “no.”
- There are some vague visible stripes on the weathered or fresh surface, so choose “yes.”
- Following these steps should yield a final answer of “a flow banded lava, bedded/welded tuff or bedded tuffaceous siltstone.”
- Because the answer is a lava or tuff, use the Composition of Lavas and Tuffs flow chart to estimate composition.
- When you look at the fresh, dry surface of the sample you may not see any frosted flakes with the naked eye. However, you can see sparse frosted flakes with a 10x magnifier. It may take a minute to train your eye to see them, especially with the crystals. Select the “I can easily see frosted flakes with a 10x magnifier” option on the flow chart.
- The next question asks what color is the weathering rind. This is a light colored weathering rind, so select “weathering is primarily light gray to cream colored and may have brown patches.” For a comparison of weathering rind colors, see the Frequently Asked Questions section.
- This should yield an answer of” intermediate to felsic lava or tuff (andesitic to dacitic).”
- There is nothing present in this sample that would require consulting the Less Common Textures section.