Montana Nutrition Guidelines By Rock Type
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Nutrition guidelines for use in conjunction with current digital geology for Montana State

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Montana State/IFTNC Nutrition Guidelines by Rock Type

Introduction

This document was prepared as a guideline for foresters to use in determining appropriate nutrient management strategies for forest stands on various rock types in forests of western Montana. Geologic maps provided through the Montana Bureau of Mines and Geology (MBMG) and the United States Geological Survey (USGS) were utilized in the development of these guidelines. The digital maps currently available for the state of Montana are available on the MBMG website at http://www.mbmg.mtech.edu/stmap.htm. For this document we utilized the Kalispell, Western Half of Cut Bank, Wallace, Choteau and Dillon 1:250K maps from the USGS, and the Wallace, Missoula West, Hamilton, Butte, Leodore and Lima 1:100K maps and Butte 1:250K map provided by the MBMG. A lookup table for each individual map accompanies this ‘Guidelines by Rock Type’ document, and may be joined to the respective digital geology map attribute table to assign the IFTNC categorization to the individual map units.

A total of 516 map units identifying various rock types were identified on the eleven maps included in this report. Each unit was assigned to one of four categories and 47 subcategories for purposes of nutrition guideline recommendations. The following section of the report discusses a little about the lithology and expected weathering behavior of each rock, and provides some nutrient management strategies for each rock category and subcategory. These guidelines are based on our current state of knowledge regarding rocks and forest growth. Our information on fertilization response for Montana forest types is currently very limited; therefore the nutrient management recommendations will be conservative and should not be viewed as absolute. We fully expect these guidelines to be further refined with additional experience and experimentation in Montana.

IMPORTANT: Geology maps are a useful tool for forest management. However, the user must be aware that geology maps were not developed for use at the forest stand level. We have found the USGS and MBMG maps to be very good for providing a general indication of the rocks likely to be found in a particular area, and often the maps are reasonably precise to the stand level. Nonetheless, foresters must always verify the rock type in the field before considering management options. The information included in this report is intended only to provide general guidelines to be considered in the formulation of silvicultural prescriptions.

Nutrients

The term “nutrient” is used to denote one of seventeen naturally-occurring elements which are considered essential for plant growth. Three of these elements, carbon (C), hydrogen (H), and oxygen (O), are abundantly available in air, earth and water, and are not considered limiting factors to plant growth. Six elements, nitrogen (N), potassium (K), phosphorus (P), calcium (Ca), sulfur (S), and magnesium (Mg), occur in limited quantities, and because plants require these in relatively large quantities (500-14000 ppm) in order to grow and function adequately, they are referred to as “macronutrients.” A number of other elements which occur in limited quantities are required by plants only in trace amounts (usually <100 ppm), and these are known as “micronutrients.” Eight elements are currently considered micronutrients, and more will probably be added to this list over time as equipment detection levels and research techniques improve. Tables 1a and 1b respectively list the macro and micronutrients, their principal functions in higher plants, and their sources.

Tables 1(a): The macronutrients -- their function and source, and 1(b): The micronutrients -- their function and source All information on nutrient function is taken from Marschner (1995) except for those indicated by (1) which are based on IFTNC research. An asterisk indicates that a nutrient is available in fertilizer form.

Table 1(a): The macronutrients -- their function and source

Symbol	Element	Function	Source
N*	Nitrogen	Biomass production[1] Photosynthesis (proteins)[1]	Organic matter N-cycle
K*	Potassium	Disease resistance[1] Osmotic potential, turgor Enzymatic transfer of glucose to starch Nitrate synthesis Photosynthesis and CO_2 fixation	Parent material
P*	Phosphorus	Structural constituent of DNA and RNA Basal metabolism (ATP and energy transfer) Photosynthesis (carbon partitioning)	Parent material
S*	Sulfur	Photosynthesis (proteins) Membrane structure Some defense substances	Atmosphere Parent material
Ca*	Calcium	Structural component (cell walls, membranes)	Parent material
Mg*	Magnesium	Chlorophyll Protein synthesis Enzymes and enzymatic reactions Carbohydrate partitioning	Parent material

Table 1(b): The micronutrients -- their function and source

Symbol	Element	Function	Source
Fe*	Iron	Chloroplast development, photorespiration Enzymatic reactions	Parent material
Mn*	Manganese	Enzymatic reactions Photosynthetic O_2 evolution	Parent material
Cu*	Copper	Nitrogen metabolism (NOTE: High N rates can induce Cu deficiency!) Cell wall lignification Pollen formation and fertilization Carbohydrate and lipid content Enzymatic reactions	Parent material
Zn*	Zinc	Metabolic functions Complexes with N, O and S DNA replication Regulation of gene expression (NOTE: High P rates can induce Zn deficiency!)	Parent material
Ni	Nickel	N metabolism	Parent material
Mo*	Molybdenum	N metabolism N_2-fixation May affect pollen formation/fruit formation Critical level increases with increasing N supply	Parent material
B*	Boron	Cell wall biosynthesis and structure Plasma membrane integrity Root elongation, apical dominance Deficient B associated with Eucosma sp. borer[1]	Parent material
Cl*	Chlorine	Photosynthetic O_2 evolution Stomatal regulation	Parent material Atmosphere

Nutrient Diagnostics

Tests of foliage and soil chemistry may be performed as site specific indicators of productivity and potential fertilization response. Foliage N has been shown to be a better predictor of site productivity than soil N tests, while soil mineralizable N may be a better predictor of fertilizer response than foliage N tests (Garrison-Johnston et al. 2006). If satisfactory information as to site productivity is available and the parent material/ash combination suggests that the site may be responsive to fertilization, managers should consider focusing on tests of soil mineralizable N. If mineralizable N is below 70 ppm, then the site should show a 6-year volume response of 10% or more, with the potential response increasing as mineralizable N decreases. Foliage N may be tested as an indicator of overall site productivity; however the time and expense of this test make it less desirable than performing simple site height/age measurements, if possible.

Nutrient Management

Cultural Operations

“Nutrient management" refers to silvicultural activities as they affect the nutrient capital of a forest stand. Because most nutrients are held in limbs and foliage (Cole and others 1967, Miller and others 1993, Pang and others 1987, Moller 2000), a conservative nutrient management strategy would be to leave the tops and limbs on-site during harvesting operations. Because the actual amount of material removed during a harvesting operation depends on the season of the year as well as the harvesting system, some consideration as to treatment timing can have an effect on management decisions. Whole-tree operations in late fall and winter, when breakage is more likely, should be more effective at leaving some nutrients on the site than those which take place in spring and summer. Bole-only extraction includes tree-length operations where trees are limbed and topped in the woods, and is considered to be a conservative nutrient management strategy year-round. The level of nutrient removal during any harvest operation also depends on the merchantability standards in effect during the harvest, and whether the sub-merchantable trees are also harvested and removed. Species differ in nutrient demand (Miller and others 1993, Moore and others 2004, Gordon 1983, Gower and others 1993, Garrison & Moore 1995), therefore planting a nutritionally-challenged site with less-demanding species would be a good nutrient management strategy. Fire suppression has increased the presence of shade-tolerant, nutrient-demanding species and has also altered the cycle by which nutrients were naturally returned to the system through fire (Feller 1988, Little and Klock 1985). Furthermore, a cool fire can effectively return much of the on-site nutrient capital to the soil. Therefore, using cool burns for slash control, site preparation or intermediate treatments would be a good nutrient management strategy.

For purposes of this report, thinning and harvesting operations have been designated as “whole-tree” or “bole-only.” Recommendations regarding whole-tree extraction generally assume 100% removal of the bole, top and limbs. However, the actual amount of material removed depends on the season of the year. In late fall and winter, there can be a significant amount of breakage of limbs during the harvesting process. Thus whole-tree operations in late fall and winter are likely to be more effective at leaving some nutrients on the site than those which take place in spring and summer. The level of nutrient removal also depends on the merchantability standards in effect during the harvest, and whether the sub-merchantable trees are also harvested and removed. The bole-only designations used in the prescription recommendations should be considered a description for any bole-only extraction method including tree-length operations where trees are limbed and topped in the woods. For the purposes of this report, nutrient management recommendations have been divided into the following categories:

- Thinning operations
  - bole-only extraction
  - whole-tree extraction
- Regeneration harvest operations
  - bole-only extraction
  - whole-tree extraction
- Species ranked from highest nutrient demand to lowest nutrient demand
  - Grand fir very high
  - Douglas-fir high
  - White pine moderate to high
  - Ponderosa pine moderate
  - Lodgepole pine low
  - Western larch low
  - Western hemlock low? (based on our observations)

<u>Fertilization</u>

Fertilization is an additional nutrient management strategy which may be used to improve the health or increase the productivity of a forest stand. As noted earlier, our fertilization experience in Montana is somewhat limited. Therefore the recommendations shown in this report will be based largely on our experiences in other IFTNC regions, including central and northeastern Washington, northeastern Oregon and northern and central Idaho.

The first criteria to consider when contemplating fertilization is site moisture regime. In our experience, vegetation series is a good proxy for site moisture regime. Moist site types, characterized by western red cedar, western hemlock and western white pine, are the highest priority for fertilization, followed in descending order by the grand fir and Douglas-fir series. We have no fertilization response data for drier site types such as true ponderosa pine types, and at this time do not recommend fertilization of such sites. Furthermore our fertilization response data for Montana is limited even on the so-called moist site types, therefore we strongly recommend further research in the form of short-term screening trials and long-term fertilization rate trials prior to scheduling operational fertilization treatments.

When selecting sites for potential fertilization or fertilization rate trials, if the vegetation series is appropriate for fertilization then rock type should next be considered. Use the guidelines in this report to determine whether a rock type is appropriate for fertilization, and which elements are recommended for application. The decision of how much of each element to apply will be dictated by our current state of knowledge, as well as your financial and other operational constraints. The IFTNC can provide guidance on application rates and expected responses.

Recent experience suggests that young stands, particularly plantations established after high levels of biomass removal and mechanical site preparation, are often deficient in sulfur and boron. This seems to be true for all rock types, but the nutrient status is relatively worse on “bad” rock types. Thus, stand management history should be considered when assigning fertilization priorities for any site.

Nutrient Assessment by Rock Type

The following section of the report discusses nutrient management strategies for each of the four broad rock categories, labeled ***IFTNC_Category***. Within each category, the subcategories (***IFTNC_Subcategory***) are used to assign nutrient management guidelines.

References

Marschner, H., 1995. Mineral Nutrition of Higher Plants. Academic Press, San Diego, CA, 889 pp.

Nutrient Management Guidelines

CATEGORY 1: Extrusive/ Basaltic Rocks

Subcategory A: Basalt

- **Basalt (good)**

Subcategory B: Non-basaltic Extrusive Rocks

- **Andesite (bad)**
- **Dacite (unknown but suspect bad)**
- **Dikes and sills (unknown but suspect bad)**
- **Rhyolite (unknown but suspect bad)**

Overview: Extrusive igneous rocks form when magma moves rapidly to the earth's surface either as a flow or eruption, and then cools rapidly producing a fine grain size. Basalts are the most common extrusive rock in western Montana, but rhyolites, dacites and andesites also occur.

Subcategory A: Basalt

Basalts are typically composed of plagioclase feldspar and clinopyroxene. Plagioclase feldspars contain Si and Al along with Ca and/or Na. A clinopyroxene is one of a group of minerals that contain Si, Ca, and some combination of Mg and/or Fe. Basalts do not contain quartz. This does not affect their chemical composition but may contribute to increased chemical and physical weathering rates due to increased surface area and increased water infiltration. Some basalts have a high content of glass, particularly those labeled as volcanic. The behavior of the high-glass content basalts is somewhat uncertain. They may break down relatively quickly due to the unstable nature of glass, or they may break down slowly due to decreased rock porosity. Due to their fine-grained nature, basalts tend to form clay-rich soils. One of the greatest values of basalt-derived soils is their moisture-holding capacity. Basaltic soils should be fairly rich in several important nutrients, including Mg and Ca. While K content of basalt rocks is fairly low, the K-retention of basaltic soils should be quite good, again due to the clay content and resulting good cation exchange capacity (CEC). High CEC and base saturation are important qualities of basaltic soils.

Nutrient management recommendations for basalt

Basalts are generally considered good rocks and good candidates for fertilization. We recommend that conservative nutrient management strategies be followed, however because of the high quality of these sites, they may be more resilient than other sites to the more extreme nutrient management strategies such as intensive whole-tree removal. Research on IFTNC study sites in central Washington and northeast Oregon indicates that good response may be expected on most basalts when N-only is applied. However experience has also shown that S may be necessary in order to elicit a growth response to N-fertilization.

Expected Soil Development: Moderate to deep, fine loamy soils
Expected Nutrient Status: Good
Recommended Nutrient Management Strategies:

- Thinning: bole-only preferred, but whole-tree removal probably OK

- Regeneration Harvest: bole-only preferred, but whole-tree removal probably OK
- Species Selection: most species will do well on this rock type

Expected Fertilization Response: Good
Fertilizer Recommendation:

- For growth response, be sure that vegetation series is Douglas-fir or moister.
- Recommended formulation: N or N+S
- Good multi-nutrient blend candidates, consider screening trials

Subcategory B: Non-basaltic Extrusive Rocks

- **Andesite**
- **Dacite**
- **Rhyolite**
- **Dikes and Sills**

Andesite is very similar in composition and appearance to basalt, but contains more silicon. Dacite and rhyolite are light-colored extrusive rocks, also high in silicon content. These rocks, particularly dacite and rhyolite, commonly occur in dikes and sills. Dikes and sills are very localized areas of rock, at points where magma intruded into small cracks and crevices in the crust, or in some cases were vents for magma flows. Dikes and sills have been mapped in a number of Montana locations. Dikes and sills often occur as outcrops, indicating poor weatherability. Sites on these rock types should be field-checked and evaluated for soil depth and stand performance. Well-performing stands on deep soils may be considered for fertilization, however to date we have not generally found these rock types to produce desirable soil and stand conditions.

Nutrient management recommendations for andesite, dacite, rhyolite, dikes and sills

These rock types are considered poor candidates for fertilization. Conservative nutrient management practices should be followed.

Expected Soil Development: Poor
Expected Nutrient Status: Poor
Recommended Nutrient Management Strategies:

- Thinning: bole-only recommended, but whole-tree may be OK for thinning from below or other light thinning
- Regeneration Harvest: bole-only
- Species Selection: select for low nutrient-demanding species

Expected Fertilization Response: Poor
Fertilizer Recommendation:

Fertilization not currently recommended.

CATEGORY 2: Intrusive/ Granitic Rocks

Subcategory A: Felsic Intrusive Rocks

- **Anorthosite (unknown but suspect bad)**
- **Granite (medium)**
- **Granodiorite (medium)**
- **Monzodiorite (medium)**
- **Monzogranite (medium)**
- **Monzonite (medium)**
- **Quartz (bad)**
- **Quartz Diorite (medium to bad)**
- **Quartz Monzonite (medium)**
- **Syenite (unknown)**
- **Tonalite (medium to bad)**

Subcategory B: Mafic and Ultramafic Intrusive Rocks

- **Dikes and Sills (bad)**
- **Diorite (bad)**
- **Gabbro (bad)**
- **Pyroxenite (bad)**
- **Ultramafic rocks (bad)**

Overview: Intrusive rocks are igneous rocks formed when magma cools inside the earth's crust. Because of this slow cooling process, intrusive rocks form large grains which are usually visible in a hand sample. Granites are the most common example of intrusive rocks. Felsic intrusive rocks are dominated by silicate minerals and tend to occur in relatively large bodies. Mafic and ultramafic rocks tend to be dark, heavy, silicon-poor rocks that occur in dikes, sills and other small localized bodies.

Subcategory A: Felsic Intrusive Rocks

- **Anorthosite**
- **Granite**
- **Granodiorite**
- **Monzodiorite**
- **Monzogranite**
- **Monzonite**
- **Quartz**
- **Quartz Diorite**
- **Quartz Monzonite**
- **Syenite**
- **Tonalite**

Those intrusive rocks that are typically light-colored in appearance such as granite, quartz monzonite, monzonite and monzogranite contain predominantly quartz and potassium feldspar, with some plagioclase feldspar, and very few dark minerals. These light-colored granites will probably be pink, orange or white in appearance. Granites which are typically darker-colored in appearance include granodiorite, monzodiorite, tonalite and quartz diorite. These rocks contain primarily quartz and plagioclase (non-potassium) feldspar, with some potassium feldspar and an abundance of dark minerals. They will probably be grayish in color or have a salt-and-pepper appearance. Tonalite and quartz diorite will have more plagioclase feldspar than granodiorite or monzodiorite, but otherwise may be difficult to distinguish from granodiorite and monzodiorite in the field. The main difference between lighter and darker granites is that one of the black minerals often contained in dark granites is biotite, a potassium-bearing black mica. Biotite expands when it weathers, which contributes to a faster breakdown of the granite, and furthermore is a good potassium source. The other dark mineral commonly found in dark granites is hornblende. In hand sample, biotite appears very shiny and breaks easily into sheets. Hornblende is more blocky, not as sparkly in the sun, and does not break into sheets. Hornblende does not have the same weathering properties as biotite, and is not a potassium source. In general, granitic rocks are expected to weather to coarse, well-drained soils with low water-holding and low nutrient-holding capacity. Soil particles will be largely composed of quartz and feldspars, with plagioclase feldspars dominating the dark granite types and potassium feldspars becoming more evident on the light granite types. In all granitic soils, clay content and cation exchange capacity (CEC) are expected to be low.

Two types of intrusive rocks that are somewhat rare but that do occur in western Montana are syenite and anorthosite. Both rock types are characterized by being composed predominantly of one mineral. Syenite is made up of of orthoclase (potassium feldspar) and is lacking in quartz. Orthoclase has a framework mineral structure that does not readily weather, thus soil development may be poor. Syenites display the coarse-grained characteristic typical of granites, and when they do decompose should form the same coarse-grained soils that granites do, except that the soil particles will be predominantly potassium feldspar with little or no quartz. Clay content and CEC are expected to be low. Anorthosite is made of principally of anorthite, a Ca-rich plagioclase feldspar. While anorthite is expected to weather somewhat more readily than orthoclase, the soil texture will still be coarse, and clay content and CEC low.

Quartz is a mineral comprised of silicon and oxygen, and is generally considered the most stable of all the silicate minerals. It does not weather readily, occurring often as veins in association with granitic rocks. As surrounding rock weathers away, the quartz remains. Quartz is not a nutrient source for plant growth and is unlikely to support forest vegetation.

Nutrient management recommendations for granite, quartz monzonite, monzonite, monzogranite, granodiorite, monzodiorite, tonalite, quartz diorite, syenite, anorthosite

Granitic rocks are generally considered ‘medium’ for tree growth, and conservative nutrient management strategies are recommended. Whole-tree removals on these rock types may run the risk of depleting some of the limited nutrients available on these sites. Generally, moderate to poor results have been obtained through fertilization with N-only on intrusive rock types. The addition of K to the blend is expected to give a better response than N alone, especially on the lighter-colored granites and the hornblende-dominated dark granites. Multinutrients might be an option here, however fertilization screening trials would be recommended as a means of evaluating the cost-effectiveness of such an operation. Field evaluation of sites on syenites and anorthosites is recommended before proceeding with nutrient management planning.

Expected Soil Development: Moderate to deep coarse soils

Expected Nutrient Status: Moderate
Recommended Nutrient Management Strategies:

- Thinning: bole-only recommended, but whole-tree may be OK
- Regeneration Harvest: bole-only recommended
- Species Selection: select for moderate to low nutrient-demanding species

Expected Fertilization Response: Moderate
Fertilizer Recommendation:

- For growth response, be sure that vegetation series is Douglas-fir or moister.
- Granite/quartz monzonite/monzonite: Do not fertilize with N-only.
- Granodiorite/monzodiorite/quartz diorite/tonalite: Maybe fertilize with N-only, but only if rock shows high biotite (K) content.
- All granitic rocks: N+K recommended.
- Possible multi-nutrient blend candidates -- recommend screening trials.

Subcategory B: Mafic and Ultramafic Intrusive Rocks

- **Dikes and Sills**
- **Diorite/gabbro (mafic)**
- **Pyroxenite/ultramafic rocks (ultramafic)**

Dikes and sills are localized bodies of rock resulting from small intrusions of magma into the earth's crust. They most often consist of mafic and ultramafic rocks, which are dark-colored rocks consisting principally of high amounts of plagioclase feldspar and little or no quartz. The difference between mafics and ultramafics has to do with how the magma separated during its journey to the earth's surface, and isn't particularly important for purposes of these forest nutrition recommendations. Diorite dikes and gabbro are mafic rocks, while pyroxenite is ultramafic. Pyroxenite almost always occurs in close association with gabbro. These and other mafic and ultramafic rocks tend to be fairly localized in occurrence. They seem to occur as fairly massive and relatively slow-weathering rocks, often in outcrops which don't weather as easily as surrounding rocks. In our experience, these rocks and others comprising dikes and sills don't tend to support good tree growth, and may harbor forest insect populations during endemic years. Until we have more information, fertilization on these rocks is not recommended.

Nutrient management recommendations for mafics, ultramafics and other intrusive dikes and sills

These rock types are considered to be poor candidates for fertilization. If they support trees at all, such stands are likely to show poor nutrition, health and growth. Conservative nutrient management practices should be followed.

Expected Soil Development: Poor
Expected Nutrient Status: Poor
Recommended Nutrient Management Strategies:

- Thinning: bole-only recommended, but whole-tree may be OK for thinning from below or other light thinning
- Regeneration Harvest: bole-only

- Species Selection: select for low nutrient-demanding species

Expected Fertilization Response: Unknown
Fertilizer Recommendation:

- Fertilization not recommended.

CATEGORY 3: Metamorphic Rocks

Subcategory A: Non-carbonate Metasedimentary Rocks

- **Amphibolite (unknown)**
- **Argillite (variable; likely bad)**
- **Gneiss (variable)**
- **Granite Gneiss (variable, likely medium)**
- **Mylonite (unknown)**
- **Quartzite (variable; likely bad)**
- **Schist (variable; can be good)**
- **Siltite (variable; likely bad)**

Subcategory B: Carbonate and Calc-silicate Metasedimentary Rocks

- **Calc-silicate gneiss (unknown but maybe good due to weathering)**
- **Carbonate-bearing metaseds (unknown but maybe good due to weathering)**
  - **co-quartzite**
  - **co-siltite**
  - **co-argillite**
  - **various combinations of the above**
- **Limestone- and dolomite-dominated metaseds (unknown but suspect bad)**
- **Marble (unknown but suspect bad)**

Overview: Much of western Montana is challenging from a geology-forest nutrition standpoint, because there are a great many sedimentary rocks that have occurred over time, some marine in origin, and a great deal of metamorphosis has occurred as well. A large proportion of land in Montana falls into the metamorphic category, and the map units often contain mixed lithologies. This category includes both metamorphosed sedimentary rocks (argillite, siltite, quartzite, marble, etc.) and metamorphosed igneous rocks (granite gneiss, gneiss, schist, etc.). It may be that as we continue to work with metamorphic, and especially metasedimentary rocks, more of the rocks currently thought unsuitable for fertilization can be reconsidered for fertilization. At the moment, we do not have strong fertilization recommendations largely because we don't have a significant number of trials on these rock types, especially in western Montana.

IMPORTANT: Metamorphic rocks are typically defined by their texture, which in turn is related to the degree of pressure and temperature changes (eg metamorphism) that they have undergone. Because metamorphic lithologies are in part determined by the degree of metamorphism, they can be ranked in order by degree of metamorphism and grain size.

Furthermore, because the rocks listed above are the products of different degrees of metamorphism, they often occur together in various combinations. Because of this gradational nature, many of the map units are of mixed lithology. If one lithology was dominant, then only that lithology was assigned to the map unit. If two to three or more lithologies were significant components of the map unit, then the first two to three were listed, in order of predominance. When considering one of these mixed-lithology units for silvicultural operations, foresters should check the site for rock type, as in many cases one of the listed lithologies will dominate a localized area. Managers may then select the nutrient management guidelines which correspond to that specific lithology.

Subcategory A: non-carbonate metasedimentary rocks

- **Argillite**
- **Siltite**
- **Quartzite**
- **Feldspathic quartzite**
- **Schist**
- **Gneiss**
- **Granite Gneiss**
- **Amphibolite**
- **Mylonite**

A large number of subcategories are discussed in this section because the frequent gradation and mixing between these rocks makes separation into just one lithology difficult. However, fertilization recommendations may vary depending on rock type, therefore any site on one or a mix of these rocks must be field checked, with rock type and stand condition verified prior to deciding upon nutrient management strategies.

Argillite, siltite and quartzite are common terms for low-grade metamorphic rocks, in other words rocks that underwent only slight pressure and temperature changes. The original 'parent' rock is usually still distinguishable. Argillites originate from claystones, and are very 'silky' in appearance and texture, with indistinguishable grains, and can be scratched with a fingernail. Argillites are likely to weather to flat, sharp-edged plates and form very shallow soils, particularly on slopes. Some argillites have a high potassium content, but little else in the way of nutrients. The IFTNC has one seedling establishment trial on a northeast Washington argillite from a group of rocks known as the Deer Trail group. This is considered a bad rock site, with very thin soils and poor tree growth. Siltites originate from siltstones, and are slightly coarser-grained than argillites, and can also be scratched with a fingernail, but with more difficulty than argillite. We have little experience with siltites, but their characteristics likely fall between those of argillite and quartzite. Quartzites originate from sandstone and contain sand-sized grains, and cannot be scratched with a fingernail. Quartzites in particular are very low in nutrients, containing mostly quartz sand. Feldspathic quartzites are those that originated from feldspathic sandstones. Since feldspathic sandstones in central Washington have been found to show very good productivity and fertilization response, we carried the feldspathic designation through to these quartzites. We do not have experience with these rocks, but do suggest a field check or some other verification as to the potential productivity of sites on feldspathic quartzite.

Schist, gneiss and mylonite are high-grade metamorphic rocks, in other words these rocks underwent greater pressure and temperature changes. Because of the higher degree of metamorphism, the original 'parent' rock is often very difficult to distinguish. Schists usually contain layers of mica or hornblende, leading to a fine-layered appearance and platy breakage patterns. Gneisses are more highly metamorphosed than schists, and are coarser rocks, with grain sizes of several millimeters. In gneisses, the mica and hornblende layers are thicker and farther apart, giving the rock a banded appearance. Gneisses do not break apart as easily as schists. If the gneiss is of granitic origin, it is designated a 'granite gneiss.' Otherwise, the label 'gneiss' may refer to either sedimentary- or igneous-origin rocks. Schists and gneisses usually contain quartz, potassium feldspar and plagioclase feldspar, along with mica and/or hornblende. Amphibolites are similar to gneisses, except they are rich in plagioclase feldspar and hornblende, and low in quartz and potassium feldspar. Amphibolites tend to be lighter-colored in appearance than gneisses and may be lacking the dark-colored bands. When we do see dark minerals in amphibolites, these are usually hornblende. Mylonites are very fine-grained rocks that occur in conjunction with metamorphic margins, and are a sort of ground-up rock containing mixtures of igneous (eg granitic and basaltic) and metamorphic minerals, depending on the rocks present at the interface of the metamorphic event.

Nutrient management recommendations for non-carbonate argillite, siltite, quartzite; and amphibolite, mylonite:

Argillite, siltite and quartzite are expected to show poor soil development. We do not have any experience with amphibolite or mylonite. We recommend field-checking stands which occur in all of these subcategories to determine the dominant rock type and assess soil development. If deep, well-weathered soils predominate, then follow the nutrient management strategies outlined below for schists and gneisses and consider fertilization screening trials. Otherwise, consider these as poor rocks, and follow conservative nutrient management strategies. We do not currently recommend fertilization on any of these rock types if they have shallow soils.

Expected Soil Development: Poor
Expected Nutrient Status: Variable
Recommended Nutrient Management Strategies:

- Thinning: bole-only recommended, but whole-tree may be OK for thinning from below or other light thinning
- Regeneration Harvest: bole-only
- Species Selection: select for low nutrient-demanding species

Expected Fertilization Response: Unknown
Fertilizer Recommendation:

- Fertilization not currently recommended.
- Screening trials may be an option to sort out possible responders in this category.

Nutrient management recommendations for schist, gneiss and granite gneiss

Schists are expected to weather to loamy to sandy soils, well-drained with low to moderate water-holding and nutrient-holding capacity. Soil particles will be largely composed of quartz, muscovite and feldspars. Cation-exchange capacity is expected to be low due to low clay content. Gneisses may weather in a similar fashion, but we recommend field-checking the site for soil depth and development, as some gneisses may be very hard rocks which weather slowly. If field examination of schist or gneiss sites show moderate to deep soil development, then they are considered 'medium' for tree growth, and conservative nutrient management strategies are recommended, and possible fertilization as indicated below. Whole-tree removals on these rock types are discouraged, as they may run the risk of depleting some of the limited nutrient availability on these sites. If the schist or gneiss sites show poor soil development, then treat then as indicated in the previous section on argillite, etc..

Expected Soil Development: Moderate to deep sandy to loamy soils
Expected Nutrient Status: Moderate
Recommended Nutrient Management Strategies:
Thinning: bole-only recommended, but whole-tree may be OK
Regeneration Harvest: bole-only recommended
Species Selection: select for moderate to low nutrient-demanding species
Expected Fertilization Response: Moderate
Fertilizer Recommendation:
Do not fertilize with N-only.
For growth response, be sure that vegetation series is Douglas-fir or moister.
N+K recommended minimum formulation, but consider N+K+S.
Possible multi-nutrient blend candidate -- recommend screening trials.

Subcategory B: Carbonate and Calc-silicate Metasedimentary Rocks

- **Calc-silicate gneiss**
- **Carbonate-bearing metaseds**
- **co-quartzite**
- **co-siltite**
- **co-argillite**
- **various combinations of the above**
- **Limestone- and dolomite-dominated metaseds**
- **Marble**

Calc-silicate and carbonate-bearing rocks are a relatively new grouping of rocks for the IFTNC, resulting from observations of differences in rock weathering rates and tree growth and response on Belt Series metasedimentary rocks of northern Idaho. To be classified a calc-silicate, a rock must contain mostly silicate minerals, with some calcareous (limestone-like) influence. The calcareous influence lends a soft, weatherable character to the rock. As a result, we have found deeply weathered soils and surprisingly productive stands on rocks in this category. We do not have any fertilization research sites on calc-silicate gneiss, however we feel that stands on this rock type would be good fertilization candidates. As such, we cautiously recommend fertilization in the form of preliminary screening trials, pending further research.

A number of argillites, siltites and quartzites in western Montana were noted as having a dolomitic, limestone or calcareous influence. If the non-carbonate component dominated the rock according to the map description, then it was labeled as a carbonate-bearing rock. The rock type designation(s) were retained with the suffix 'co' to designate these rocks. For example, a carbonate-bearing quartzite was designated as 'co-quartzite,' a carbonate-bearing mixed siltite and argillite was labeled 'co-siltite/argillite' and so on. If the limestone or dolomite component appeared to dominate (for example, a limestone quartzite or dolomitic siltite), then the rock was labeled as limestone-msed or dolomite-msed respectively. As with the noncarbonated metasedimentary rocks, mixing and interlayering is common.

Marble is the product of the metamorphosis of limestone and/or dolomite. We don't expect marble to support coniferous forest stands and have no nutritional or silvicultural recommendations for this rock type.

Nutrient management recommendations for calc-silicate gneiss and carbonate-bearing metasedimentary rocks

Field examination of stands on these rock types should be performed prior to determining silvicultural activities. If these sites show poor soil development, then refer to the nutrient management guidelines for argillites etc. above. If these sites show moderate to deep soil development, then they are considered 'medium' for tree growth, and conservative nutrient management strategies are recommended, with possible fertilization as indicated below. Whole-tree removals on these rock types are discouraged, as they may run the risk of depleting some of the limited nutrients available on these sites. We cautiously recommend fertilization on this rock type. If a stand is performing well, we suggest multinutrient fertilization screening trials including N, K and S, and perhaps micronutrients.

Expected Soil Development: Moderate to good
Expected Nutrient Status: Unknown
Recommended Nutrient Management Strategies:

- Thinning: bole-only recommended, but whole-tree may be OK
- Regeneration Harvest: bole-only recommended
- Species Selection: select for moderate to low nutrient-demanding species

Expected Fertilization Response: Unknown
Fertilizer Recommendation:

- For Douglas-fir or moister site types, fertilization screening trials including, N, K, S and micronutrients are recommended.

Nutrient management recommendations for limestone- and dolomite-dominated metasedimentary rocks:

Coniferous forest stands are unlikely to occur on these rock types. If you do encounter coniferous forest stands on this rock type, follow the above recommendations for carbonate-bearing metasedimentary rocks.

Expected Soil Development: Unknown
Expected Nutrient Status: Poor for coniferous trees
Expected Fertilization Response: Unknown
Fertilizer Recommendation:

- Fertilization not currently recommended.

CATEGORY 4: Mixed Rocks

Subcategories and quick-evaluation:

Subcategory A: Consolidated Sedimentary Non-carbonate Rocks

- **Biotite-sandstone (unknown)**
- **Conglomerate (unknown)**
- **Feldspathic sandstone (good)**
- **Mudstone/shale (unknown)**
- **Sandstone (variable)**
- **Siltstone (variable)**

Subcategory B: Consolidated Sedimentary Carbonate Rocks

- **Dolomite (bad)**
- **Limestone (bad)**
- **Carbonate-bearing sedimentary rocks (variable)**

Subcategory C: Unconsolidated Mixed Materials

- **Alluvial Deposits (variable)**
- **Colluvial Deposits (variable)**
- **Glacial deposits (variable; likely medium to good)**
- **Gravel Deposits (variable)**
- **Lacustrine Deposits (variable)**
- **Sedimentary deposits (variable)**

Subcategory D: Volcanic Materials

- **Volcanic (unknown, maybe bad)**

Subcategory E: Miscellaneous Sedimentary Rock Units

- **Iron Formation (unknown)**
- **Mature Soil (unknown)**
- **Mine Dumps (unknown)**

Overview: “Mixed rock deposits" refer to deposits of rocks which were transported from another site to their present site, either by wind, water, glacial activity, tectonic activity, volcanic activity, other geomorphic processes, or some combination thereof. Included in this category are consolidated sedimentary rocks, unconsolidated sedimentary deposits including volcanic deposits (includes both volcanic flows and volcaniclastic shards, pumice, breccia and other material “blown out” during volcanic eruptions), carbonate rocks and miscellaneous sedimentary rock units. The varied nature of these materials results in a wide variety of rock types and sizes, leading to a wide array of possible geochemical and mineralogical characteristics. This not only makes these rocks difficult to assign to a single rock-type subcategory, but also makes them difficult to categorize for nutrient management purposes. In any case, the site should be examined and evaluated for rock type, soil development and stand health prior to selecting nutrient management strategies.

Subcategory A: Consolidated Sedimentary (non-carbonate) Rocks

- **Conglomerate**
- **Feldspathic sandstone**
- **Mudstone**
- **Sandstone**
- **Siltstone**

These rocks consist of mineral grains or rock fragments that originated from the weathering of igneous, metamorphic or other sedimentary rocks, were transported to another location and then became cemented together (lithified). Conglomerates consist of rounded pebbles of various rock types and sizes in a cement matrix, while sandstones, siltstones and mudstones (shales) consist of sand-sized, silt-sized and clay-sized grains (respectively) in a cement matrix. Potassium is often a component of the cement which holds the mineral grains and rock fragments together in a sedimentary rock. The mineral grains most commonly found in sedimentary rocks are quartz, potassium feldspars, and perhaps mica, all of which are common rock-forming minerals resistant to weathering.

Some sandstones in western Montana are noted as being feldspathic or high in feldspar composition. In our experience, forest stands on feldspathic sandstones of central Washington are among the highest responders to N fertilization in the inland northwest. Therefore, these rocks have been categorized separately for western Montana. Field examination and fertilization screening trials should be carried out to determine whether these rocks behave the same way in Montana as they did in central Washington. Another unit found on the Lima 1:100K quadrangle was defined as a biotite-sandstone . Biotite is a potassium-bearing mineral that expands as it weathers, leading to relatively fast and deep weathering of the parent rock. While this characteristic has been primarily observed in biotite-bearing granites, we expect a similar behavior in biotite-bearing sandstone. Therefore, this rock unit may be treated in the same manner as the feldspathic sandstones.

Nutrient management recommendations for non-feldspathic and non-carbonate sedimentary rocks:

Little is known about the nutritional value of non-feldspathic sandstones and conglomerate rocks. Assess these sites for soil depth and texture and stand performance prior to initiating silvicultural operations. If field examination shows poor soil development, then treat the site as for argillites etc. in the prior section on metamorphic rocks. Otherwise, given moderate to deep soil development, these are considered medium-to-good sites for tree growth, and conservative nutrient management strategies are recommended. Screening trials are recommended before proceeding with operational fertilization.

Expected Soil Development: Moderate to deep, clayey to loamy soils
Expected Nutrient Status: Unknown
Recommended Nutrient Management Strategies:

- Thinnings: bole-only recommended, but whole-tree may be OK
- Regeneration Harvest: bole-only recommended

- Species Selection: Select for moderate to low nutrient-demanding species

Expected Fertilization Response: Unknown
Fertilizer Recommendation:

- If stands seem reasonable candidates for fertilization, and are on Douglas-fir or moister vegetation series, then fertilization screening trials including, N, K, S and micronutrients are recommended.

Nutrient management recommendations for feldspathic and biotite sandstones:

Forest stands on feldspathic sandstones are generally considered good candidates for fertilization. We have no experience with biotite sandstone, but expect it to behave similarly to the feldspathic sandstones. Good nutrient management strategies should be followed, however based on our experiences in central Washington, they may be more resilient than other sites to extreme nutrient management strategies such as whole-tree removal. Good fertilization response is expected, and fertilization with N-only is acceptable. As noted previously, these recommendations should be treated cautiously pending further research in to the behavior of these rocks in western Montana.

Expected Soil Development: Moderate to deep, loamy soils
Expected Nutrient Status: Good
Recommended Nutrient Management Strategies:

- Thinning: bole-only preferred, but whole-tree removal probably OK
- Regeneration Harvest: bole-only preferred, but whole-tree removal probably OK
- Species Selection: most species will respond well on this rock type

Expected Fertilization Response: Good
Fertilizer Recommendation:

- Growth response is expected if vegetation series is Douglas-fir or moister.
- Recommended formulation: N-only
- Good multi-nutrient blend candidates, consider screening trials.

Subcategory B: Unconsolidated Sedimentary Materials

- **Alluvial Deposits**
- **Glacial Deposits**
- **Gravel Deposits**
- **Lacustrine Deposits**
- **Colluvial Deposits**
- **Sedimentary Deposits**

Many of the units in this subcategory are relatively young, Quaternary era occurrences. Alluvial deposits may occur near rivers as part of a floodplain or occupy wide expanses across drainages showing moderate to steep slopes. They may be comprised of pure to mixed rock types and sizes, depending on the source and distance of transport. Lacustrine deposits are associated with old or modern lakebeds, and include the deposits associated with Glacial Lake Missoula. Likely components of lacustrine deposits are sand, silt and clay sized particles of the stable minerals quartz, potassium feldspar and mica. Organic-rich rocks can also form in lacustrine environments. Gravel deposits in western Montana occurred mostly during the Tertiary (preglaciation) era. Similarly, many of the generically labeled sedimentary deposits also date to the Tertiary era. In some cases more detail as to the nature of these deposits is given in the reports accompying the geology maps, therefore those reports should be consulted to help characterize particular deposits. Otherwise, alluvial, lacustrine, gravel and sedimentary deposits are largely indeterminate in origin and can vary widely in nutrient value. In all cases, soil development and tree growth should be evaluated in the field on a site-specific basis.

Glacial deposits can contain a wide array of rocks varying in both lithology and size. Many of the glacial deposits in western Montana were deposited by continental glaciers that carried rocks in from distant areas. Unconsolidated deposits containing a variety of rocks of different mineralogies and at different stages of weathering may provide a fair to good nutrient environment for tree growth. Current stand condition and stand history should be assessed. For example, sites on the glacial flats in the Rathdrum Prairie area of northern Idaho were subjected to agricultural activities such as plowing and discing prior to stand establishment. These activities displaced and/or removed organic materials and topsoil to the extent that the nutrient environment was considerably altered. Forest plantations on these glacial flats often show signs of nutrient stress at or shortly after crown closure.

Colluvial deposits are rock fragments that have been transported downslope as either a slow gravity-driven creep or as a landslide or avalanche deposit. They are likely somewhat homogenous in composition though not necessarily in size, and localized in distribution depending on the source rock. They may be modern or older in age. Whereas modern scree-type deposits will obviously not provide much in the way of soil development for tree growth, older deposits may have well-developed soils and support forest stands. The recommended approach is to treat the site based on the lithology of the deposited material. The rock type should be verified on site. This information will often be available in the literature which accompanies the area geology map.

Fertilization recommendation for non-colluvial sedimentary deposits:

Glacial deposits generally show moderate to deep soil development, and are considered ‘medium’ for tree growth. Other unconsolidated deposits are more variable, and run the risk of poor nutrient status if the deposit consists of homogenous, well-sorted and highly weathered material or if the source rock was itself a ‘bad’ rock. Conservative nutrient management strategies are recommended. Whole-tree removals on these rock types are discouraged, as they may run the risk of depleting some of the limited nutrient availability on these sites. Good response to nitrogen fertilization has been obtained on glacial deposits. We don't currently have response data for alluvial and other mixed unconsolidated deposits. Due to the wide array of possible parent rocks in these deposits, we would recommend the addition of K with N to assure proper nutrient balance. Sulfur is another element which might be recommended for these mixed deposits. In the case of extensive prior agricultural use or otherwise altered sites, preliminary data indicate that P and B may also be necessary. Mixed sedimentary deposits would be good candidates for multinutrient screening trials.

Expected Soil Development: Moderately deep to deep, loamy soils
Expected Nutrient Status: Moderate to Good
Recommended Nutrient Management Strategies:

- Thinning: bole-only recommended, but whole-tree may be OK
- Regeneration Harvest: bole-only recommended
- Species Selection: select for moderate to low nutrient-demanding species

Expected Fertilization Response: Glacial till good, mixed unconsolidated unknown
Fertilizer Recommendation:

- For growth response, be sure that vegetation series is Douglas-fir or moister.
- Glacial deposits: N-only probably OK, but N+K, and maybe S, recommended.
- Possible multi-nutrient blend candidate screening trials recommended.
- Extensive agricultural use prior to forest stand establishment may dictate a need for P and B in the fertilization blend
- Mixed unconsolidated sites should have screening trials installed before initiating operational fertilization operations.

Nutrient management recommendations for colluvial sedimentary deposits:

Determine the source rock for the deposit. This information may be found in the map description, and will certainly entail field verification. Treat the site based on the dominant lithology of the deposit.

Subcategory C: Volcanic Deposits

- **Volcanic**

Units mapped as volcanic or volcaniclastic rocks can be composed of a wide array of materials, from solidified ash to rock shards to glass. This unit includes breccia, a rock similar to conglomerate except that the rock fragments are angular rather than rounded. The magmatic composition of volcanic flow rocks can vary from rhyolitic (high potassium and silicon) to basaltic (low potassium and silicon). In our experience, volcanic rocks are very difficult to characterize due to the wide variety of materials, including everything from ash to siliceous fragments to pumice. Sites labeled in this manner should be field-checked and evaluated for soil depth and stand performance. Well-performing stands on deep soils may be considered for fertilization. However, in the absence of some evidence as to site productivity and stand performance we do not currently recommend fertilization on volcanic rocks.

Nutrient management recommendations for volcanic/volcaniclastic rocks:

We do not currently recommend fertilization on these rock types. Conservative nutrient management practices should be followed.

Expected Soil Development: Variable
Expected Nutrient Status: Variable
Recommended Nutrient Management Strategies:

- Thinning: bole-only recommended, but whole-tree may be OK for thinning from below or other light thinning
- Regeneration Harvest: bole-only
- Species Selection: select for low nutrient-demanding species

Expected Fertilization Response: Unknown
Fertilizer Recommendation:

- Fertilization not recommended.

Subcategory D: Carbonate Sedimentary Rocks

- **Limestone**
- **Limestone/sedimentary rocks (limestone-sedrx)**
- **Dolomite**
- **Dolomite/sedimentary rocks (dolomite-sedrx)**
- **Carbonate-bearing sedimentary rocks (co-sedrx)**

Limestone is a non-silicate rock consisting primarily of calcium carbonate. Dolomite is a non-silicate rock consisting mostly of calcium-magnesium carbonate. Gradations between limestone and dolomite often occur, and interbeds of limestone and dolomite are common. The metamorphosis of limestone and dolomite produces marble. We have no fertilization trials on limestone, dolomite or marble. We have observed that these highly weatherable rocks do not tend to support coniferous forest stands. Various hardwoods seem to do better on these rocks.

In western Montana, limestone and dolomite are frequently interlayered with other sedimentary rocks. The label 'carbonate-bearing' includes rocks noted as limestone-bearing, dolomitic, carbonate and/or calcareous. When the limestone or dolomite seemed to dominate the rock complex, the unit was labeled as limestone-sedrx or dolomite-sedrx respectively. When sedimentary rocks appeared to dominate the complex, they were labeled as carbonate-bearing sedimentary rocks (co-sedrx). The relative degree of mixing between the carbonate and non-carbonate layers of sedimentary rocks in western Montana warrants close scrutiny in field examination. A small amount of carbonate or calcareous material distributed throughout an otherwise non-carbonate sedimentary rock can have a positive effect on soil formation by contributing to increased rock weatherability. Increased rock weatherability should in turn lead to deep soils and potentially good forest productivity. These rocks may be treated similarly to the 'calc-silicate gneiss' rocks discussed in the Metamorphic Rocks Category. The greater the amount of carbonate rock, the more likely the rock is to behave like a limestone or dolomite. Carbonate-bearing sedimentary rocks that are dominated by limestone or dolomite should be treated as limestone or dolomite, respectively.

Nutrient management recommendations for limestone and dolomite

Coniferous forest stands are unlikely to occur on these rock types. If you were to find and manage for coniferous forest stands on this rock type, follow the recommendations for mudstone/sandstone etc. discussed under Subcategory A above.

Expected Soil Development: Unknown
Expected Nutrient Status: Poor for coniferous trees
Expected Fertilization Response: Unknown
Fertilizer Recommendation:

- Fertilization not currently recommended.

Nutrient management recommendations for carbonate-bearing sedimentary rocks

If dominated by the non-carbonate fraction of the rock, refer to the 'calc-silicate gneiss' subcategory under Metamorphic Rocks. If dominated by the carbonate fraction of the rock, refer to 'limestone and dolomite' above.

Subcategory E: Miscellaneous Sedimentary Rock Units

- **Iron Formation**
- **Mature Soil**
- **Mine Dumps**

We created a category for these geologic map units because they occur in western Montana, but we do not have any experience or recommendations for them. An ancient marine environment is the likely source of iron formation rocks, which may have formed as bands of algae repeatedly flourished (producing oxygen that combined with free iron in the water and was deposited as an iron oxide) and died (after the oxygen production overwhelmed the capacity of the iron ions to remove it from the water, leading to oxygen-induced algal death). Iron formations are reported only on the Dillon 1:250K quadrangle. The mature soil category occurs as the Ledford Pass Soil on the Lima 1:100K quadrangle, and is simply noted as being a pre-glacial, mature soil. Mine dumps occur on the Butte 1:250K quadrangle.

APPENDICES

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Appendix A

Instructions for using this document

Get Maps
Obtain maps pertaining to the area of interest as shown in Figure A. All maps are available through the Montana Bureau of Mines and Geology. Digital map products are available through their website at:

http://www.mbmg.mtech.edu/stmap.htm

FIGURE A PENDING

<u>If Using Paper Maps</u>
If using paper maps, locate the rock unit for the location of interest and look that unit up in the corresponding classification table in Appendix C.

<u>If Using Digital Maps</u>
If using digital maps, the same procedures described above may be followed, by looking up the rock unit label for the stand of interest and referring to Appendix C. Additionally, a set of electronic dBASE (*.dbf) files accompany this report. The set consists of twelve files, one for each of the twelve maps used to compile this report. Each file contains one table identical to the corresponding classification table provided in Appendix C (pending). Each table may be brought directly into ArcView as an event table and joined to the attribute table of the corresponding map using the MBMG Code or USGS Label field.

<u>Classification Tables</u>
The tables shown in Appendix C and the electronic tables which accompany this report contain seven columns.

The first column lists the quadrangle name and scale. The second column is labeled '**LABEL**' for the USGS maps and '**MBMG_Code**' for the MBMG maps, and includes a list of all the rock unit labels for the corresponding map. This is the same label found on paper or digital maps, and is an abbreviated text label for the rock mapped in that area. The LABEL field may be used to join the electronic table to the map attribute table in a GIS.

The next column is the **IFTNC_Label**, which for most units is the same as the USGS Label or MBMG_Code. The only exception is when the same rock unit code was used for different rock types on different maps. In those cases, we assigned a slightly different code to enable compilation of all maps without duplicate labels occurring for different rock types.

The next column gives the broad grouping labeled '**CATEGORY**.' The category assigns each map unit to a broad lithology category, including intrusive/granite, extrusive/basalt, metamorphic rocks and mixed rocks.

The next column is '**LITHOLOGY**' and gives just a few words describing what type of rock the LABEL refers to. The short description used in the original geology maps is also included for reference in the '**DESCRIPTION'** column. The '**LITH_LABEL**' column assigns each map unit to a subcategory of rock for nutrient management guidelines. More detailed rock descriptions are available in the original map documentation.

Appendix B: Quick Evaluation Guide to Montana Rocks

Extrusive/Basaltic:

- Andesite (bad)
- Basalt (good)
- Dacite (unknown but suspect bad)
- Dikes and sills (unknown but suspect bad)
- Rhyolite (unknown but suspect bad)

Intrusive/Granitic:

- Anorthosite (unknown but suspect bad)
- Dikes and Sills (bad)
- Diorite (bad)
- Gabbro (bad)
- Granite (medium)
- Granodiorite (medium)
- Monzodiorite (medium)
- Monzogranite (medium)
- Monzonite (medium)
- Syenite (unknown)
- Tonalite (medium to bad)
- Pyroxenite (bad)
- Quartz (bad)
- Quartz Diorite (medium to bad)
- Quartz Monzonite (medium)
- Ultramafic rocks (bad)

Metamorphic:

- Amphibolite (unknown)
- Argillite (variable; likely bad)
- Calc-silicate gneiss (unknown but maybe good due to weathering)
- Carbonate-bearing metaseds (unknown but maybe good due to weathering)
- Gneiss (variable)
- Granite Gneiss (variable, likely medium)
- Limestone- and dolomite-dominated metaseds (unknown but suspect bad)
- Marble (unknown but suspect bad)
- Mylonite (unknown)
- Quartzite (variable; likely bad)
- Schist (variable; can be good)
- Siltite (variable; likely bad)

Mixed Rocks:

- Alluvial Deposits (variable)
- Biotite-sandstone (unknown)

- Carbonate-bearing sedimentary rocks (variable)
- Colluvial Deposits (variable)
- Conglomerate (unknown)
- Dolomite (bad)
- Feldspathic sandstone (good)
- Glacial deposits (variable; likely medium to good)
- Gravel Deposits (variable)
- Iron Formation (unknown)
- Lacustrine Deposits (variable)
- Limestone (bad)
- Mature Soil (unknown)
- Mine Dumps (unknown)
- Mudstone/shale (unknown)
- Sandstone (variable)
- Sedimentary deposits (variable)
- Siltstone (variable)
- Volcanic (unknown, maybe bad)

Appendix C: Quadrangles; map polygon codes and corresponding IFTNC codes; IFTNC categorization, dominant lithology and lithology category; IFTNC quick evaluation; map description

Quadrangle Map	MBMG Code/ USGS Label	IFTNC Code	IFTNC Category	IFTNC Dominant Lithology	IFTNC Lithology Category	Map Description
Lima100	Ta	Ta	Extrusive/basaltic	andesite	andesite	Andesite
Chot250	Ta	Ta	Extrusive/basaltic	andesite	andesite	biotite trachyandesite and andesite
Lima100	Tcan	Tcan	Extrusive/basaltic	andesite	andesite	Andesite of Challis Volcanic Group
Chot250	Ydi	Ydi	Extrusive/basaltic	andesite, basaltic andesite, dacite	andesite	andesite, basaltic andesite, and dacite
Butte250	Tab	Tab	Extrusive/basaltic	andesitic and basaltic rocks	andesite	Andesitic and basaltic rocks (Eocene and Oligocene)
Lima100	Tcb	Tcb	Extrusive/basaltic	basalt	basalt	Basalt of Challis Volcanic Group (Eocene)
Dillon250	Ts	Tbas	Extrusive/basaltic	basalt	basalt	Balsatic rocks near Sweetwater Creek (Pliocene)
Lima100	Tsct	Tsct	Extrusive/basaltic	basalt	basalt	Timber Hill Basalt Member, informal, Sixmile Creek Formation
Lima100	Trvb	Trvb	Extrusive/basaltic	basalt over volcanics	basalt	Basalt Cap of Dillon Volcanics Member, informal, Renova Formation
Lima100	Trvh	Trvh	Extrusive/basaltic	basalt over volcanics	basalt	Hall Spring Basalt of Dillon Volcanics Member, informal, Renova Formation
Kalispell250	Ypr	Ypr	Extrusive/basaltic	basaltic lava	basalt	Purcell Lava
Chot250	Tb	Tb	Extrusive/basaltic	basaltic volcanic	basalt	basalt
Lima100	Tba	Tba	Extrusive/basaltic	basaltic volcanic	basalt	Basalt
Wall250	Tcr	Tcr	Extrusive/basaltic	Columbia River Basalt	basalt	Columbia River Basalt Group
Dillon250	Kvu	Kvu	Extrusive/basaltic	dacite, andesite	dacite	High potassium dacite and minor andesite and dacite (Late Cretaceous)
Dillon250	Ti	Ti	Extrusive/basaltic	dikes and sills	extrusive dikes and sills	Intrusive rocks (Tertiary)
Lima100	Ti	Ti	Extrusive/basaltic	dikes and sills	extrusive dikes and sills	Intrusive rocks, undivided
Dillon250	Tibd	Tibd	Extrusive/basaltic	dikes and sills	extrusive dikes and sills	Intrusive basalt and diorite (Early Tertiary)

Chot250	TKi	TKi	Extrusive/basaltic	dikes and sills	extrusive dikes and sills	trachyandesite sills
Chot250	Td	Td	Extrusive/basaltic	dikes and sills, dacite	extrusive dikes and sills	dacite - volcanic neck or plug and sills
MissW100	Td	Td	Extrusive/basaltic	dikes and sills, dacite	extrusive dikes and sills	Dacite dike
Chot250	TKr	TKr	Extrusive/basaltic	dikes and sills, rhyolite	extrusive dikes and sills	rhyolite dikes and sills
MissW100	Tr	Tr	Extrusive/basaltic	rhyolite dike	extrusive dikes and sills	Rhyolite dike
Chot250	Kl	Kl	Extrusive/basaltic	latite	extrusive sills and dikes	latite sill
Butte250	Kl	Kl	Extrusive/basaltic	latite	extrusive sills and dikes	Latite sill (Cretaceous)
Dillon250	Trd	Trd	Extrusive/basaltic	rhyodacite, dacite, andesite, rhyolite	rhyolite	Rhyodacite, dacite, andesite, and rhyolite (Tertiary)
Lima100	Tcr	Tcr	Extrusive/basaltic	rhyolite	rhyolite	Rhyolite of Challis Volcanic Group (Eocene)
Lima100	Tr	Tr	Extrusive/basaltic	rhyolite	rhyolite	Rhyolite or rhyolitic sediment
Butte250	Trv	Trv	Extrusive/basaltic	rhyolite	rhyolite	Rhyolitic volcanic rocks (Eocene through Miocene)
Hamilton100	Tra	Tra	Extrusive/basaltic	rhyolite and andesite	rhyolite	Rhyolite and andesite
NezPerce100	Tra	Tra	Extrusive/basaltic	rhyolite and andesite	rhyolite	Rhyolite and andesite
Lima100	Trvr	Trvr	Extrusive/basaltic	rhyolite over volcanic rocks	rhyolite	Rhyolitic lava flows of Dillon Volcanics Member, informal, Renova Formation
Wall250	Xan	Xan	Intrusive/granitic	anorthosite	anorthosite	anorthosite
Hamilton100	Yan	Yan	Intrusive/granitic	anorthosite	anorthosite	Anorthosite
MissW100	Yan	Yan	Intrusive/granitic	anorthosite	anorthosite	Anorthosite
Wall100	TKgb	TKgb	Intrusive/granitic	diorite and gabbro	diorite	Diorite and gabbro
MissW100	TKgb	TKgb	Intrusive/granitic	diorite and gabbro	diorite	Diorite and gabbro
Wall250	Td	Tdi	Intrusive/granitic	dioritic rocks	diorite	dioritic intrusive rocks
Butte250	TKgb	TKgb	Intrusive/granitic	gabbro	gabbro	Gabbroic rocks (Tertiary or Cretaceous)
Butte250	ZYg	ZYg	Intrusive/granitic	gabbro	gabbro	Gabbroic rocks (Middle or Late Proterozoic)
Butte250	Kgb	Kgb	Intrusive/granitic	gabbroic rocks	gabbro	Gabbroic rocks (Cretaceous)
Dillon250	Khg	Khg	Intrusive/granitic	hornblend gabbro	gabbro	Hornblende gabbro (Late Cretaceous)
NezPerce100	Ymg	Ymg	Intrusive/granitic	metagabbro	gabbro	Metagabbro

Dillon250	Kal	Kal	Intrusive/granitic	alaskite, aplite, pegmatite	granite	Alaskite, aplite, and pegmite and related felsic rocks (Cretaceous)
Butte250	Ka	Ka	Intrusive/granitic	aplite	granite	Aplitic rocks (Cretaceous)
Dillon250	TKg	TKg	Intrusive/granitic	biotite-muscovite granite	granite	Biotite-muscovite granite (Tertiary and Cretaceous)
Kalispell250	Kg	Kg	Intrusive/granitic	felsic plutons	granite	felsic plutons
Wall250	Kg	Kg	Intrusive/granitic	felsic plutons	granite	felsic plutons
Hamilton100	TKg	TKg	Intrusive/granitic	granite	granite	Granite
NezPerce100	TKg	TKg	Intrusive/granitic	granite	granite	Granite
Butte250	TKg	TKg	Intrusive/granitic	granite	granite	Granitic rocks (Tertiary or Cretaceous)
Leodore100	SOg	SOg	Intrusive/granitic	granite	granite	Granite
Hamilton100	Tg	Tg	Intrusive/granitic	granite	granite	Granite
NezPerce100	Tg	Tg	Intrusive/granitic	granite	granite	Granite
MissW100	Tg	Tg	Intrusive/granitic	granite	granite	Granite
Dillon250	Yg	Yg	Intrusive/granitic	granite	granite	Prophyritic granite (Middle Proterozoic)
Dillon250	Xg	Xg	Intrusive/granitic	granite, aplite, pegmatite	granite	Granite, aplite, and pegmatite (Early Proterozoic)
Butte250	Kg	Ki	Intrusive/granitic	granitic rocks	granite	Granitic rocks (Cretaceous)
Dillon250	Ki	Ki	Intrusive/granitic	granitic rocks	granite	Granitic rocks, undivided (Late Cretaceous)
NezPerce100	Tgpr	Tgpr	Intrusive/granitic	medium to coarse grained granite	granite	Painted Rocks Pluton
Dillon250	Kbgg	Kbgg	Intrusive/granitic	biotite granodiorite	granodiorite	Biotite granodiorite and granite (Late Cretaceous)
MissW100	Kgd	Kgd	Intrusive/granitic	biotite granodiorite	granodiorite	Biotite granodiorite
NezPerce100	TKgc	TKgc	Intrusive/granitic	biotite granodiorite and others	granodiorite	Canyon Lake Pluton
Dillon250	Tbmg	Tbmg	Intrusive/granitic	granodiorite	granodiorite	Biotite-muscovite granodiorite (Tertiary)
Dillon250	Tgd	Tgd	Intrusive/granitic	granodiorite	granodiorite	Granodiorite (Tertiary)
Butte250	Tgd	Tgd	Intrusive/granitic	granodiorite	granodiorite	Granodioritic rocks (Eocene)
Hamilton100	Tgs	Tgs	Intrusive/granitic	granodiorite	granodiorite	Granodiorite of the Skalkaho Stock
Hamilton100	Tgw	Tgw	Intrusive/granitic	granodiorite	granodiorite	Granodiorite of the Willow Creek Stock
Butte250	TKgd	TKgd	Intrusive/granitic	granodiorite	granodiorite	Granodioritic rocks (Tertiary or Cretaceous)
MissW100	TKgd	TKgd	Intrusive/granitic	granodiorite	granodiorite	Granodioritic rocks
Dillon250	Kgd	Kgd	Intrusive/granitic	granodiorite	granodiorite	Granodiorite (Cretaceous)
Butte250	Kgd	Kgd	Intrusive/granitic	granodiorite	granodiorite	Granodioritic rocks (Cretaceous)

Dillon250	Kgtd	Kgtd	Intrusive/granitic	granodiorite	granodiorite	Granodiorite, tonalite, and quartz diorite (Late Cretaceous)
Hamilton100	TKp	TKp	Intrusive/granitic	granodiorite and monzogranite	granodiorite	Granodiorite and monzogranite of the Paradise Pluton
NezPerce100	TKp	TKp	Intrusive/granitic	granodiorite and monzogranite	granodiorite	Granodiorite and monzogranite of the Paradise Pluton
Dillon250	Kfgt	Kfgt	Intrusive/granitic	granodiorite, tonalite	granodiorite	Foliated hornblende-biotite granodiorite and tonalite (Cretaceous)
Dillon250	TKgd	TKgd	Intrusive/granitic	hornblende biotite granodiorite	granodiorite	Hornblende-biotite granodiorite (Tertiary and Cretaceous)
NezPerce100	Tgb	Tgb	Intrusive/granitic	muscovite-biotite granodiorite	granodiorite	Burnt Ridge Pluton
NezPerce100	TKh	TKh	Intrusive/granitic	dikes and sills	intrusive dikes and sills	Hypabyssal intrusive or flows
Dillon250	Tsi	Tsi	Intrusive/granitic	dikes and sills	intrusive dikes and sills	Silicic dikes (Tertiary)
Dillon250	Yd	Yd	Intrusive/granitic	dikes and sills	intrusive dikes and sills	Diabase (Middle Proterozoic)
Kalispell250	Yd	Yd	Intrusive/granitic	dikes and sills	intrusive dikes and sills	mafic sills
Wall250	Tg	Tg	Intrusive/granitic	dikes and sills, granite	intrusive dikes and sills	granitic plutons and plugs
Leodore100	Tqdm	Tqdm	Intrusive/granitic	quartz diorite and quartz monzonite stock	intrusive dikes and sills	Quartz diorite and Quartz monzonite, Little Eightmile Stock
Chot250	Zd	Zd	Intrusive/granitic	sills and dikes, diorite	intrusive dikes and sills	diorite sills and local dikes
Kalispell250	ZYd	ZYd	Intrusive/granitic	sills and dikes, mafic	intrusive dikes and sills	mafic sills
Kalispell250	Zyd	Zyd	Intrusive/granitic	sills and dikes, mafic	intrusive dikes and sills	mafic sills
Wall250	ZYd	ZYd	Intrusive/granitic	sills and dikes, mafic	intrusive dikes and sills	mafic sills and dikes
CutBank250	ZYd	ZYd	Intrusive/granitic	sills and dikes, mafic	intrusive dikes and sills	mafic sills and dikes
Butte250	Kmd	Kmd	Intrusive/granitic	monzodiorite	monzodiorite	Monzodioritic rocks (Cretaceous)
Dillon250	Kmg	Kmg	Intrusive/granitic	monzodiorite	monzodiorite	Monzogranite (Cretaceous)
Dillon250	Tq	Tq	Intrusive/granitic	monzogranite, granodiorite and others	monzogranite	Monzogranite, granodiorite, quartz monzodiorite, and related intrusive granitic rocks (Tertiary)

NezPerce100	Tgpi	Tgpi	Intrusive/granitic	pink biotite monzogranite	monzogranite	Piquett Creek Pluton
Chot250	Tm	Tmonz	Intrusive/granitic	hornblende monzonite	monzonite	hornblende monzonite
Chot250	Tmp	Tmp	Intrusive/granitic	monzonite	monzonite	monzonite porphyry
Kalispell250	Kpy	Kpy	Intrusive/granitic	pyroxenite	pyroxenite	pyroxenite
Butte250	TKa	TKa	Intrusive/granitic	pyroxenite, syenite	pyroxenite	Alkalic rocks (Tertiary or Cretaceous)
Lima100	Tqtz	Tqtz	Intrusive/granitic	quartz	quartz	Quartz
Chot250	TKp	TKp	Intrusive/granitic	quartz monzonite	quartz monzonite	quartz monzonite porphyry
Kalispell250	Ks	Ks	Intrusive/granitic	syenite	syenite	syenite
Wall250	Ks	Ks	Intrusive/granitic	syenite	syenite	syenite
MissW100	Kto	Kto	Intrusive/granitic	tonalite	tonalite	Tonalite
Lima100	Aum	Aum	Intrusive/granitic	ultramafic rocks	ultramafic rocks	Ultramafic rock
Dillon250	XAu	XAu	Intrusive/granitic	ultramafic rocks	ultramafic rocks	Ultramafic rocks (Early Proterozoic? and Archean)
Dillon250	Aa	Aa	Metamorphic	amphibolite	amphibolite	Amphibolite (Archean)
Hamilton100	Yam	Yam	Metamorphic	amphibolite	amphibolite	amphibolite
NezPerce100	Yam	Yam	Metamorphic	amphibolite	amphibolite	Amphibolite
Kalispell250	Ypa	Ypa	Metamorphic	argillite	argillite	argillite member of the Prichard Formation
Kalispell250	Ywu	Ywu	Metamorphic	argillite	argillite	upper member of the Wallace Formation
Wall250	Ywu	Ywu	Metamorphic	argillite	argillite	upper member of the Wallace Formation
Chot250	Yg	Yg	Metamorphic	argillite, siltite	argillite/siltite	Greyson Formation
Butte250	Yg	Yg	Metamorphic	argillite, siltite	argillite/siltite	Greyson Formation (Middle Proterozoic)
Kalispell250	Yl	Ylib	Metamorphic	argillite, siltite	argillite/siltite	Libby Formation, undivided
Wall250	Yl	Ylib	Metamorphic	argillite, siltite	argillite/siltite	Libby Formation
Kalispell250	Ym	Ym	Metamorphic	argillite, siltite	argillite/siltite	McNamara Formation
Wall250	Ym	Ym	Metamorphic	argillite, siltite	argillite/siltite	Mc Namara Formation
CutBank250	Ym	Ym	Metamorphic	argillite, siltite	argillite/siltite	McNamara Formation
Chot250	Ym	Ym	Metamorphic	argillite, siltite	argillite/siltite	McNamara Formation
MissW100	Ym	Ym	Metamorphic	argillite, siltite	argillite/siltite	McNamara Formation
Wall100	Ym	Ym	Metamorphic	argillite, siltite	argillite/siltite	McNamara Formation
Butte250	Ym	Ym	Metamorphic	argillite, siltite	argillite/siltite	McNamara Formation (Middle Proterozoic)
Kalispell250	Ypu	Ypu	Metamorphic	argillite, siltite	argillite/siltite	upper member of the Prichard Formation
Wall250	Ypu	Ypu	Metamorphic	argillite, siltite	argillite/siltite	upper part of the Prichard Formation

Kalispell250	Yap	Yap	Metamorphic	argillite, siltite, quartzarenite	argillite/siltite	Appekunny Formation
CutBank250	Yap	Yap	Metamorphic	argillite, siltite, quartzarenite	argillite/siltite	Appekunny Formation
Kalispell250	Ysn	Ysn	Metamorphic	argillite, siltite quartzite	argillite/siltite/ quartzite	red and green facies of the Snowslip Formation
Wall250	Ysn	Ysn	Metamorphic	argillite, siltite quartzite	argillite/siltite/ quartzite	Snowslip Formation
CutBank250	Ysn	Ysn	Metamorphic	argillite, siltite quartzite	argillite/siltite/ quartzite	Snowslip Formation
Chot250	Ysn	Ysn	Metamorphic	argillite, siltite quartzite	argillite/siltite/ quartzite	Snowslip Formation
MissW100	Ysn	Ysn	Metamorphic	argillite, siltite quartzite	argillite/siltite/ quartzite	Snowslip Formation
Wall100	Ysn	Ysn	Metamorphic	argillite, siltite quartzite	argillite/siltite/ quartzite	Snowslip Formation
Butte250	Ysn	Ysn	Metamorphic	argillite, siltite quartzite	argillite/siltite/ quartzite	Snowslip Formation (Middle Proterozoic)
Kalispell250	Ysng	Ysng	Metamorphic	argillite, siltite quartzite	argillite/siltite/qua rtzite	green facies of the Snowslip Formation
Kalispell250	Ylu	Ylu	Metamorphic	argillite, siltite, quartzite	argillite/siltite /quartzite	upper part of the Libby Formation
Hamilton100	Ycg	Ycscg	Metamorphic	calc-silicate gneiss	calc-silicate gneiss	Calc-silicate gneiss of the middle Belt carbonate
MissW100	Ywcs	Ywcs	Metamorphic	calc-silicate gneiss	calc-silicate gneiss	Calc-silicate rocks of the Wallace Formation
Kalispell250	Ysh	Ysh	Metamorphic	argillite, dolomitic siltite	co-argillite/siltite	Shepard Formation
Wall250	Ysh	Ysh	Metamorphic	argillite, dolomitic siltite	co-argillite/siltite	Shepard Formation
CutBank250	Ysh	Ysh	Metamorphic	argillite, dolomitic siltite	co-argillite/siltite	Shepard Formation
Chot250	Ysh	Ysh	Metamorphic	argillite, dolomitic siltite	co-argillite/siltite	Shepard Formation
MissW100	Ysh	Ysh	Metamorphic	argillite, dolomitic siltite	co-argillite/siltite	Shepard Formation
Wall100	Ysh	Ysh	Metamorphic	argillite, dolomitic siltite	co-argillite/siltite	Shepard Formation
Butte250	Ysh	Ysh	Metamorphic	argillite, dolomitic siltite	co-argillite/siltite	Shepard Formation (Middle Proterozoic)

Kalispell250	Ye	Ye	Metamorphic	argillite, siltite, dolomite	co-argillite/siltite	Empire Formation
Wall250	Ye	Ye	Metamorphic	argillite, siltite, dolomite	co-argillite/siltite	Empire Formation
CutBank250	Ye	Ye	Metamorphic	argillite, siltite, dolomite	co-argillite/siltite	Empire Formation
Chot250	Ye	Ye	Metamorphic	argillite, siltite, dolomite	co-argillite/siltite	Empire Formation
Butte250	Ye	Ye	Metamorphic	argillite, siltite, dolomite	co-argillite/siltite	Empire Formation (Middle Proterozoic)
Chot250	Yes	Yes	Metamorphic	argillite, siltite, dolomite	co-argillite/siltite	Spokane and Empire Formations, undivided
Kalispell250	Ymsu	Ymsu	Metamorphic	argillite, siltite, dolomite	co-argillite/siltite	upper part of the Mount Shields Formation
Wall250	Ysp	Ysp	Metamorphic	argillite, siltite, possible carbonates	co-argillite/siltite	Striped Peak Formation
Kalispell250	Ysw	Yssw	Metamorphic	carbonate rocks, quartzite	co-quartzite	Shepard, Snowslip and Wallace Formations, undivided
Butte250	Yss	Yss	Metamorphic	carbonte rocks, quartzite	co-quartzite	Snowslip and Shepard Formations (Middle Proterozoic)
Lima100	Oks	Oks	Metamorphic	quartzite and dolomite	co-quartzite	Kinnikinnic and Summerhouse Formations, undivided
Wall100	Yms2	Yms2	Metamorphic	quartzite w/ dolomitic blebs	co-quartzite	Mount Shields Formation , member 2, informal
MissW100	Yms2	Yms2	Metamorphic	quartzite w/ dolomitic blebs	co-quartzite	Mount Shields Formation, member 2
Kalispell250	PPr	PPr	Metamorphic	quartzite, common carbonate	co-quartzite	Rocky Mountian Formation
Kalispell250	Yhl	Yhl	Metamorphic	dolomitic or calcareous siltite	co-siltite	lower member of the Helena Formation
Kalispell250	Ywl	Ywl	Metamorphic	siltite, argillite w/carbonate	co-siltite/argillite	lower member of the Wallace Formation
Wall250	Ywl	Ywl	Metamorphic	siltite, argillite w/carbonate	co-siltite/argillite	lower member of the Wallace Formation
MissW100	Ywl	Ywl	Metamorphic	siltite, argillite w/carbonate	co-siltite/argillite	Wallace Formation, lower member
Wall100	Ywl	Ywl	Metamorphic	siltite, argillite w/carbonate	co-siltite/argillite	Wallace Formation, lower member, informal
Kalispell250	Ysr	Ysr	Metamorphic	siltite, argillite, dolomitic siltite	co-siltite/argillite	St. Regis Formation

Wall250	Ysr	Ysr	Metamorphic	siltite, argillite, dolomitic siltite	co-siltite/argillite	St. Regis Formation
Wall100	Ysr	Ysr	Metamorphic	siltite, argillite, dolomitic siltite	co-siltite/argillite	St. Regis Formation
CutBank250	Ys	Ys	Metamorphic	siltite, argillite, quartzite	co-siltite/argillite	Spokane Formation
Kalispell250	Yw	Yw	Metamorphic	carbonate-bearing siltite, quartzite	co-siltite/quartzite	upper, middle and lower members of the Wallace Formation, undivided
Wall250	Yw	Yw	Metamorphic	carbonate-bearing siltite, quartzite	co-siltite/quartzite	middle and lower members (undivided) of the Wallace Formation
MissW100	Yw	Yw	Metamorphic	carbonate-bearing siltite, quartzite	co-siltite/quartzite	Wallace Formation, undivided
Kalispell250	Ywm	Ywm	Metamorphic	carbonate-bearing siltite, quartzite	co-siltite/quartzite	middle member of the Wallace Formation
Wall250	Ywm	Ywm	Metamorphic	carbonate-bearing siltite, quartzite	co-siltite/quartzite	middle member of the Wallace Formation
MissW100	Ywm	Ywm	Metamorphic	carbonate-bearing siltite, quartzite	co-siltite/quartzite	Wallace Formation, middle member
Wall100	Ywm	Ywm	Metamorphic	carbonate-bearing siltite, quartzite	co-siltite/quartzite	Wallace Formation, middle member, informal
Leodore100	Ybc	Ybc	Metamorphic	feldspathic quartzite	fld-quartzite	Big Creek Formation of Lemhi Group
Leodore100	Ygs	Ygs	Metamorphic	feldspathic quartzite	fld-quartzite	Gunsight Formation of Lemhi Group
Dillon250	Yl	Yl	Metamorphic	feldspathic quartzite, siltite	fld-quartzite/siltite	Lemhi Group (Middle Proterozoic)
Leodore100	Yl	Yl	Metamorphic	feldspathic quartzite, siltite	fld-quartzite/siltite	Lemhi Group
Dillon250	Yy	Yy	Metamorphic	feldspathic quartzite; siltite, argillite	fld-quartzite/siltite	Yellowjacket Formation (Middle Proterozoic)
Leodore100	Yy	Yy	Metamorphic	feldspathic quartzite; siltite, argillite	fld-quartzite/siltite	Yellowjacket Formation
Dillon250	X(A)b	X(A)b	Metamorphic	biotite gneiss and schist	gneiss	Biotite gneiss (Early Proterozoic and Archean)
Dillon250	X(A)g	X(A)g	Metamorphic	garnetiferous gneiss and schist	gneiss	Garnetiferous gneiss and schist (Early Proterozoic and Archean)
Butte250	Ymb	Ymb	Metamorphic	gneiss and others	gneiss	Metamorphosed rocks of the Belt Supergroup (Middle Proterozoic)
Wall250	Xgn	Xgn	Metamorphic	gneiss and schist	gneiss	gneiss and schist

Dillon250	Xga	Xga	Metamorphic	gneiss, amphibolite	gneiss	Gneiss and amphibolite (Early Proterozoic)
Hamilton100	Ybm	Ybm	Metamorphic	gneissic metasedimentary rocks	gneiss	Gneissic metasedimentary rocks, undivided
NezPerce100	Ybm	Ybm	Metamorphic	gneissic metasedimentary rocks	gneiss	Gneissic metasedimentary rocks, undivided
Dillon250	X(A)m	X(A)m	Metamorphic	mylonitic biotite gneiss	gneiss	Mylonitic biotite gneiss (Early Proterozoic and Archean)
Dillon250	Xmb	Xmb	Metamorphic	mylonitic gneiss	gneiss	Mylonitic biotite gneiss (Early Proterozoic)
Dillon250	Xi	Xi	Metamorphic	mylonitic orthogneiss; grnite sills	gneiss	Mylonitic orthogneiss and granite sills (Early Proterozoic)
Dillon250	X(A)qf	X(A)qf	Metamorphic	quartz-feldspar-biotite gneiss	gneiss	Quartz-feldspar-biotite gneiss (Early Proterozoic and Archean)
Dillon250	X(A)q	X(A)q	Metamorphic	quartzofeldspathic gneiss	gneiss	Quartzofeldspathic gneiss (Early Proterozoic and Archean)
Hamilton100	Yqf	Yqf	Metamorphic	quartzofeldspathic gneiss	gneiss	Quartzofeldspathic gneiss
NezPerce100	Yqf	Yqf	Metamorphic	quartzofeldspathic gneiss	gneiss	Quartzofeldspathic gneiss
MissW100	Yqfg	Yqfg	Metamorphic	quartzofeldspathic gneiss	gneiss	Quartzofeldspathic gneiss of the Belt Supergroup
Dillon250	Ag	Ag	Metamorphic	granite gneiss	granite gneiss	Gneissic rocks (Archean)
Lima100	Ag	Ag	Metamorphic	granite gneiss	granite gneiss	Granite gneiss
Lima100	Agn	Ag	Metamorphic	granite gneiss	granite gneiss	Gneissic rocks
Dillon250	Aqf	Aqf	Metamorphic	granite gneiss	granite gneiss	Quartzofeldspathic gneiss (Archean)
Leodore100	Aqfg	Aqf	Metamorphic	granite gneiss	granite gneiss	Quartzofeldspathic gneiss
Dillon250	Kfr	Kfr	Metamorphic	granite gneiss	granite gneiss	Granite gneiss fo Foolhen Ridge (Cretaceous?)
Hamilton100	TKag	TKag	Metamorphic	granite gneiss	granite gneiss	Augen gneiss
NezPerce100	Yagn	Yagn	Metamorphic	granite gneiss	granite gneiss	Augen gneiss
Dillon250	Khbg	Khbg	Metamorphic	hornblende biotite gneiss	granite gneiss	Hornblende biotite gneiss (Cretaceous?)
Hamilton100	Yog	Yog	Metamorphic	orthogneiss	granite gneiss	orthogneiss
Kalispell250	Yh	Yh	Metamorphic	limestone, dolomite, siltite	limestone/ dolomite/siltite	main body of the Helena Formation

Wall250	Yh	Yh	Metamorphic	limestone, dolomite, siltite	limestone/ dolomite/siltite	Helena Formation
CutBank250	Yh	Yh	Metamorphic	limestone, dolomite, siltite	limestone/ dolomite/siltite	Helena Formation
Chot250	Yh	Yh	Metamorphic	limestone, dolomite, siltite	limestone/ dolomite/siltite	Helena Formation
Dillon250	Yhe	Yhe	Metamorphic	limestone, dolomite, siltite	limestone/ dolomite/siltite	Helena and Empire Formations (Middle Proterozoic)
Kalispell250	Yhw	Yhw	Metamorphic	limestone, dolomite, siltite	limestone/ dolomite/siltite	main body of the Helena Formation and middle member of the Wallace Formation
Hamilton100	Yc	Yc	Metamorphic	limestone, dolomite, siltite, quartzite	limestone/ dolomite/siltite	Middle Belt carbonate, informal
Butte250	Yc	Yc	Metamorphic	limestone, dolomite, siltite, quartzite	limestone/ dolomite/siltite	Middle Belt carbonate (Middle Proterozoic)
Dillon250	Am	Am	Metamorphic	marble	marble	Marble (Archean)
Hamilton100	Tm	Tm	Metamorphic	mylonitic rocks	mylonite	Mylonite
NezPerce100	Tm	Tm	Metamorphic	mylonitic rocks	mylonite	Mylonite
MissW100	Tm	Tm	Metamorphic	mylonitic rocks	mylonite	Mylonitic rocks
MissW100	^f	^f	Metamorphic	quartzite	quartzite	Flathead Quartzite
Dillon250	Aq	Aq	Metamorphic	quartzite	quartzite	Quartzite (Archean)
Leodore100	Ok	Ok	Metamorphic	quartzite	quartzite	Kinnikinic Quartzite
Dillon250	Oq	Oq	Metamorphic	quartzite	quartzite	Quartzite of Dickie Peak (Ordovician)
Chot250	Yb	Ybo	Metamorphic	quartzite	quartzite	Bonner Quartzite
Kalispell250	Ybo	Ybo	Metamorphic	quartzite	quartzite	Bonner Quartzite
Wall250	Ybo	Ybo	Metamorphic	quartzite	quartzite	Bonner Quartzite
CutBank250	Ybo	Ybo	Metamorphic	quartzite	quartzite	Bonner Quartzite
MissW100	Ybo	Ybo	Metamorphic	quartzite	quartzite	Bonner Quartzite
Wall100	Ybo	Ybo	Metamorphic	quartzite	quartzite	Bonner Formation
Butte250	Ybo	Ybo	Metamorphic	quartzite	quartzite	Bonner Quartzite (Middle Proterozoic)
Chot250	Ymi	Ymi	Metamorphic	quartzite	quartzite	Bonner Quartzite, Mount Shields Fm, Shepard Fm, and Snowslip Fm, undivided
Dillon250	Ymm	Ymm	Metamorphic	quartzite	quartzite	Foliated metasedimentary rocks, probably part of the Bonner Quartzite and Mount Shields Formation (Middle Proterozoic)
Wall250	Ypi	Ypi	Metamorphic	quartzite	quartzite	Pilcher Quartzite
MissW100	Ypi	Ypi	Metamorphic	quartzite	quartzite	Pilcher Quartzite

Butte250	Ypi	Ypi	Metamorphic	quartzite	quartzite	Pilcher Quartzite (Middle Proterozoic)
Kalispell250	Ypq	Ypq	Metamorphic	quartzite	quartzite	quartzite member of the Prichard Formation
Dillon250	Yq	Yq	Metamorphic	quartzite	quartzite	Quartzite of Grace Lake (Middle Proterozoic?)
Hamilton100	Yq	Yq	Metamorphic	quartzite	quartzite	Quartzite, undifferentiated
NezPerce100	Yq	Yq	Metamorphic	quartzite	quartzite	Quartzite, undifferentiated
MissW100	Yq	Yq	Metamorphic	quartzite	quartzite	Quartzite of the Belt Supergroup
Butte250	Yq	Yq	Metamorphic	quartzite	quartzite	Quartzite of the Belt Supergroup (Middle Proterozoic)
Dillon250	Ys	Ysw	Metamorphic	quartzite	quartzite	Swauger Formation (Middle Proterozoic)
Leodore100	Ysw	Ysw	Metamorphic	quartzite	quartzite	Swauger Formation
Dillon250	Ytm	Ytm	Metamorphic	quartzite	quartzite	Quartzite of Table Mountain (Middle Proterozoic)
Wall250	Ywq	Ywq	Metamorphic	quartzite	quartzite	quartzite member of the Wallace Formation
Kalispell250	Yms	Yms	Metamorphic	quartzite, argillite, siltite	quartzite	Mount Shields Formation, undivided
Leodore100	Yms	Yms	Metamorphic	quartzite, argillite, siltite	quartzite	Mount Shields Formation
Wall250	Yms	Yms	Metamorphic	quartzite, argillite, siltite	quartzite	Mount Shields Formation
CutBank250	Yms	Yms	Metamorphic	quartzite, argillite, siltite	quartzite	Mount Shields Formation
Chot250	Yms	Yms	Metamorphic	quartzite, argillite, siltite	quartzite	Mount Shields Formation
MissW100	Yms	Yms	Metamorphic	quartzite, argillite, siltite	quartzite	Mount Shields Formation, undivided
Butte250	Yms	Yms	Metamorphic	quartzite, argillite, siltite	quartzite	Mount Shields Formation (Middle Proterozoic)
Wall250	Ygr	Ygr	Metamorphic	quartzite, argillite	quartzite/argillite	Garnet Range Formation
CutBank250	Ygr	Ygr	Metamorphic	quartzite, argillite	quartzite/argillite	Garnet Range Formation
Chot250	Ygr	Ygr	Metamorphic	quartzite, argillite	quartzite/argillite	Garnet Range Formation
MissW100	Ygr	Ygr	Metamorphic	quartzite, argillite	quartzite/argillite	Garnet Range Formation
Wall100	Ygr	Ygr	Metamorphic	quartzite, argillite	quartzite/argillite	Garnet Range Formation
Butte250	Ygr	Ygr	Metamorphic	quartzite, argillite	quartzite/argillite	Garnet Range Formation (Middle Proterozoic)
Kalispell250	Ypl	Ypl	Metamorphic	quartzite, argillite	quartzite/argillite	lower part of the Prichard Formation

Wall250	Ypl	Ypl	Metamorphic	quartzite, argillite	quartzite/argillite	lower part of the Prichard Formation
Kalispell250	Yr	Yr	Metamorphic	quartzite, argillite	quartzite/argillite	Revett Formation
Wall250	Yr	Yr	Metamorphic	quartzite, argillite	quartzite/argillite	Revett Formation
Wall100	Yr	Yr	Metamorphic	quartzite, argillite	quartzite/argillite	Revett Formation
Dillon250	Ym	Ymis	Metamorphic	quartzite, argillite, siltite	quartzite/argillite/ siltite	Missoula Group (Middle Proterozoic)
Hamilton100	Ymi	Ymis	Metamorphic	quartzite, argillite, siltite	quartzite/argillite/ siltite	Missoula Group
Lima100	Aqm	Aqm	Metamorphic	quartzite and marble	quartzite/marble	Quartzite and Marble
Kalispell250	Ygl	Ygl	Metamorphic	quartzarenite	quartzite/siltite	Grinnell Formation
CutBank250	Ygl	Ygl	Metamorphic	quartzarenite	quartzite/siltite	Grinnell Formation
Chot250	Ybe	Ybe	Metamorphic	quartzite, siltite, possible limestone strata	quartzite/siltite	McNamara Fm, Bonner Quartzite, Mount Shields Fm, Shepard Fm, Snowslip Fm, Helena Fm, Empire Fm, and Spokane Fm.
Dillon250	Ysc	Ysc	Metamorphic	quartzite,siltite, argillite	quartzite/siltite	Quartzite, siltite, and argillite of Swamp Creek (Middle Proterozoic)
Kalispell250	Yb	Yb	Metamorphic	sericitic quartzite/siltite	quartzite/siltite	Burke Formation
Dillon250	Kfm	Kfm	Metamorphic	meta-igneous rocks	schist	Foliated meta-igneous rocks (Cretaceous?)
NezPerce100	Yqs	Yqs	Metamorphic	quartzitic schist	schist	Quartzitic schist
Dillon250	Aas	Aas	Metamorphic	schist	schist	Aluminous schist (Archean)
MissW100	Ysgn	Ysgn	Metamorphic	schist and gneiss	schist	Schist and gneiss of the Belt Supergroup
Dillon250	Asg	Asg	Metamorphic	schist and gneiss	schist	Interlayered schist and gneiss (Archean)
Kalispell250	Ybos	Ybos	Metamorphic	siltite	siltite	siltite facies of the Bonner Quartzite
Wall100	Yms3	Yms3	Metamorphic	siltite, argillite	siltite/argillite	Mount Shields Formation, member 3, informal
MissW100	Yms3	Yms3	Metamorphic	siltite, argillite	siltite/argillite	Mount Shields Formation, member 3
Wall250	Yb	Yb	Metamorphic	siltite/argillite	siltite/argillite	Burke Formation
Wall100	Yb	Yb	Metamorphic	siltite/argillite	siltite/argillite	Burke Formation
Kalispell250	Ys	Ys	Metamorphic	siltite, argillite, quartzite	siltite/argillite/ quartzite	Spokane Formation
Wall250	Ys	Ys	Metamorphic	siltite, argillite, quartzite	siltite/argillite/ quartzite	Spokane Formation
Chot250	Ys	Ys	Metamorphic	siltite, argillite, quartzite	siltite/argillite/ quartzite	Spokane Formation

Butte250	Ys	Ys	Metamorphic	siltite, argillite, quartzite	siltite/argillite/ quartzite	Spokane Formation (Middle Proterozoic)
Dillon250	Ysg	Ysg	Metamorphic	siltite, argillite, quartzite	siltite/argillite/ quartzite	Spokane and Greyson Formations (Middle Proterozoic)
Kalispell250	Ypt	Ypt	Metamorphic	siltite, quartzite	siltite/quartzite	transition member of the Prichard Formation
CutBank250	Ypt	Ypt	Metamorphic	siltite, quartzite	siltite/quartzite	transition member of the Prichard Formation
Kalispell250	Yu	Yu	Metamorphic	siltite, quartzite	siltite/quartzite	unnamed formation, a facies of either the Burke or Appekunny Formation
Leodore100	Yac	Yac	Metamorphic	siltite, quartzite	siltite/quartzite	Apple Creek Formation of Lemhi Group
Dillon250	Qa	Qa	Mixed	alluvium	alluvial deposits	Alluvium (Holocene)
Chot250	Qa	Qa	Mixed	alluvium	alluvial deposits	sed
Hamilton100	Qaf	Qaf	Mixed	alluvium	alluvial deposits	Alluvial fan deposit
Lima100	Qaf	Qaf	Mixed	alluvium	alluvial deposits	Alluvial fan deposit
NezPerce100	Qaf	Qaf	Mixed	alluvium	alluvial deposits	Alluvial fan deposit
Lima100	Qafo	Qafo	Mixed	alluvium	alluvial deposits	Alluvial fan deposit, older
Hamilton100	Qal	Qal	Mixed	alluvium	alluvial deposits	Alluvium of modern channels and flood plains
Kalispell250	Qal	Qal	Mixed	alluvium	alluvial deposits	alluvial deposits
Leodore100	Qal	Qal	Mixed	alluvium	alluvial deposits	Alluvium of modern channels and floodplains
Lima100	Qal	Qal	Mixed	alluvium	alluvial deposits	Alluvium of modern channels and flood plains
Wall250	Qal	Qal	Mixed	alluvium	alluvial deposits	alluvial deposits
CutBank250	Qal	Qal	Mixed	alluvium	alluvial deposits	alluvial deposits
NezPerce100	Qal	Qal	Mixed	alluvium	alluvial deposits	Alluvium of modern channels and flood plains
MissW100	Qal	Qal	Mixed	alluvium	alluvial deposits	Alluvium of modern channels and floodplains
Wall100	Qal	Qal	Mixed	alluvium	alluvial deposits	Alluvium of modern channels and floodplains
Lima100	Qao	Qao	Mixed	alluvium	alluvial deposits	Alluvium, older, undivided
MissW100	Qao	Qao	Mixed	alluvium	alluvial deposits	Older alluvium, undivided
Wall100	Qao	Qao	Mixed	alluvium	alluvial deposits	Alluvium, older, undivided
Hamilton100	Qat	Qat	Mixed	alluvium	alluvial deposits	Alluvium of alluvial terrace deposit
NezPerce100	Qat	Qat	Mixed	alluvium	alluvial deposits	Alluvium of alluvial terrace deposit

MissW100	Qat	Qat	Mixed	alluvium	alluvial deposits	Alluvium of alluvial terrace deposit
Dillon250	Qf	Qaf	Mixed	alluvium	alluvial deposits	Alluvial-fan deposits (Holocene and Pleistocene)
Wall100	QTaf	QTaf	Mixed	alluvium	alluvial deposits	Alluvial fan deposits
Dillon250	QTg	QTg	Mixed	alluvium	alluvial deposits	Alluvial and Pediment gravels (Quaternary and Tertiary)
Hamilton100	Taf	Taf	Mixed	alluvium	alluvial deposits	Alluvial fan deposit
MissW100	Taf	Taf	Mixed	alluvium	alluvial deposits	Alluvial fan deposit
Lima100	Tcbs	Tcbs	Mixed	biotite-bearing sandstone	bio-sandstone	Biotite-bearing sandstone of Challis Volcanic Group (Eocene)
Lima100	Qa	Qaval	Mixed	avalanche	colluvial deposits	Avalanche deposit
Hamilton100	Qc	Qc	Mixed	colluvium	colluvial deposits	Colluvium
Lima100	Qc	Qc	Mixed	colluvium	colluvial deposits	Colluvium
Dillon250	Ql	Qls	Mixed	landslide	colluvial deposits	Landslide deposits (Holocene and Pleistocene)
Hamilton100	Qls	Qls	Mixed	landslide	colluvial deposits	Landslide deposit
Leodore100	Qls	Qls	Mixed	landslide	colluvial deposits	Landslide deposit
Lima100	Qls	Qls	Mixed	landslide	colluvial deposits	Landslide deposit
NezPerce100	Qls	Qls	Mixed	landslide	colluvial deposits	Landslide deposit
MissW100	Qls	Qls	Mixed	landslide	colluvial deposits	Landslide deposit
Wall100	Qls	Qls	Mixed	landslide	colluvial deposits	Landslide deposit
Kalispell250	Qs	Qls	Mixed	landslide	colluvial deposits	landslide deposits
Wall250	Qs	Qls	Mixed	landslide	colluvial deposits	landslide deposits
CutBank250	Qs	Qls	Mixed	landslide	colluvial deposits	landslide deposits
Chot250	Qs	Qls	Mixed	landslide	colluvial deposits	landslide deposits
Lima100	Qta	Qta	Mixed	landslide	colluvial deposits	Talus deposit
Lima100	Tcab	Tcab	Mixed	landslide deposit	colluvial deposits	Breccia (Landslide deposit)
Dillon250	Ycg	Ycg	Mixed	conglomerate	conglomerate	Conglomerate (Middle Proterozoic?)
Lima100	TKbq	TKbq	Mixed	quartzite conglomerate	conglomerate	Quartzite Conglomerate, Beaverhead Group
Wall250	Ts	Ts	Mixed	semi-consolidated conglomerates, volc.ash	conglomerate	sedimentary rocks
Lima100	Tccs	Tccs	Mixed	conglomerate and sandstone	conglomerate/ sandstone	Conglomerate and sandstone of Challis Volcanic Group (Eocene)
Lima100	Tcs	Tcs	Mixed	conglomerate and sandstone	conglomerate/ sandstone	Conglomerate and sandstone

Kalispell250	Tk	Tk	Mixed	conglomerate, sandstone, siltstone, coal	conglomerate/ sandstone	Kishenehn Formation
CutBank250	Tk	Tk	Mixed	conglomerate, sandstone, siltstone, coal	conglomerate/ sandstone	Kishenehn Formation
Leodore100	&Msb	&Msb	Mixed	calcareous sandstone	co-sandstone	Snaky Canyon Formation and Bluebird Mountain Formation
Lima100	Kbm	Kbm	Mixed	calcareous sandstone	co-sandstone	Monida Sandstone of Beaverhead Group
Lima100	Kbsn	Kbsn	Mixed	calcareous sandstone	co-sandstone	Snowslip Sandstone of Beaverhead Group
Dillon250	&Mq	&Mq	Mixed	sandstone w/ minor dolomite influence	co-sandstone	Quadrant Formation (Pennsylvanian and Upper Mississippian)
Dillon250	Jm	Jm	Mixed	calcareous mudstone, limestone, siltstone	co-sedrx	Morrison Formation (Upper Jurassic)
Lima100	Jmet	Jmet	Mixed	calcareous mudstone, limestone, siltstone	co-sedrx	Morrison Formation, Ellis Group, and Twin Creek Formation, undivided
Chot250	Km	Km	Mixed	calcareous mudstone, limestone, siltstone	co-sedrx	Marias River Shale
Lima100	^wf	^wf	Mixed	calcareous sandstone, siltstone, shale	co-sedrx	Wolsey and Flathead Formations
Leodore100	@d	@d	Mixed	calcareous siltstone, sandstone, shale	co-sedrx	Dinwoody Formation
Lima100	@td	@td	Mixed	calcareous siltstone, sandstone, shale	co-sedrx	Thaynes, Woodside, and Dinwoody Formations
Dillon250	@u	@u	Mixed	calcareous siltstone, sandstone, shale	co-sedrx	Triassic rocks, undivided
Leodore100	Ths	Ths	Mixed	calcareous tufa	co-sedrx	Hot springs deposits
Lima100	Ts	Ts	Mixed	conglom., sandstone, mudstone, limestone	co-sedrx	Sediment or sedimentary rocks, undivided
Dillon250	TKb	TKb	Mixed	conglomerate, sandstone, limestone	co-sedrx	Beaverhead Group (Tertiary? Upper Cretaceous)

Lima100	TKb	TKb	Mixed	conglomerate, sandstone, limestone	co-sedrx	Beaverhead Group
Kalispell250	Jf	Jf	Mixed	dolomitic sandstone, siltstone, shale	co-sedrx	Fernie Formation
Wall100	Yp	Yp	Mixed	dolomitic shales, sandstone	co-sedrx	Prichard Formation
Butte250	PDs	PDs	Mixed	mixed seds and carbonates	co-sedrx	Sedimentary rocks (Permian through Devonian)
Lima100	MDmt	MDmt	Mixed	mudstone, limestone, sandstone	co-sedrx	McGowan Creek and Three Forks Formations, undivided
Lima100	Mmg	Mmg	Mixed	mudstone, limestone, sandstone	co-sedrx	McGowen Creek Formation
CutBank250	Kl	Kl	Mixed	mudstone, sandstone, some limestone	co-sedrx	Lower Cretaceous rocks, undivided
CutBank250	Ku	Ku	Mixed	mudstone, siltstone, shale, limestone, dolomite	co-sedrx	Upper Cretaceous rocks, undivided
Chot250	Ku	Ku	Mixed	mudstone, siltstone, shale, limestone, dolomite	co-sedrx	Upper and Lower Cretaceous rocks, undivided. Includes Two Medicine Fm, Virgelle Sandstone, Telegraph Creek Fm, Marias river Shale, Blackleaf Fm, Kootenai Fm, and Mount Pablo Fm.
Lima100	Kblq	Kblq	Mixed	quartzite and limestone conglomerate	co-sedrx	Little Sheep Quartzite of Beaverhead Group
Lima100	O^s	O^s	Mixed	quartzite, sandstone, conglomerate, dolomite	co-sedrx	Sedimentary rocks, undivided
Lima100	&q	&q	Mixed	sandstone w/ minor dolomite influence	co-sedrx	Quadrant Formation
Leodore100	DOs	DOs	Mixed	sandstone, dolomite, quartzite and siltstone	co-sedrx	Sedimentary rocks, undivided

Lima100	DOs	DOs	Mixed	sandstone, dolomite, quartzite and siltstone	co-sedrx	Sedmentary rocks, undivided
Dillon250	Ynl	Ynl	Mixed	sandstone, dolomitic shale	co-sedrx	Newland and LaHood Formations (Middle Proterozoic)
Lima100	Trbt	Trbt	Mixed	sandstone, mudstone, limestone	co-sedrx	Blacktail Member, informal, Renova Formation
Lima100	^s	^s	Mixed	sandstone, siltstone, dolomite	co-sedrx	Sedimentary rocks, undivided
Butte250	^s	^s	Mixed	sandstone, siltstone, dolomite	co-sedrx	Sedimentary rocks (Cambrian)
Dillon250	^u	^u	Mixed	sandstone, siltstone, dolomite	co-sedrx	Cambrian rocks, undivided (Upper and Middle Canbrian)
Lima100	Js	Js	Mixed	sedimentary rocks	co-sedrx	Sedimentary rocks, undivided
Lima100	^pf	^pf	Mixed	shale, limestone-dolomite, sandstone	co-sedrx	Park, Meagher, Wolsey and Flathead Formations
Lima100	Kf	Kf	Mixed	siltstone, mudstone, sandstone, limestone	co-sedrx	Frontier Formation
Chot250	KJ	KJ	Mixed	siltstone, mudstone, sandstone, volcaniclastics	co-sedrx	Lower Cretaceous and Jurassic rocks, undivided
Leodore100	MDtj	MDtj	Mixed	siltstone, shale, limestone,sandstone	co-sedrx	Three Forks Formation and Jefferson Formation, undivided
Lima100	MDtj	MDtj	Mixed	siltstone, shale, limestone,sandstone	co-sedrx	Three Forks Formation and Jefferson Formation, undivided
Dillon250	MDu	MDu	Mixed	siltstone, shale, limestone,sandstone	co-sedrx	Three Forks Shale and Jefferson Formation (Mississippian? and Upper and Middle Devonian), undivided
Butte250	KJs	KJs	Mixed	undivided sedimentary formations	co-sedrx	Sedimentary rocks (Cretaceous and Jurassic)
Dillon250	Km	Km	Mixed	undivided sedimentary formations	co-sedrx	Sedimentary rocks of McCartney Mountain (Cretaceous)

Dillon250	Ks	KJs	Mixed	undivided sedimentary formations	co-sedrx	Sedimentary rocks (upper and lower parts) and Blackleaf Formation, undivided (Upper and Lower Cretaceous)
Lima100	Ob	Ob	Mixed	dolomite	dolomite	Bighorn Dolomite
Leodore100	SOm	SOm	Mixed	dolomite	dolomite	Saturday Mountain Formation
MissW100	^h	^h	Mixed	dolomite	dolomite	Hasmark Formation
Chot250	Mu	Mu	Mixed	dolomite and limestone	dolomite	Upper and Lower Mississippian rocks, undivided
MissW100	Yspp	Yspp	Mixed	dolomite, argillite	dolomite/ argillite	dolomite and black laminated argillite members of the Clark Fork section
Lima100	^sr	^sr	Mixed	dolomite, calcareous siltstone, mudstone, shale and sandstone	dolomite/ co-sedrx	Snowy Range Formation
Chot250	Pz	Pz	Mixed	dolomite,limestone	dolomite/ limestone	Paleozoic rocks. includes part or all of Mississippian, Devonian, & Cambrian sequences.
Dillon250	Pp	Pp	Mixed	dolomite, limestone, chert	dolomite/ limestone/chert	Phosphoria Formation (Permian)
Leodore100	Pp	Pp	Mixed	dolomite, limestone, chert	dolomite/ limestone/chert	Phosphoria Formation
Lima100	Pp	Pp	Mixed	dolomite, limestone, chert	dolomite/ limestone/chert	Phosphoria Formation
Lima100	Ppp	Ppp	Mixed	dolomite, limestone, chert	dolomite/ limestone/chert	Phosphoria and Park City Formations
Dillon250	PMu	PMu	Mixed	dolomite, chert, mudstone	dolomite/sedrx	Permian to Mississippian rocks-Includes the Phosphoria Formation (Permian) and Quadrant Formation (Pennsylvanian and Upp
Lima100	^ppm	^ppm	Mixed	dolomite-limestone, shale	dolomite/sedrx	Pilgrim,Park, and Meagher Formations
MissW100	^rl	^rl	Mixed	interbedded dolomite and siltstone overlain by limestone and shale	dolomite/sedrx	Red Lion Formation
Lima100	ZYs	ZYs	Mixed	feldspathic sandstone	fld-sandstone	Sedimentary Rocks, undivided
Kalispell250	Qg	Qg	Mixed	glacial deposits	glacial deposits	glacial and fluvioglacial deposits
Leodore100	Qg	Qg	Mixed	glacial deposits	glacial deposits	Glacial deposits, undivided

Wall250	Qg	Qg	Mixed	glacial deposits	glacial deposits	glacial, fluvioglacial, and flood deposits
CutBank250	Qg	Qg	Mixed	glacial deposits	glacial deposits	glacial and fluvioglacial deposits
Chot250	Qg	Qg	Mixed	glacial deposits	glacial deposits	glacial deposits
Lima100	Qgl	Qgl	Mixed	glacial deposits	glacial deposits	Glacial lake deposit
MissW100	Qgl	Qgl	Mixed	glacial deposits	glacial deposits	Glacial lake deposit
Wall100	Qgl	Qgl	Mixed	glacial deposits	glacial deposits	Glacial lake deposit
Lima100	Qgm	Qgm	Mixed	glacial deposits	glacial deposits	Glacial moraine
Lima100	Qgo	Qgo	Mixed	glacial deposits	glacial deposits	Glacial outwash deposit
Hamilton100	Qgt	Qgt	Mixed	glacial deposits	glacial deposits	Glacial till
NezPerce100	Qgt	Qgt	Mixed	glacial deposits	glacial deposits	Glacial till
MissW100	Qgt	Qgt	Mixed	glacial deposits	glacial deposits	Glacial till
Wall100	Qgt	Qgt	Mixed	glacial deposits	glacial deposits	Glacial till
Dillon250	Qm	Qm	Mixed	glacial deposits	glacial deposits	Till (Pleistocene)
Dillon250	Qo	Qo	Mixed	glacial deposits	glacial deposits	Glacial outwash (Pleistocene)
Lima100	Qgr	Qgr	Mixed	gravel deposits of uncertain origin, poorly sorted	gravel deposits	Gravel
Wall250	QTg	QTg	Mixed	gravel deposits of uncertain origin, poorly sorted	gravel deposits	gravels
Lima100	QTgr	QTgr	Mixed	gravel deposits of uncertain origin, poorly sorted	gravel deposits	Gravel
Butte250	Qs	Qs	Mixed	mixed surface sedimentary deposits	gravel deposits	Surficial sedimentary deposits (Pleistocene and Holocene)
Chot250	QTog	QTog	Mixed	older alluvial gravel deposits	gravel deposits	Gravel
Dillon250	Aif	Aif	Mixed	iron-formation	iron-formation	Iron-formation (Archean)
Kalispell250	Ql	Ql	Mixed	lacustrine deposits	lacustrine deposits	lake sediments
Wall250	Ql	Ql	Mixed	lacustrine deposits	lacustrine deposits	lake sediments
Chot250	Ql	Ql	Mixed	lacustrine deposits	lacustrine deposits	lake deposits
Lima100	Qle	Qle	Mixed	lacustrine deposits	lacustrine deposits	Lake deposits and overlying eolian deposits

Lima100	Qlk	Qlk	Mixed	lacustrine deposits	lacustrine deposits	Lake deposits
Dillon250	Qs	Qs	Mixed	lacustrine deposits	lacustrine deposits	Lacustrine sand and silt (Holocene and Pleistocene)
Chot250	Tla	Tla	Mixed	lake sediments	lacustrine deposits	lake sediments
Lima100	Ml	Ml	Mixed	limestone	limestone	Lodgepole Limestone
Lima100	Mmc	Mmc	Mixed	limestone	limestone	Mission Canyon Limestone
Lima100	Msp	Msp	Mixed	limestone	limestone	Scott Peak Formation
Lima100	Ttr	Ttrav	Mixed	limestone	limestone	Travertine; lake or hot-spring deposits
Wall250	Cl	Cl	Mixed	limestone and dolomite	limestone	limestone and dolomite
Kalispell250	Mu	Mu	Mixed	limestone and minor mixed seds	limestone	Mississippian sedimentary rocks, undivided
Lima100	Mmd	Mmd	Mixed	limestone, chert	limestone	Middle Canyon Formation
Lima100	Mtd	Mtd	Mixed	limestone, chert, sandstone	limestone	Tendoy Group
Lima100	Mm	Mm	Mixed	limestone, dolomitic limestone	limestone	Madison Group, undivided
CutBank250	Mm	Mm	Mixed	limestone, dolomitic limestone	limestone	Madison Group
Lima100	Ms	Ms	Mixed	limestone, some sandstone	limestone	Sedimentary rocks, undivided
Lima100	Tj	Tj	Mixed	silicified limestone	limestone	Jasperoid
Lima100	&Msr	&Msr	Mixed	limestone and calcareous sedimentary rocks	limestone/sedrx	Snowcrest Range Group or Snowcrest Range Formation
Dillon250	&Mu	&Mu	Mixed	limestone and calcareous sedimentary rocks	limestone/sedrx	Snowcrest Range Group (Lower Pennsylvanian Upper Mississippian) and Madison Group (Upper and Lower Mississippian), undiv
Lima100	Kbdc	Kbdc	Mixed	limestone and quartzite conglomerates	limestone/sedrx	Divide Creek comglomerate unit of Beaverhead Group, McKnight Canyon
Lima100	TKbl	TKbl	Mixed	limestone conglomerate	limestone/sedrx	Limestone conglomerate of the Beaverhead Group
Lima100	TKbr	TKbr	Mixed	limestone conglomerate	limestone/sedrx	Red Butte Conglomerate, Beaverhead Group

Lima100	Kblc	Kblc	Mixed	limestone conglomerate	limestone/sedrx	Lima conglomerate of the Beaverhead Group
Lima100	Kbmc	Kbmc	Mixed	limestone conglomerate	limestone/sedrx	Quartzite conglomerate unit of Beaverhead Group, McKnight Canyon
Lima100	Kbml	Kbml	Mixed	limestone conglomerate	limestone/sedrx	Lower limestone conglomerate unit of Beaverhead Group, McKnight Canyon
Lima100	Kbmo	Kbmo	Mixed	limestone conglomerate	limestone/sedrx	Oncoid limestone unit of Beaverhead Group, McKnight Canyon
MissW100	^sh	^sh	Mixed	limestone, calcareous siltstone, shale, sandstone	limestone/sedrx	Silver Hill Formation
Dillon250	J@u	J@u	Mixed	limestone, calcareous siltstone, shale, sandstone	limestone/sedrx	Jurassic and Triassic rocks
Lima100	Mlm	Mlm	Mixed	limestone, calcareous siltstone, shale, sandstone	limestone/sedrx	Lombard Formation, Kibbey Formation, and Madison Group
Lima100	QTlt	QTlt	Mixed	limestone, calcareous tufa	limestone/sedrx	Limestone and calcareous tufa
Wall250	Cs	Cs	Mixed	limestone, dolomite, mudstone	limestone/sedrx	Cambrian sedimentary rocks, undivided
Kalispell250	DCu	DCu	Mixed	limestone, dolomite, mudstone	limestone/sedrx	Devonian and Middle Cambrian sedimentary rocks, undivided
Kalispell250	Du	Du	Mixed	limestone, dolomite, mudstone	limestone/sedrx	Devonian sedimentary rocks, undivided
CutBank250	Du	Du	Mixed	limestone, dolomite, mudstone	limestone/sedrx	Three Forks, Jefferson, and Maywood Formations, undivided
Chot250	Du	Du	Mixed	limestone, dolomite, mudstone	limestone/sedrx	Upper and Middle Devonian rocks, undivided
Lima100	Dtm	Dtm	Mixed	limestone, dolomite, sandstone, siltstone	limestone/sedrx	Three Forks, Jefferson, Maywood? Formations, undivided
Kalispell250	Cu	Cu	Mixed	limestone, mudstone	limestone/sedrx	Middle Cambrian sedimentary rocks, undivided
CutBank250	Cu	Cu	Mixed	limestone, mudstone	limestone/sedrx	Upper and Middle Cambrian rocks, undivided
Chot250	Cu	Cu	Mixed	limestone, mudstone	limestone/sedrx	Cambrian rocks, undivided

Lima100	KJke	KJke	Mixed	limestone, sandstone, calcareous siltstone	limestone/sedrx	Kootenai Formation and Ellis Group, undivided
CutBank250	KJu	KJu	Mixed	limestone, sandstone, calcareous siltstone	limestone/sedrx	Mount Pablo Formation, Morrison Formation, and Ellis Group, undivided
Dillon250	Kk	Kk	Mixed	limestone, sandstone, siltstone, mudstone	limestone/sedrx	Kootenai Formation (Lower Cretaceous)
Lima100	Kk	Kk	Mixed	limestone, sandstone, siltstone, mudstone	limestone/sedrx	Kootenai Formation
Leodore100	&Ms	&Ms	Mixed	limestone, siltstone, mudstone	limestone/sedrx	Sedimentary rocks, undivided
Lima100	Mrc	Mrc	Mixed	limestone, siltstone, mudstone	limestone/sedrx	Railroad Canyon Formation
Lima100	Mrm	Mrm	Mixed	limestone, siltstone, mudstone	limestone/sedrx	Railroad Canyon through McGowan Creek Formations, undivided
Lima100	QTl	QTl	Mixed	mature soil pre-glacial	mature soil	Ledford Pass Soil
Butte250	md	md	Mixed	mine dumps	mine dumps	Tailings, mine dumps, and slag piles (Holocene)
Chot250	Ktm	Ktm	Mixed	mudstone, sandstone	mudstone/ sandstone	Two Medicine Formation
Chot250	Kvt	Kvt	Mixed	mudstone, sandstone	mudstone/ sandstone	Virgelle Sandstone and Telegraph Creek Formation
Chot250	Ksmr	Ksmr	Mixed	mudstone, sandstone, volcanics	mudstone/ sandstone	St. Mary River Formation
Leodore100	Os	Os	Mixed	quartzite, feldspathic sandstone	quartzite/ fldsandstone	Sedimentary rocks, undivided
Chot250	Kh	Kh	Mixed	sandstone, mudstone	sandstone/ mudstone	Horsethief Sandstone and Bearpaw-Horsethief transition unit
Lima100	Tsc	Tsc	Mixed	sandstone, siltstone, conglomerate	sandstone/ mudstone	Sixmile Creek Formation
Leodore100	Ts	Ts	Mixed	tuffaceous sandstone, siltstone, shale	sandstone/ mudstone	Sediment or sedimentary rock, undivided

Chot250	Ktv	Ktv	Mixed	volcanic sandstones, mudstones	sandstone/ mudstone	volcanic-rich sedimentary rocks, flows, and tuffs
Butte250	Ts	Ts	Mixed	fan deposits; sandstones, conglomerates	seddep	Sedimentary deposits and rocks (Eocene through Pliocene)
Lima100	Tsca	Tsca	Mixed	tephra, silt, sand, gravel	seddep	Anderson Ranch Member, informal, Sixmile Creek Formation
Hamilton100	Tgc	Tgc	Mixed	tertiary sedimentary deposits	seddep	Gravel and clay
NezPerce100	Tgc	Tgc	Mixed	tertiary sedimentary deposits	seddep	Gravel and clay
MissW100	Tgc	Tgc	Mixed	tertiary sedimentary deposits	seddep	Gravel and clay
Wall100	Tgc	Tgc	Mixed	tertiary sedimentary deposits	seddep	Gravel and clay
Lima100	Tgr	Tgr	Mixed	tertiary sedimentary deposits	seddep	Gravel
Lima100	TKgr	TKgr	Mixed	tertiary sedimentary deposits	seddep	Gravel and conglomerate of uncertain affinities
MissW100	Tsf	Tsf	Mixed	unconsolidated material	seddep	Fluvial sedimentary deposits
Leodore100	QTs	QTs	Mixed	undivided sedimentary formations	seddep	Sediment, undivided
Dillon250	Tbz	Tbz	Mixed	valley-fill deposits	seddep	Bozeman Group and related valley-fill deposits, undivided (Pliocene to Eocene)
Lima100	Tos	Tos	Mixed	organic-rich shale	shale	Organic-rich shale
Wall250	Csq	Csq	Mixed	shale and quartzite	shale	shale and quartzite
Lima100	Kfb	Kfb	Mixed	siltstone, mudstone, sandstone, volcaniclastics	siltstone/ mudstone	Frontier and Blackleaf Formations
Lima100	QTba	QTba	Mixed	basaltic volcanic	volcanic	Basaltic volcanic rocks
Lima100	Tcbt	Tcbt	Mixed	biotite-bearing tuff	volcanic	Biotite-bearing tuff of Challis Volcanic Group (Eocene)
MissW100	Ttr	Ttr	Mixed	rhyolite tuff	volcanic	Rhyolite tuff
Lima100	Trvp	Trvp	Mixed	rhyolitic volcanic rocks	volcanic	Rhyolitic pyroclastic rocks of Dillon Volcanics Member, informal, Renova Formation

Lima100	Tcqt	Tcqt	Mixed	tuff	volcanic	Quartzite-bearing tuff of Challis Volcanic Group (Eocene)
Lima100	Tct	Tct	Mixed	tuff	volcanic	Tuffs, chiefly quartz and sanidine-bearing
Lima100	Tcts	Tcts	Mixed	tuff	volcanic	Tuffs, undivided, and sandstone of Challis Volcanic Group (Eocene)
Dillon250	Kem	Kem	Mixed	tuff, breccia, flows	volcanic	Elkhorn Mountain Volcanics (Late Cretaceous)
Butte250	Kem	Kem	Mixed	tuff, breccia, flows	volcanic	Elkhorn Mountains Volcanics (Cretaceous)
Lima100	Trw	Trw	Mixed	tuffaceous sandstone, bentonite clay	volcanic	White Hills Member, informal, Renova Formation
Lima100	Tts	Tts	Mixed	tuffaceous shale	volcanic	Tuffaceous shale
Lima100	Trc	Trc	Mixed	tuffacious mudstone; sandstone, volc. Ash	volcanic	Cook Ranch Member, informal, Renova Formation
Lima100	Trsd	Trsd	Mixed	tuffacious sandstone, mudstone, conglom.	volcanic	Sage Creek and Dell Members, informal, Renova Formation
Dillon250	Tc	Tc	Mixed	volcanic rocks	volcanic	Challis Volcanics (Eocene)
Leodore100	Tcv	Tcv	Mixed	volcanic rocks	volcanic	Challis Volcanics
Lima100	Tcv	Tcv	Mixed	volcanic rocks	volcanic	Challis Volcanics
Butte250	TKab	TKab	Mixed	volcanic rocks	volcanic	Andesitic and basaltic volcanic rocks (Tertiary or Cretaceous)
Butte250	Tlc	Tlc	Mixed	volcanic rocks	volcanic	Lowland Creek Volcanics (Eocene)
Leodore100	Tmlv	Tmlv	Mixed	volcanic rocks	volcanic	Medicine Lodge Volcanics
Lima100	Tre	Tre	Mixed	volcanic rocks	volcanic	Renova Formation
Hamilton100	Tv	Tv	Mixed	volcanic rocks	volcanic	Volcanic rocks, undivided
Wall250	Tv	Tv	Mixed	volcanic rocks	volcanic	volcanic rocks
NezPerce100	Tv	Tv	Mixed	volcanic rocks	volcanic	Volcanic rocks, undivided
Chot250	Tva	Tva	Mixed	volcanic rocks	volcanic	Adel Mountain volcanics of Lyons (1944)
MissW100	Tvf	Tvf	Mixed	volcanic rocks	volcanic	Felsic volcanic rocks
Dillon250	Tvu	Tvu	Mixed	volcanic rocks	volcanic	Volcanic rocks (Tertiary)
Lima100	Kbl	Kbl	Mixed	volcaniclastic mudstones, clays, siltstones	volcanic	Blackleaf Formation