# Lithology-Based Landscape Classification for the SAMI Aquatic Effects Assessment

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## *Introduction*

The Southern Appalachian Mountain Initiative has undertaken an aquatic effects assessment that will provide information on the current and prospective acid-base status of stream waters in the eight-state SAMI region. As part of this effort, watershed acidification modeling will be conducted for approximately 170 streams for which sufficient data are available for model input. Although this work will provide a general perspective on the regional effects of acidic deposition, the specific analysis will apply to individual streams. In order to provide a basis for extrapolation to the SAMI region it is necessary to develop and evaluate a landscape classification scheme to account for observed spatial variation in the current acid-base status of streams in the region.

Previous work showed that watershed bedrock is a primary determinant of stream water acid neutralization capacity (ANC) and response to acidic deposition in the southern Appalachian mountain region (Lynch and Dise, 1985, Bricker and Rice, 1989, Webb et al., 1994, Webb, 1999, and Webb et al., 2001). Bulger et al. (2000) demonstrated that classification of landscape by bedrock type can provide a basis for regionalizing the results of watershed acidification modeling in western Virginia. These observations, plus the availability of recently developed geologic map coverage for most of the SAMI region, suggested that a useful landscape classification scheme could be developed based on the relationship between lithology and stream water ANC.

A first step toward development of a lithology-based landscape classification to account for variation in the acid-base status of streams in the SAMI region involved geographic extension and analysis of a three-unit classification scheme represented by the acid-sensitivity map developed by Peper et al. (1995) for use in the Southern Appalachian Assessment (SAA; SAMAB, 1996). Based on this initial work, a decision was made to proceed with development of a more-detailed, five-unit classification scheme. This report presents the results of that additional effort.

## *Data Sources*

The stream water composition data available for development and evaluation of a landscape classification scheme for the SAMI region were compiled in support of the SAMI aquatic effects assessment. High-quality analyses were assembled for stream waters associated with forested mountain watersheds in both the SAMI region and in adjacent areas within physiographic provinces represented in the SAMI region. These data were obtained from a number of national and regional databases, including the National Stream Survey, the Environmental Monitoring and Assessment Project, the Virginia Trout Stream Sensitivity Study, and a number of localized studies coordinated by the National Park Service, the USDA Forest

Service, and the Tennessee Valley Authority. For the present analysis, the available stream water data were screened to only include sampling sites for which complete geologic map coverage is available for the watershed. The total number of sampling sites used in the analysis was 999. Figure 1 indicates the distribution of all the available sites in relation to the SAMI region.

Stream water ANC served as the primary criterion variable for evaluation of the landscape classification scheme. Consistent with other components of the SAMI aquatic effects assessment, the ANC values referenced in the present report were calculated for each of the study streams as the difference in the sums of base cations ($Ca^{2+}$, $Mg^{2+}$, $Na^{+}$, and $K^{+}$) and strong-acid anions ($SO_4^{2-}$, $NO_3^{-}$, and $Cl^{-}$) expressed in units of µeq/L. A single ANC value was associated with each sample stream. In cases where multiple sample values were available, samples most nearly representing the spring of 1995 were selected.

The geologic map coverage that served as the basis for the landscape classification was provided by the Eastern Mineral Resources Team of the USGS, which has aggregated map units from available state geologic maps (1:500,000 scale or better) to develop uniform multistate lithologic maps (personal communication, Bruce Johnson, USGS, Reston, VA, 2000). This coverage has been developed for all of the SAMI states except for South Carolina, for which work is in progress (Figure 2). As described below, the 59 lithologic units represented in this regional coverage for the SAMI study area were further aggregated for the present five-unit landscape classification scheme.

A geographic information system was used to calculate the percentage distribution of each of the USGS lithologic map units and the derivative landscape classes in each of the study watersheds. Watershed boundaries were determined for this purpose by analysis of Digital Elevation Model data and by manual digitizing.

## *Classification Method*

The combination of the USGS lithologic map units to create the five-unit landscape classification generally based on composition and weathering properties of the primary rock type associated with each lithologic map unit. These units and examples of included rock types are:

- Siliceous: sandstone, quartzite
- Argillaceous: shale, siltstone
- Felsic: granite, gneiss
- Mafic: basalt, anorthosite
- Carbonate: limestone, dolomite

Figure 3 presents the general scheme used to classify the non-carbonate lithologic units according to the properties expected to determine the ANC of associated stream waters. Note that lithologic map units with primary rock types defined by structure rather than composition were classified based on secondary rock type or state-by-state formation descriptions. Examples of lithologic map units in this category include: conglomerate, metasedimentary rock, breccias, and schist.

A map of the resulting five-unit landscape classification scheme for the SAMI region is provided in Figure 4. Appendix 1 indicates the assignment of individual lithologic units to the five units.

## *Evaluation of the Landscape Classification Scheme*

Although important information is provided by other stream water solutes, ANC concentration provides the best single criterion for evaluation of the landscape classification scheme. ANC is both a measure of current acid-base status and a product of watershed processes that determine the presence of acidic and basic constituents in solution. We can expect future response to acidic deposition to differ among streams with different ANC levels. ANC has thus served as a primary variable for stratifying streams to be modeled for the SAMI aquatic effects assessment.

Four ANC ranges were defined for acidification modeling:

| | |
|---|---|
| ANC < 0 μeq/L | acidic |
| ANC 0 to < 20 μeq/L | highly sensitive to chronic and episodic acidification |
| ANC 20 to < 50 μeq/L | sensitive to chronic and episodic acidification |
| ANC 50 to 150 μeq/L | may be sensitive to episodic acidification resulting in low ANC values at current and/or likely future deposition levels |
| ANC > 150 μeq/L | insensitive to acidic deposition and not included in the modeling and assessment domain |

The five-unit lithology-based landscape classification scheme developed for the SAMI region was examined in relation to the above ANC ranges.

Figure 5 presents cumulative frequency distributions (CDFs) for the ANC of water quality sampling sites associated with single landscape classes (n = 487). Because there is considerable overlap in ANC values among the classes, it is evident that the classification scheme does not provide a good basis for predicting the ANC of individual streams. However, given the general separation in ANC distributions among the classes in the ANC range (<150 μeq/L) included within the SAMI modeling domain, it evident that the classification scheme will serve to indicate areas with high percentages of low-ANC streams, as well as areas without low-ANC streams.

As indicated in Figure 6 and Table 1, almost all of the acidic streams (ANC <0 μeq/L) and most of the highly sensitive streams (ANC 0 to <20 μeq/L) are associated with the siliceous landscape class. All of the streams in the sensitive class (ANC 20 to <50 μeq/L) are associated with the siliceous, felsic, and argillaceous classes. All of the streams associated with the mafic and carbonate classes are relatively insensitive (ANC ≥50 μeq/L). This information can be used to indicate the geographic distribution of acidic and sensitive streams throughout the SAMI region.

An additional issue concerns the discrimination between the felsic and argillaceous landscape classes. Given that the ANC distributions are similar, it might seem reasonable to represent these as a single class. However, these classes are different with respect to important acid-base properties that determine differences in response to acidic deposition. Examination of detailed data for a number of Virginia watersheds associated with these classes indicates differences in both base-cation availability and sulfur retention between these landscape types (Webb, 1999). Streams associated with felsic landscape have low base-cation concentrations and low sulfate concentrations. In contrast, streams associated with argillaceous landscape have both relatively higher base-cation concentrations and relatively higher sulfate concentrations. Although ANC, which is determined by the difference in base-cations and acid-anions (such as sulfate), is about the same for streams associated with each landscape type, this is a coincidence that may not extend to future responses to acidic deposition.

## *Discussion*

Several source of uncertainty affect the effort to correlate ANC with regional lithology. These include uncertainties associated with the water quality data, the delineation of watershed boundaries, past and present landuse, and geologic mapping. The latter may be the most problematic.

A major problem with the presently available geologic mapping is unreliable identification of carbonate rock distribution. As clearly indicated in the plotted CDFs, a percentage of the streams associated with even the siliceous (most-acidic) landscape class have very high ANC. This suggests the presence of unmapped, but chemically significant, carbonate rock inclusions in geologic formations that are primarily noncarbonate. In many cases carbonate rock types are indicated as secondary lithologies in descriptions of non-carbonate formations. The presence of these secondary lithologies is geographically variable and efforts to account for their effect in the landscape classification schemes were not successful. This problem, and perhaps other mapping problems, limits the use of the lithology-based classification schemes for prediction of ANC for particular streams.

However, as demonstrated, the described lithology-based landscape classification scheme does serve to indicate the geographic distribution of acidic and sensitive streams throughout the SAMI region. This will be useful for characterizing both the current and projected future acid-base status of streams within the SAMI region.

## *Acknowledgement*

A number of geologist with regional expertise provided valuable assistance and advice concerning development of the classification scheme. These include Owen Bricker, Bruce Johnson, Julia Mueller, John Peper, and Karen Rice, all with the U.S. Geological Survey, and Tom Gathright, III, with the Virginia Division of Mineral Resources. Their contribution to the effort is greatly appreciated.

## *Citations*


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**Table 1 - Distribution of SAMI region sites grouped by lithology-based landscape class in relation to ANC criteria (n=487)**

| ANC (µeq/L) | Siliceous | Argillaceous | Felsic | Mafic | Carbonate |
|---|---|---|---|---|---|
| <0 | 15 | 1 | 0 | 0 | 0 |
| 0 to <20 | 14 | 6 | 4 | 0 | 0 |
| 20 to <50 | 18 | 11 | 17 | 0 | 0 |
| 50 to <150 | 17 | 36 | 38 | 58 | 9 |
| >150 | 36 | 46 | 42 | 42 | 91 |

[1]The distributions include streams associated with single landscape classes

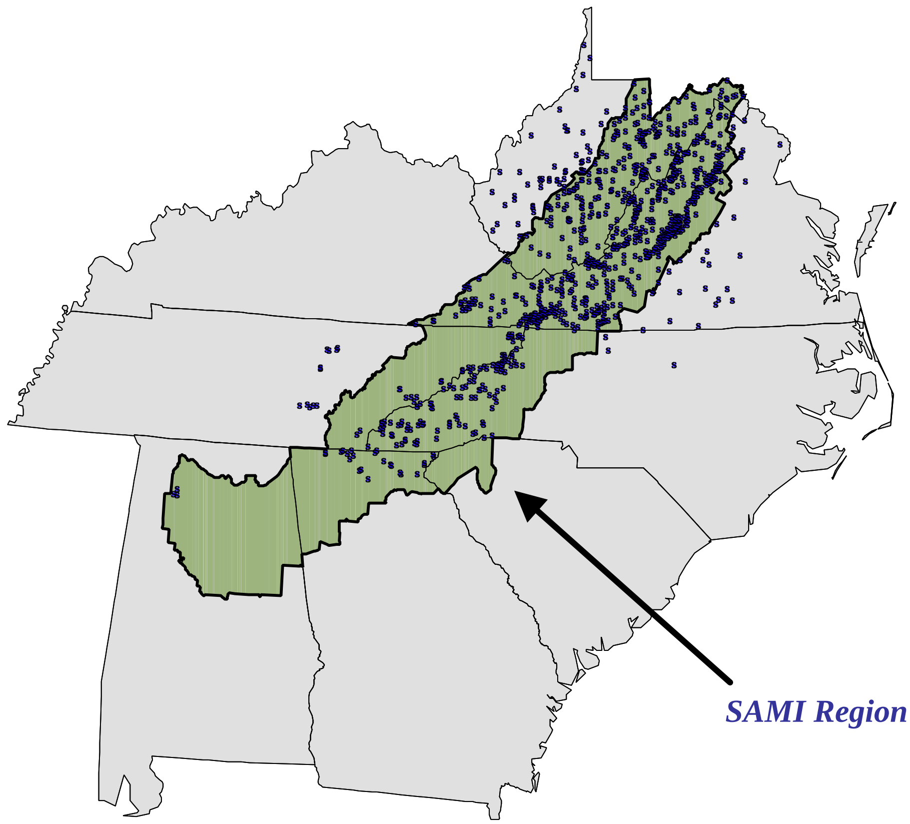


**Figure 1:** *Distribution of water quality sampling sites available for evaluation of landscape classification in the SAMI region (n = 999).*

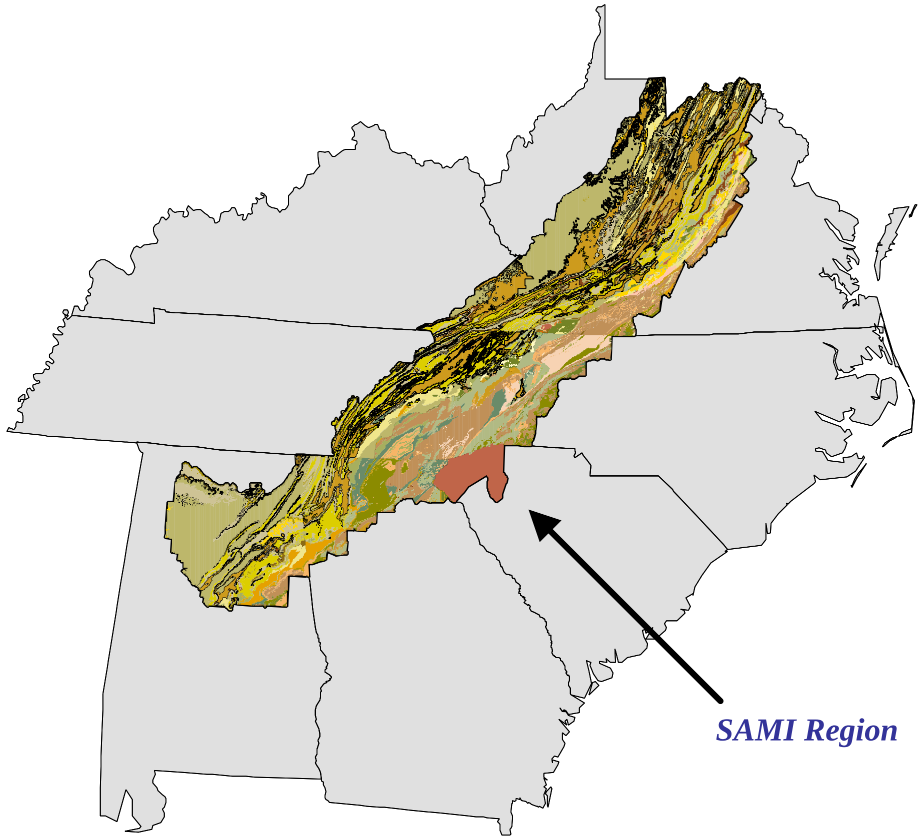


Figure 2: *USGS Lithologic Map Units for SAMI Region. 60 lithologic units aggregated from state geologic maps (minimum map scale: 1:500,000.*

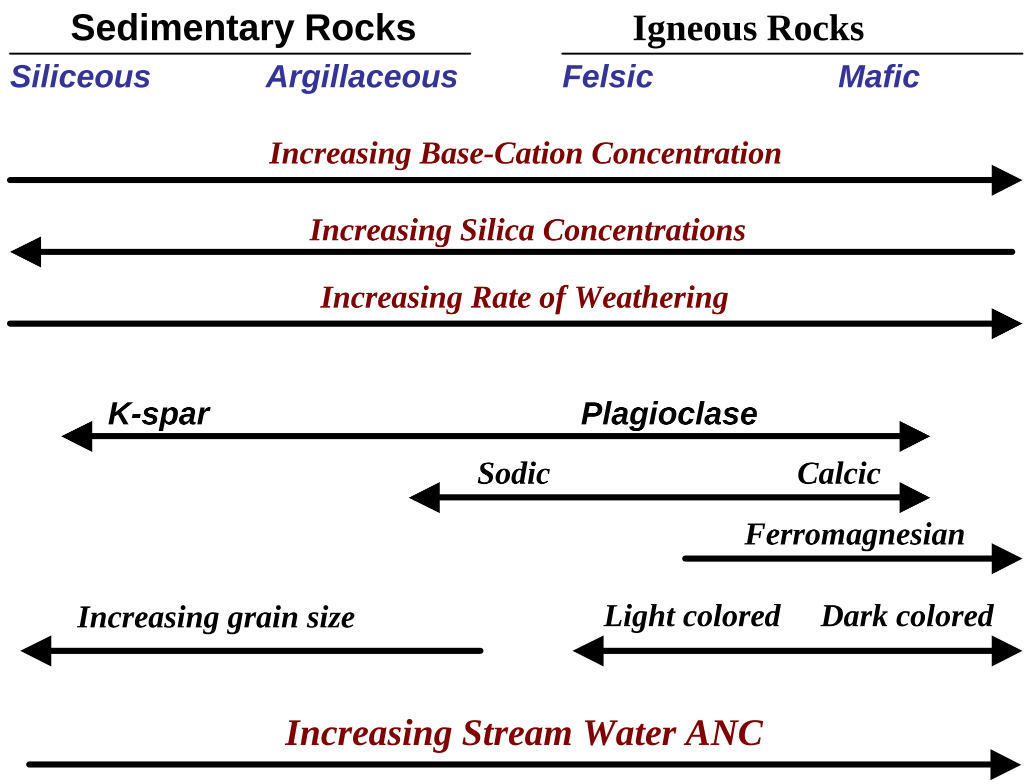


**Figure 3:** *Conceptual scheme for lithologic classification.*

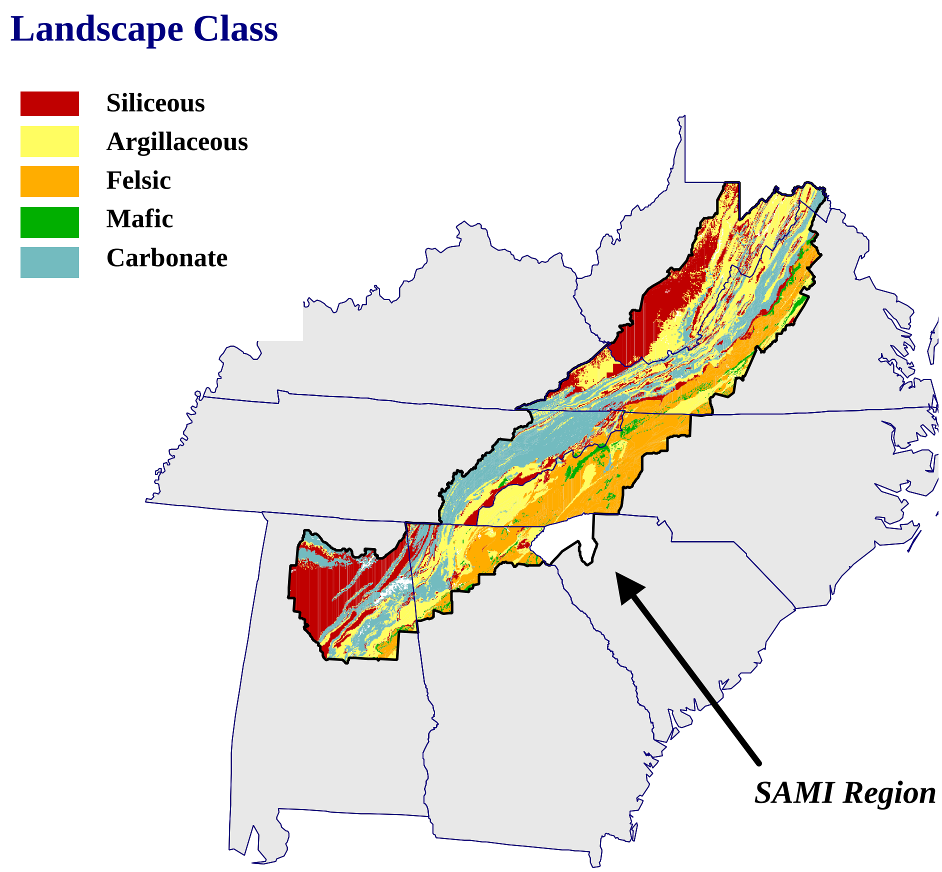


**Figure 4:** *Acid-Base Response Classification for SAMI Region*

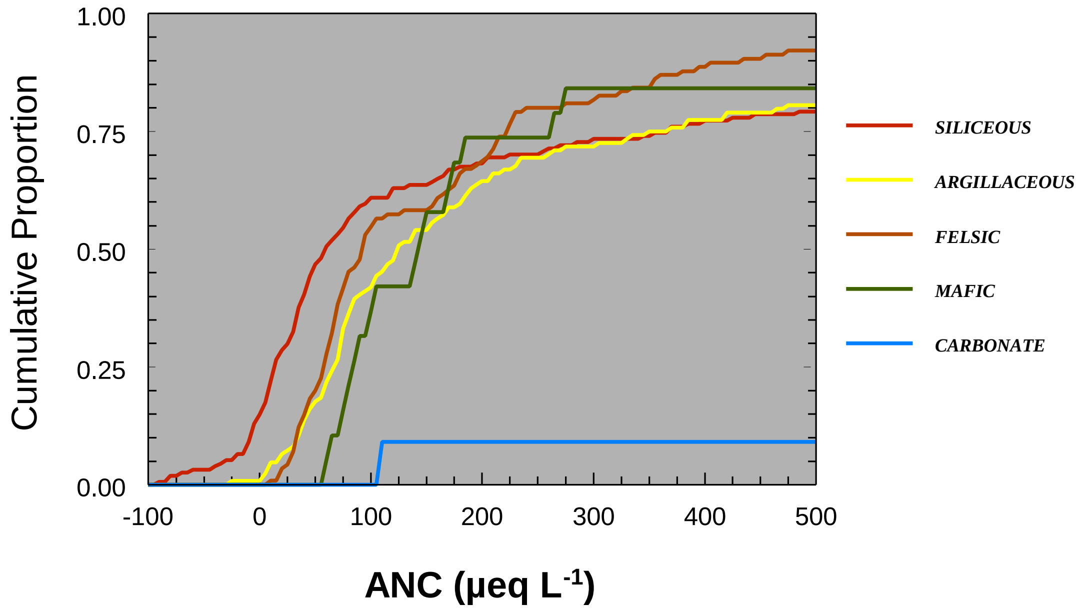


*Figure 5: ANC Distribution for SAMI region sites grouped by acid-base response class. All sites represent single landscape classes (n = 487).*

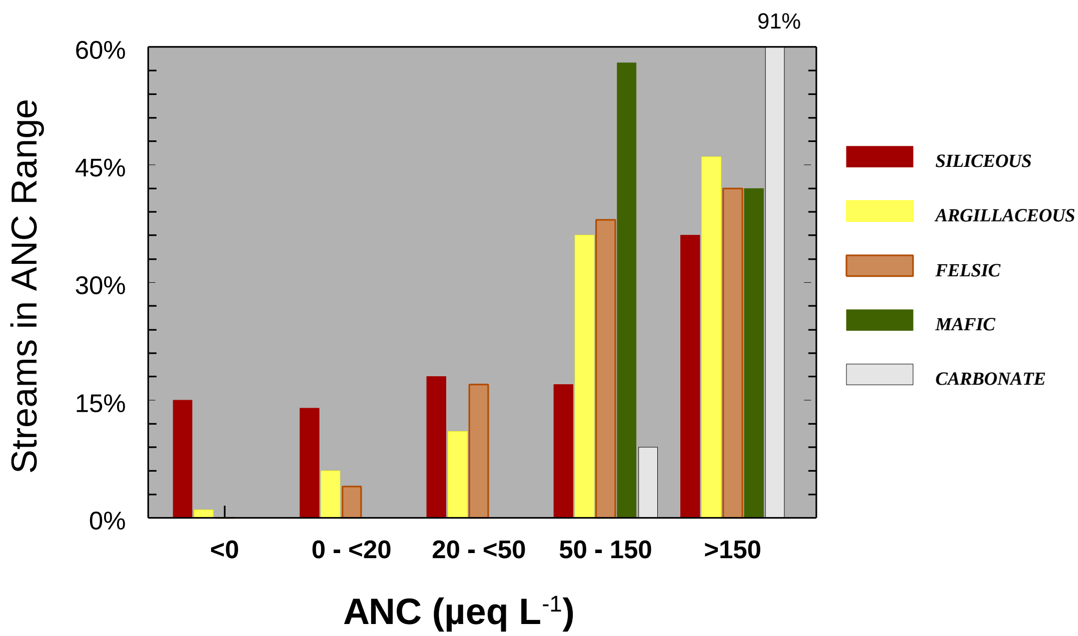


**Figure 6:** *Distribution of SAMI region sites grouped by acid-base response class in relation to ANC criteria. All sites represent single landscape classes (n – 487).*

## *Appendix I*

# *SAMI Region Lithology-Based Landscape Classification Scheme*

| CLASS | PRIMARY LITHOLOGY | OTHER CLASSIFICATION INFORMATION |
|---|---|---|
| | | |
| Argillaceous | black shale | |
| Argillaceous | claystone | |
| Argillaceous | conglomerate | graywacke |
| Argillaceous | conglomerate | mudstone |
| Argillaceous | conglomerate | shale |
| Argillaceous | graywacke | |
| Argillaceous | meta-argillite | |
| Argillaceous | metasedimentary rock | |
| Argillaceous | metasedimentary rock | graywacke |
| Argillaceous | metasedimentary rock | meta-argillite |
| Argillaceous | metasedimentary rock | mica schist |
| Argillaceous | metasedimentary rock | phyllite |
| Argillaceous | mudstone | |
| Argillaceous | phyllite | |
| Argillaceous | schist | |
| Argillaceous | sedimentary breccia | |
| Argillaceous | sedimentary breccia | mudstone clasts |
| Argillaceous | shale | |
| Argillaceous | siltstone | |
| Argillaceous | slate | |
| | | |
| | | |

| CLASS | PRIMARY LITHOLOGY | OTHER CLASSIFICATION INFORMATION |
|---|---|---|
| | | |
| Carbonate | dolomite (dolostone) | |
| Carbonate | dolostone (dolomite) | |
| Carbonate | limestone | |
| Carbonate | marble | |
| | | |
| Felsic | alaskite | |
| Felsic | augen gneiss | |
| Felsic | biotite gneiss | |
| Felsic | conglomerate | arkose |
| Felsic | dacite | |
| Felsic | felsic gneiss | |
| Felsic | felsic metavolcanic rock | |
| Felsic | felsic volcanic rock | |
| Felsic | gneiss | |
| Felsic | granite | |
| Felsic | granitic gneiss | |
| Felsic | granodiorite | |
| Felsic | granulite | |
| Felsic | mica schist | |
| Felsic | migmatite | granitic gneiss |
| Felsic | mylonite | gneiss |
| Felsic | orthogneiss | |
| Felsic | quartz diorite | |
| Felsic | quartz monzonite | |
| Felsic | rhyolite | |
| Felsic | sedimentary breccia | arkose |
| Felsic | syenite | |

| CLASS | PRIMARY LITHOLOGY | OTHER CLASSIFICATION INFORMATION |
|---|---|---|
| | | |
| Mafic | amphibole schist | |
| Mafic | amphibolite | |
| Mafic | anorthosite | |
| Mafic | basalt | |
| Mafic | diabase | |
| Mafic | diorite | |
| Mafic | dunite | |
| Mafic | gabbro | |
| Mafic | greenstone | |
| Mafic | mafic gneiss | |
| Mafic | mafic metavolcanic rock | |
| Mafic | meta-basalt | |
| Mafic | metavolcanic rock | |
| Mafic | norite | |
| Mafic | peridotite | |
| Mafic | schist | actinolite schist |
| Mafic | ultramafic intrusive rock | |
| | | |
| Siliceous | arenite | |
| Siliceous | chert | |
| Siliceous | conglomerate | |
| Siliceous | conglomerate | sandstone |
| Siliceous | metasandstone | |
| Siliceous | orthoquartzite | |
| Siliceous | quartzite | |
| Siliceous | sandstone | |