GEOLOGIC CONTROLS ON TREE NUTRITION AND FOREST HEALTH IN THE INLAND NORTHWEST

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Abstract: The Intermountain Forest Tree Nutrition Cooperative (IFTNC) has been studying forest growth and health throughout the Inland Northwest since the early 1980's. Early fertilization work indicated that while nitrogen (N) was important to tree growth, other elements were important to tree physiological processes and forest health. In particular, potassium (K) appeared to alleviate tree susceptibility to fungal disease and insect attack. To further test this theory, the IFTNC designed an N-and-K fertilization-rate experiment encompassing three vegetation series (an expression of climatic regimes) and four rock types (basalt, granite, glacial deposit, and metasedimentary rock). Of the 36 sites required by the experimental design, only 31 were established because of difficulty in finding suitable, healthy and intact forest stands on metasedimentary rock types. Further examination of the effect of rock on forest growth and health was deemed necessary. With the exception of N and sometimes sulfur, all elements essential for plant growth originate from rock. Rock samples were collected from a variety of IFTNC research sites and analyzed for major and selected trace elements. While this allowed for quantitative comparison of individual elements such as K, an assessment of overall elemental availability to plants via rock weathering was also desired. A modification of Reiche's (1943) weathering potential index (WPI) was selected to evaluate rock contribution to plant-available nutrient pools. Comparison of WPI calculations across 30 IFTNC research sites showed that while basalts and granites had fairly narrow WPI ranges, metasedimentary rocks varied widely. Most of the metasedimentary rocks underlying Inland Northwest forests belong to the Belt Supergroup, which encompasses several formations and a wide variety of lithologies. In order to better categorize the geochemical variation of metasedimentary and other rocks, WPI values were calculated for a wide variety of samples collected by Idaho Geological Survey and U.S. Geological Survey personnel throughout northern Idaho. The WPI values were tabulated by lithology and formation and analyzed for differences that might help explain variation in forest nutritional status.

Introduction

The Intermountain Forest Tree Nutrition Cooperative (IFTNC) was established in the late 1970's to test the effects of fertilization on forest growth. Early work with nitrogen (N) fertilizer indicated that high rates of N could increase forest growth and yield, but in some cases could also increase tree mortality (Mika et al., 1993; Moore et al., 1994; Mandzak and Moore, 1994). Where tree mortality occurred, it often coincided precisely with square plot treatment areas, in a phenomenon which came to be known as "square death." Causes of mortality included root disease and insect attack. In some cases no obvious mortality agent was detected, but less obvious changes in physiological processes were suspected. Subsequent research indicated that forest potassium (K) status, as measured by foliar K concentration, was an important predictor of forest health status. Where high rates of N-fertilizer were applied to high-K trees, high growth rates resulted. Where high rates of N-fertilizer were applied to low-K trees, mortality resulted.

These early findings of the IFTNC led to the development of a Forest Health Study, initiated in 1994. Because parent rock is such an important source of ecosystem K, rock type was included as a stratification variable in this study, along with potential vegetation series, which is also known to affect site productivity (Moore et al., 1991). The resulting experimental design called for three study sites to be established in each of four rock type and three vegetation series categories (Table 1). In order to be selected for study, sites supporting live, healthy, second-rotation crops of forest trees were required. After three years of site visits to over 100 candidate stands, only one suitable study stand was found to represent the metasedimentary rock type category on drier (Douglas-fir and grand fir) vegetation series. Such sites did not host the live, healthy forest stands required for the study. Because of this apparent inability to support healthy forest stands, metasedimentary rocks were perceived to be 'bad rocks' from a forest nutrition point of view. Even more significantly, this finding called attention to the importance of rock as a factor affecting forest health conditions and nutrient status in the inland northwestern United States. Several subsequent studies and reviews have further emphasized the important effect of parent rock, and the negative effect of metasedimentary rock, on forest health conditions (Moore and Mika, 1997; Moore et al., 2000; Shen et al., 2000; Moore et al., 2003; Garrison-Johnston et al., 2003).

Table 1. Experimental design for IFTNC Forest Health study. Design called for three sites in each category. The number in parenthesis indicates the actual number of sites found in each category. Dry site types on metamorphic rock types were not found to support successful stands for inclusion in the study.

Rock Type/Veg. Series	Douglas-fir	Grand Fir	Cedar/Hemlock
Granite	3 (3)	3 (3)	3 (3)
Basalt	3 (3)	3 (3)	3 (3)
Metamorphic	3 (**0**)	3 (**1**)	3 (3)
Mixed	3 (3)	3 (3)	3 (3)

Geology of the inland northwest, particularly the north Idaho region, is dominated by a group of Precambrian metasedimentary rocks known as the Belt Supergroup. The Belt Supergroup is comprised of a series of formations, including the Wallace, Prichard, Burke, Revett, St. Regis, Striped Peak, and Libby (Harrison and Campbell, 1963). The Wallace formation is further subdivided into upper and lower members while the Burke, Revett and St. Regis formations are often grouped together and called the Ravalli group. The formal nomenclature of Belt rocks is based on their stratigraphy, or the order in which they were laid down during the original process of sedimentation. Almost all of the Belt rocks underwent low-level metamorphism following sedimentation, such that their original protolith (parent rock) is still identifiable. The lithology of Belt rocks reflects this metamorphism, such that all formations contain argillite, siltite and/or quartzite, which are metamorphosed claystone, siltstone and sandstone, respectively. The dominant lithologies of the Belt formations include quartzite for the Revett and portions of the Striped Peak, layered gray siltite and argillite for the Prichard and portions of the upper Wallace and Striped Peak, layered green or red siltite and argillite for the Burke, St. Regis and Libby formations, carbonate-bearing siltite and quartzite for the lower

Wallace and portions of the upper Wallace and Striped Peak, and dolomite for portions of the Striped Peak (Munts and Idaho Geological Survey, 2000). Other lithologies common to the area include glacial deposits, Columbia River flood basalts, and various intrusive rocks.

Because of the importance of K in forest health assessment, rocks underlying a variety of forested sites were examined in an effort to correlate rock K status with health and nutrition trends. However, it soon became evident that other rock characteristics were equally important in assessing the geologic contribution to forest nutritional conditions. Rock weathering characteristics appear to be at least as important as rock chemical composition in determining soil textural and chemical characteristics. Forest nutrition has become an increasingly important component of the management of public, private and industrial forest lands in north Idaho and the inland northwest. Third-party certification criteria include examination of forest nutrient management practices on industrial forest lands, while nutrient management has become the subject of increased litigation on public forest lands. Because of this increased public focus on forest nutrition, an improved understanding of the mechanisms underlying rock type's effect on forest nutrition is becoming increasingly important. As part of ongoing mapping efforts, Idaho Geological Survey (IGS) and United States Geological Survey (USGS) personnel have been collecting rock samples throughout north Idaho since 1990. In an effort to help determine whether geochemistry might help to explain the perceived variation in forest nutrient conditions by rock type, these data were compiled for analysis of weathering potential.

Methodology

Geochemical data from 446 samples collected by IGS and USGS personnel between 1990 and 2002 were compiled. A modification of Reiche's (1943) Weathering Potential Index (WPI) was selected for analysis.

$$WPI = \frac{100*moles(Na_2O+K_2O+MgO+CaO)}{moles(Na_2O+K_2O+MgO+CaO+SiO_2+Al_2O_3+Fe_2O_3)}$$

In order to make the molar conversion, each whole-rock geochemical value was divided by the sum of its component atomic weights. In the original index, H_2O was subtracted from the cations on top of the equation (Reiche, 1943). Because the 446 samples included in this analysis were not routinely examined for water, this information was not available, and therefore was not included in the current analysis. For analysis, the 446 samples were categorized in several ways. The first was using the basic IFTNC classification of basalt, granite, and metamorphic/metasedimentary. Then, the samples were assigned to one of 32 lithology categories. Finally, the 446 samples were categorized by formation, or as 'other' if no formation was noted. Statistical analysis was then performed using a general linear models procedure (SAS Institute Inc., 1990), to determine whether variation in WPI or SiO_2 was explained by any of the three categorization schemes.

Results and Discussion

The first step of analysis was to examine WPI by a broad classification scheme commonly used by foresters and resource managers in the inland northwest, including basalt, granite, metasedimentary and other. The 'basalt' category, including basalts and andesites, had the highest average WPI of 22.8, and showed the narrowest range of variation (Figure 3). The 'granite' category, including granites, granodiorites, diorites, quartz diorites, and tonalities, had the next highest average WPI of 13.7, with a range approximately twice that of the basalt category (Figure 4). The 'metasedimentary' category included several lithologies, and showed the lowest average WPI of 10.7, and the highest range of variation, from 1.0 to 75.2 (Figure 5). Statistically, this broad classification scheme did not perform well, explaining only about 30% of the variation in WPI across the 446 samples examined. However, this type of broad classification is commonly used by non-geologists to categorize and understand rocks. The IFTNC used this classification to assess tree growth and forest health in a region-wide fertilization trial, and found that basalts generally showed good tree growth, while granites and metasedimentary rocks showed variable tree growth . Variation in rock weathering characteristics is a likely reason for the observed variation in tree growth. This application of Reiche's (1943) WPI demonstrates the variability inherent in such a broad classification scheme, and suggests that some other classification might be more useful for analyzing forest growth and health data.

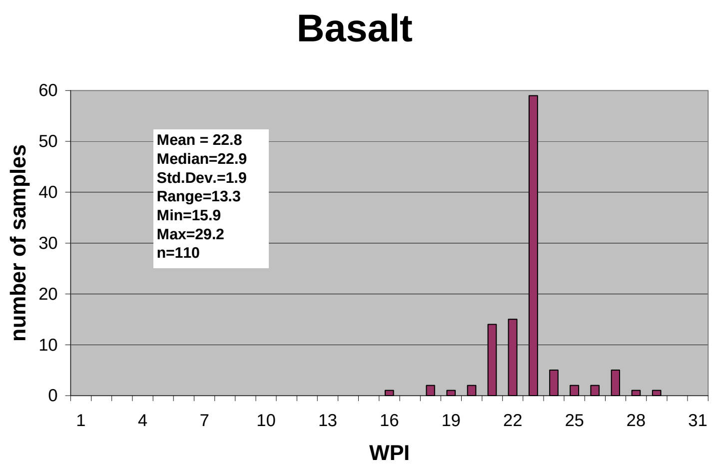

Figure 1. *Histogram of distribution of WPI values on basalt rocks.*

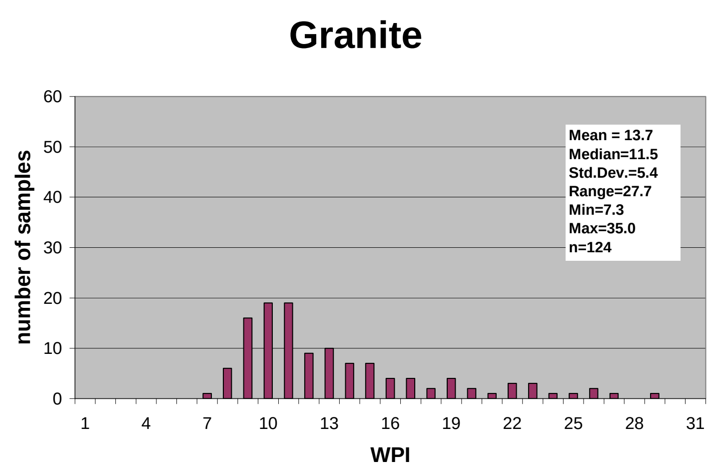

Figure 2. *Histogram of distribution of WPI values on granite rocks*

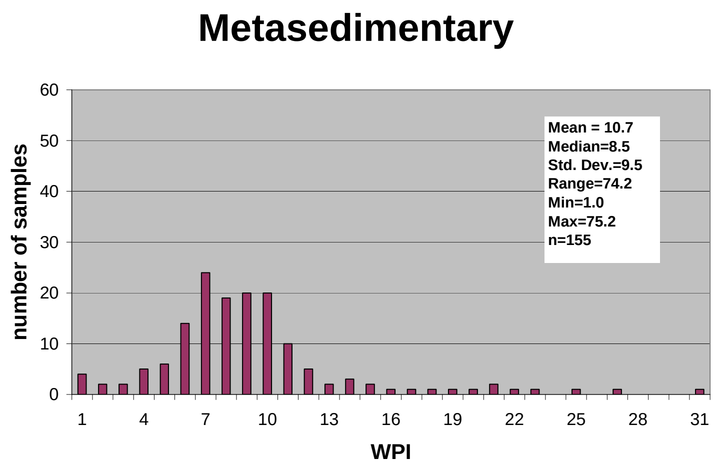

Figure 3. *Histogram of distribution of WPI values on metasedimentary rocks*

The second phase of analysis was to examine WPI using a more detailed lithology classification containing 32 categories. Silicon dioxide was also analyzed using this classification scheme, as a possible surrogate for the WPI calculation. Statistically, this classification performed much better than the broad classification used in the first phase of analysis, explaining about 85% of the variation in WPI values and about 80% of the variation in SiO_2 values (Figure 6). Dolomite showed a significantly higher WPI and lower SiO_2 than any other rocks, as expected based on chemical composition. Carbonate and calc-silicate rocks also tended to rank high in WPI, along with basalt and diorite. Plagioclase-bearing, siliceous igneous rocks (tonalite, granodiorite, quartz diorite, dacite) fell into the mid-range of WPI values, while the more alkaline igneous (granite, rhyolite) and metasedimentary rocks fell into the lower end of the range. As compared to the broad categorization scheme first analyzed, the lithology categorization provided a much-improved means of explaining the observed variability in WPI. Also, WPI seemed to capture expected weathering characteristics, while SiO_2 did not. For example, quartzites ranked low in WPI and high in SiO_2 due to their high SiO_2 content. However, rocks in the ‘quartzite-carbonate’ category showed a significantly higher WPI than non-carbonate quartzites (as expected for carbonate-bearing rocks), while the SiO2 ranking for the ‘quartzite-carbonate’ category remained very high, and in fact was second only to the non-carbonate quartzites. Two important points were revealed in this phase of analysis. First, complete and consistent lithology descriptors can be used to gain some general idea of expected weathering trends, and second, that WPI was better than SiO_2 in describing expected weathering trends.

Because Precambrian metasedimentary rocks are so common in north Idaho, and are often mapped and described by stratigraphic formation rather than lithology, a third analysis was performed using formation names. Formation names were available for all Belt rocks, as well as the Syringa formation and many of the Columbia River basalt flows. If a ‘carbonate’ or ‘calc-silicate’ modifier was available, that was also included with the formation name. The St. Regis, Burke and Revett formation rocks were grouped into the Ravalli Group for this analysis. Other basalts, granites and non-Precambrian rocks were grouped into an ‘Other’ category. Weathering potential index and SiO_2 were analyzed using the resulting 16 categories (Figure 7). Statistically, this classification technique also worked reasonably well, explaining about 60% of the variation in WPI, and 53% of the variation in SiO_2. The carbonate and calc-silicate members of Precambrian metasedimentary formations (except Prichard), along with the basalts, had significantly higher WPI rankings than the other Precambrian metasedimentary rocks. Among the other metasedimentary formations, WPI ranked in the order Libby > Wallace >Prichard > Syringa > Prichard-carbonate > Striped Peak > Ravalli Group. The concurrent increase in SiO2 showed variability similar to that discussed above for lithology. This phase of analysis re-emphasized the importance of including information on calc-silicate or carbonate properties as geologic modifiers, if available. This analysis also showed that calc-silicate or carbonate-bearing properties were perhaps more important than formation itself in determining rock weathering trends.

Conclusions

This modification of Reiche's (1943) WPI provided a useful and logical means of detecting perceived geologic controls on tree nutrition and forest health in the inland northwest. By applying WPI to several classification schemes, the value of providing clear lithological terminology to non-geologist end-users emerged as an important factor. The calculation of the WPI provided a convenient means of reducing a large amount of geochemical information into a single value, which could then be analyzed categorically. Weathering potential index provided a better explanation of expected weathering trends than did SiO_2 alone. While further work on the contribution of rock mineral composition to rock weathering patterns is needed, WPI appeared to provide a suitable means of describing observed weathering pattern variation using easily-available geochemical data. Conversely, lithologic descriptors, including calc-silicate or carbonate modifiers, were very useful in explaining expected weathering characteristics.

Citations

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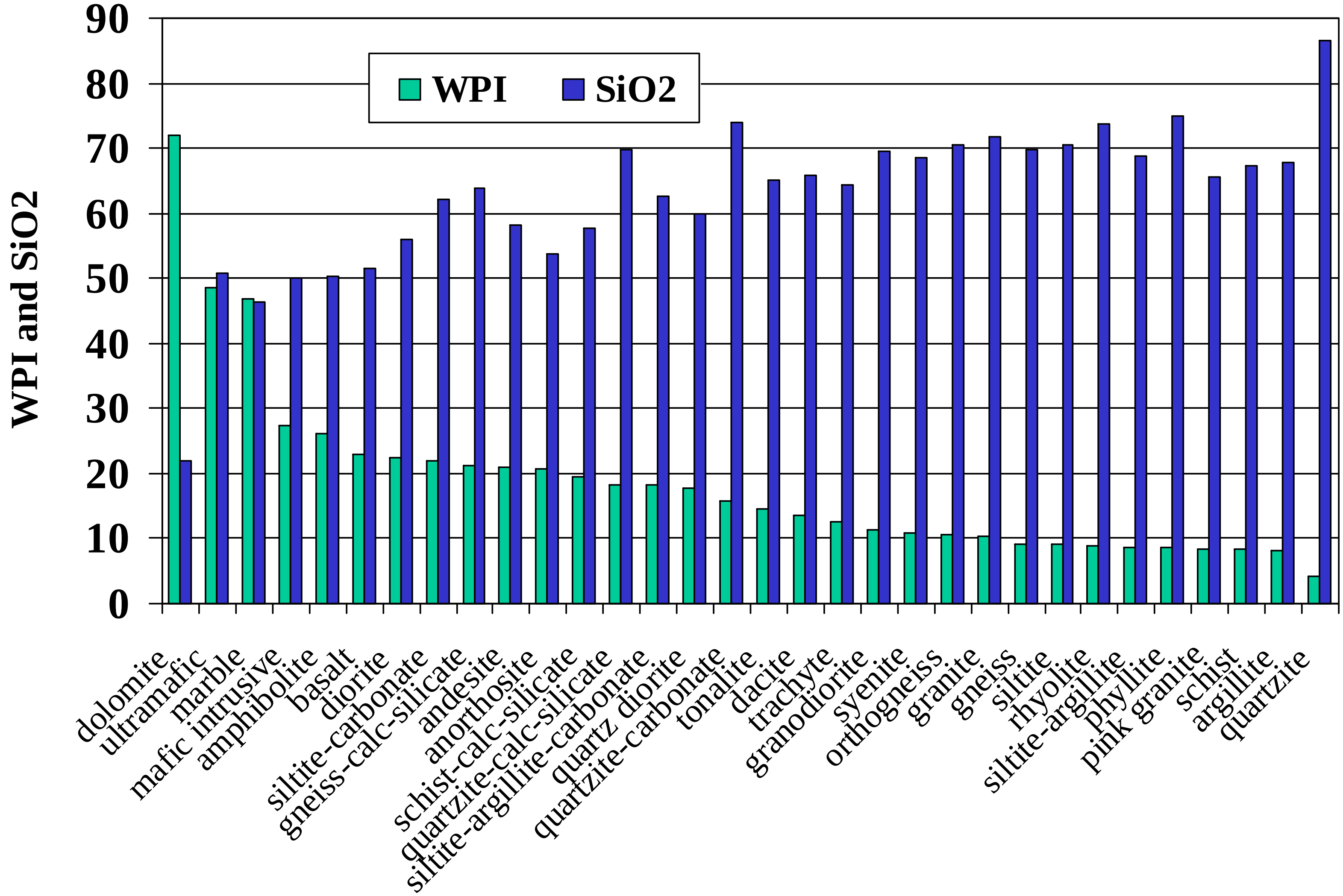

Figure 6. *WPI and SiO_2 values for 32 lithology groups identified in northern Idaho*

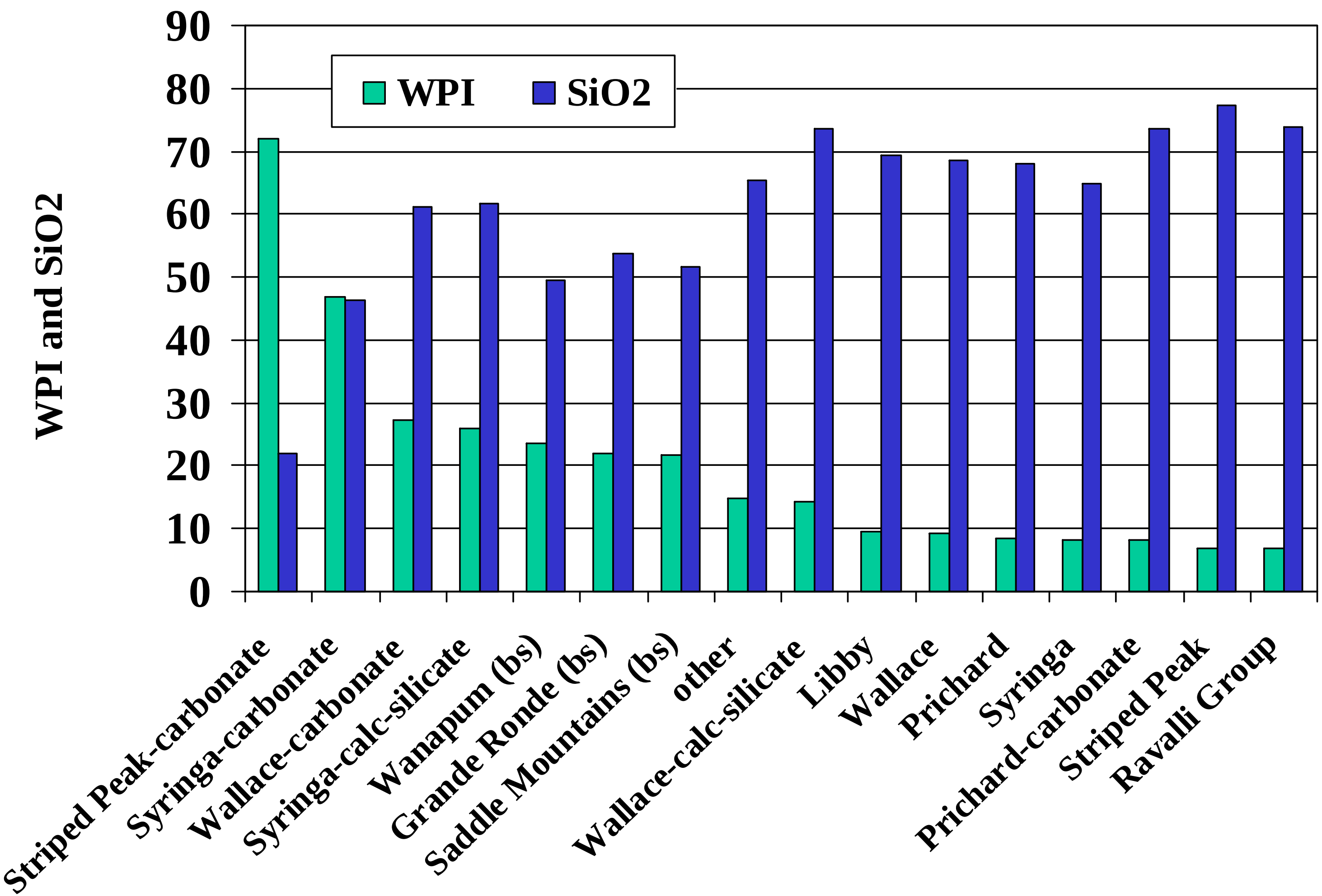

Figure 7. *WPI and SiO_2 values for 16 formation-based categories identified in northern Idaho*