# ABRASION pH, AN INDEX OF CHEMICAL WEATHERING

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**Abstract** — If a series of rock samples with granitic composition in various stages of chemical weathering is ground in a mortar with distilled water and the pH of the slurry produced is determined, it will be evident that the pH declines as the weathering increases. This relationship can be made useful by plotting abrasion pH against some other index of weathering such as the percentage of clay mineral or the bulk density of the weathered rock. Factors controlling abrasion pH are the cations such as K, Na, Ca, and Mg and the amount of clay mineral present.

## INTRODUCTION

STEVENS and Carron (1948) established the use of abrasion pH as an aid in mineral identification. Grant (1963, 1964) used abrasion pH as an indicator of rock weathering but offered no explanation as to the mechanisms involved. The following work is designed to show why abrasion pH is a useful index of weathering.

The scope of this work is such that abrasion pH data are valid for saprolites derived from granitic rocks from tropical and humid subtropical regions where the major weathering products are kaolin minerals. The rocks used in this study are adamellites. Abrasion pH curves have been made for many common rocks including an ultramafic. The details of abrasion pH curves vary with the primary mineral composition of the rock. The general patterns are the same.

## PROCEDURES AND METHODS

Extraction of soluble cations and abrasion pH determination is done as follows: Weigh 20g of crushed rock or saprolite into an agate mortar (capacity 425 ml, weight of pestle 370g) which has been washed with distilled water and dried; add 40ml of distilled water; grind for $2\frac{1}{4}$ min; allow 2 min for settling of the suspended matter; extract 15 ml of the supernatant liquid and put it aside in a centrifuge tube for later chemical analysis and finally determine the abrasion pH of the remaining slurry.

The determination of potassium, sodium, calcium and magnesium in the supernatant liquid is done as follows: Centrifuge the sample to clear the liquid, as suspended clay will cause erroneously high potassium values. Using suitable standards analyze for Na, K, Ca, and Mg with an atomic absorption spectrophotometer. No preliminary treatment was found necessary.

Semi-quantitative kaolin determinations are made by differential thermal analysis using a modification of the method of Kerr and Kulp (1948, p. 418). Sample sizes are about 0·5g and the rate of temperature rise is 70°C/min. Eberbach portable DTA equipment was used.

Artificially weathered rocks were made by using weighed amounts of crushed fresh granite and commercial Georgia kaolinite in desired mixtures.

## EFFECTS OF GRINDING

Figure 1 shows the effects of grinding duration on the abrasion pH of some natural and artificially weathered rocks. Figure 1 shows that abrasion pH rises sharply during the first minute of grinding and then continues to rise more slowly with further grinding. On the deeply weathered rock which contains 28% kaolinite, the early rise is less pronounced and continued grinding produces little change in pH. There is a slight decline in pH with continued grinding. This decline is attributed to the reduction of kaolinite particle size, and attendant increase in cation exchange capacity which results from the removal of metal ions from the solution, hence, a decline in pH. A continuing addition of $CO_2$ from the atmosphere might also cause a decline in pH. Rocks intermediate in completeness of chemical weathering will produce curves which are intermediate between A and C, Fig. 1. The natural curves, A and C, Fig. 1, show a leveling off under all conditions after $1\frac{1}{2}$ min grinding, hence, for practical purposes, on weathered rocks a grinding time between 2 and $2\frac{1}{2}$ min is adequate for abrasion pH determination. Reproducibility of such data
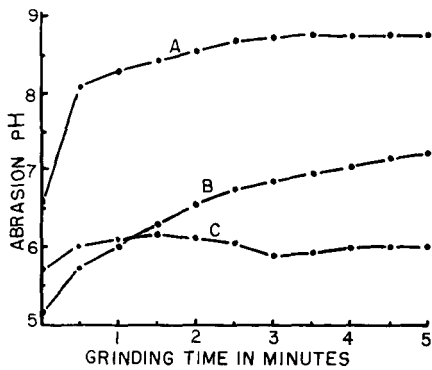
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Fig. 1. The relation of grinding time to abrasion pH in (A) fresh rock, (B) artificial weathered rock, and (C) a completely weathered rock.

strongest tendency to cause drift in the pH meter while very weathered rocks show very little drift. This is perhaps due to a buffering capacity of the kaolinite. The curves show that for practical determination a contact time of the electrode in the slurry of between 1 and 2 min is adequate.

## RELATION OF ABRASION pH TO WEATHERING

Figure 3, curve A, shows the relation between abrasion pH and kaolinite content of a naturally weathered rock, (Stone Mountain Granite, an adamellite containing roughly 30% quartz, 30% oligoclase, 30% microcline and the remainder mica, mainly muscovite). Curve B, shows what happens to abrasion pH as increasing amounts of kaolinite are added to crushed fresh granite (artificially weathered rock). Since the concentration of the metal ions in the synthetic mixture must be constant, the decline in abrasion pH must be attributed to the kaolinite. Graham (1941) showed that clays can behave as acids.

on granitic rock on the average is within $\pm 0.08$ pH units with a maximum deviation of $0.18$. An artificially weathered rock is shown in Fig. 1, curve B. It is the same rock as curve A but with 10% kaolinite added. Comparison of curves A, B and C shows the importance of the quantity of kaolin in abrasion pH determinations. The abrasion pH of pure kaolinite is quite variable. The abrasion pH of kaolin used in these experiments was $4.0$. A kaolinite with a higher abrasion pH would simply raise curve B in Figs. 1 and 3.

The time allowed for the electrode to come to equilibrium with the slurry is another factor. Figure 2 shows a curve for a nearly fresh granite, curve A, and a strongly weathered saprolite, curve B. Fresh or slightly weathered rocks have the
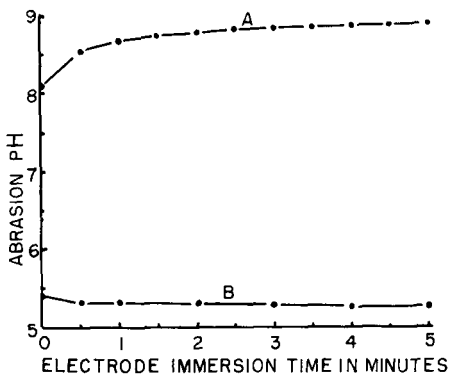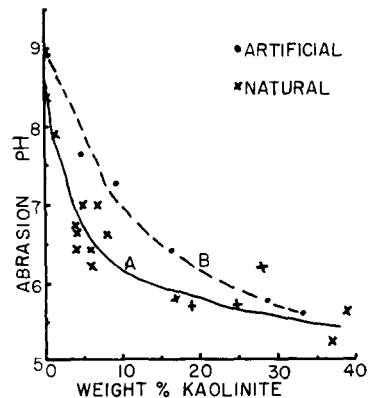


Fig. 3. The relationship of the amount of kaolinite to the abrasion pH in artificial and naturally weathered rock.

As a further test of the effect of kaolinite on abrasion pH, the clay was partially washed from rocks by mulling in distilled water and then determining abrasion pH. This was initially $6.1$ and rose to $6.4$ after removal of the clay. The residual mineral composition was quartz and microcline; the latter accounting for the rise in pH. In a less weathered rock the same procedure changed abrasion pH from $6.7$ to $6.8$. The washing procedure tends to destroy the desired results by removing dissolved cations as well as clay, but even with this defect the conclusion that the kaolinite content is a major factor in abrasion pH remains secure.



Fig. 2. A graph showing the effect of immersion time on abrasion pH in nearly fresh rock, curve A, and deeply weathered rock, curve B.

## DISSOLVED CATIONS

Comparison of curves A and B, Fig. 3, shows the center part of natural curve A is displaced toward lower pH values. This can only be explained by leaching of cations as a result of weathering. No leaching was possible in the synthetic curve B. This shows that dissolved cations also effect abrasion pH.

The relation of the dissolved cations in the slurry to abrasion pH is shown in Figs. 4 and 5. The amount of sodium in the solution is plotted against abrasion pH in Fig. 4. In general, sodium concentration declines as abrasion pH declines. Comparison of Fig. 4 with curve A of Fig. 3 shows a rapid decline in sodium concentration in the earlier phases of weathering. This is a result of rapid decomposition of oligoclase. The fact that four-fifths of the sodium is lost before one-fifth of the kaolinite is formed suggests that the sodium has little influence on the growth of clay minerals.

Figure 5 shows the relation of potassium to

abrasion pH. It is quite similar to sodium. In the weathering process the quantity of potassium declines steadily as does sodium. The major difference between loss of sodium and potassium is in the rate. Sodium is lost more quickly than potassium. Both elements are present in roughly equal amounts in the fresh rock. This supports the well known fact that plagioclases decompose more rapidly than potash feldspars. The fact that the potassium is low in abrasion pH solutions from highly weathered rocks, does not mean that it is absent from the rock residue. Some of it is present in residual microcline and mica, and some is adsorbed on clay particles.

Calcium and magnesium are present in some abrasion pH solutions. Their maximum concentrations are about 1 ppm for calcium and about 0·7 ppm for magnesium in fresh and slightly weathered granites.

## GROSS RELATIONSHIP TO THE WEATHERING ENVIRONMENT

Figure 6 shows an idealized distribution of abrasion pH as it would probably appear if one took a series of abrasion pH readings across a weathered profile below the B-horizon at progressively greater depths. The diagram shows that on the average abrasion pH increases with depth while individual sample points vary widely. The channel-like contours of pH 5 might have been parallel to joints along which the first weathering solutions penetrated the rock. Interpretation of the diagram in qualitative terms of the physical strength of weathered material is possible. Areas with abrasion pH of 5 and 6 are easy to crumble in the hand,
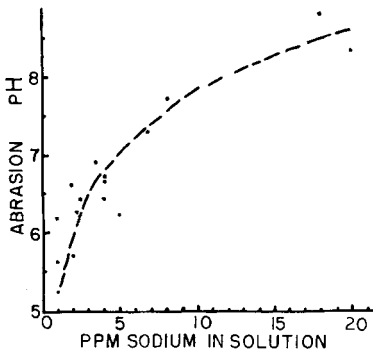


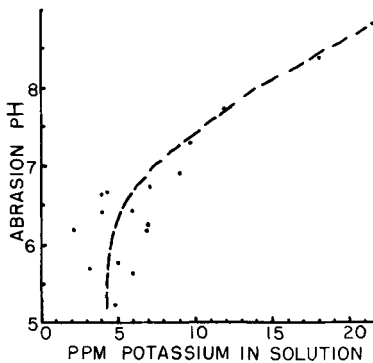Fig. 4. The relation of abrasion pH to the amount of sodium in solution.



Fig. 5. The relation of abrasion pH to the amount of potassium in solution.
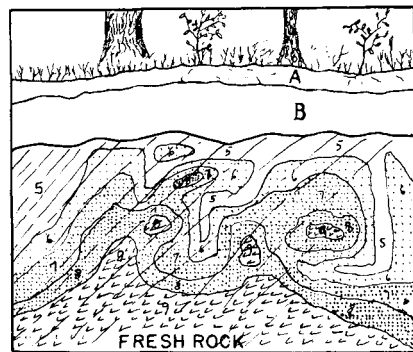


Fig. 6. An idealized sketch showing the relationship of abrasion pH to the weathering environment. The diagonal lines across the zone of weathering represent preserved foliation. The stippled areas and clear areas with numbers represent the abrasion pH of that area.

pHs between 6 and 7·5 the saprocks are broken in the hand with difficulty, above 7·5 the use of a hammer is essential. The relative resistance to breaking or weatheredness of rocks in various parts of the profile is shown by intensity of stippling.

### SOURCES OF ERROR AND VARIATION

The points in Fig. 3 show considerable scattering on the natural weathering curve A. The artificial curve B shows much less scattering. Figure 7 shows the effect of adding a few tenths of a gram of dried lichen, Parmelia conspersa (Ach.) Ach., to the rock slurry used in abrasion pH determination. The procedure for making the curves in Fig. 7 is the same as ordinary abrasion pH but with air dried lichen fragments ground into the slurry. It can be seen that as little as 50 mg of lichen can lower the abrasion pH by nearly a whole pH unit. Hence in collecting samples for chemical weathering studies, rock with an abundant lichen growth should be considered different from a similar specimen devoid of lichen. Samples of deeply weathered saprolite taken from dilation joints (horizontal and

If the product of weathering is gibbsite a different abrasion pH curve will result. Other clay minerals would be expected to yield different curves.

### CONCLUSIONS

Abrasion pH is controlled by the quantity of residual cations released from primary minerals by grinding and the amount of clay mineral. The method takes into consideration both the reactants and the products of the weathering equation. In the early phases of weathering, abrasion pH is controlled by the liberation of metal ions into solution. In the middle phases of weathering, the clay mineral and the residual cations compete for control of abrasion pH. In the final weathering phases, clay of acidic reaction controls the abrasion pH.

Abrasion pH of a weathered rock is a function of the kind and amount of clay mineral present and the kind and amount of primary minerals present.

The "weathering potential index" as developed by Reiche (1943, 1950) and utilized by Ruxton (1968) has a distinct relationship to abrasion pH.

$$WPI = \frac{100 \times Mols\ (CaO + Na_2O + MgO + K_2O - H_2O)}{Mols\ (SiO_2 + Al_2O_3 + Fe_2O_3 + CaO + Na_2O + MgO + K_2O)}.$$

often water bearing), usually have a higher pH because of the proximity of fresh rock. The fresh rock is often only a few inches away from the saprolite. Other possible causes of variation are the presence of humic acids from decomposition of overlying plant debris, variations in the amount of carbonic acid and lack of homogeniety of the sample. In spite of these difficulties abrasion pH – weight per cent kaolin curves are reproducible with ten to twenty samples.

Abrasion pH can be expressed as follows:

$$Abrasion\ pH \approx f\ \frac{(Na + K + Ca + Mg)}{(Clay\ Mineral)}.$$

The numerator of the "weathering potential index" contains all the alkalis and the alkaline earths. The numerator in the abrasion pH relationship is similar. The denominator of the "weathering potential index" is composed mainly of silica and alumina. The clay minerals constituting the denominator of the abrasion pH relationship are also dominated by alumina and silica. It is concluded that abrasion pH is an index of weathering of the same general value as the "weathering potential index."

Abrasion pH data do not represent equilibrium conditions but they appear to approach it. With this in mind it can be seen that the term $\log [K^+]/[H^+]$ used by Garrels and Christ (1965) in the diagram of the system $K_2O \cdot Al_2O_3 \cdot SiO_2 \cdot H_2O$ contains $[H^+]$ which is directly related to pH. If a rock contained only potash feldspar, abrasion pH could be substituted for $\log [K^+]/[H^+]$ with a similar diagram resulting. With real rocks which usually contain four pH controlling ions it would be necessary to determine the ions individually along with the $[H_4SiO_4]$ concentration in order to relate abrasion pH to the systems given by Garrels and Christ.
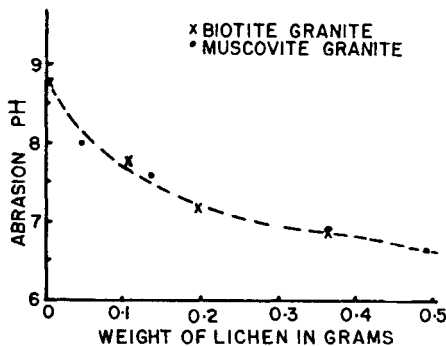


Fig. 7. The effect of adding weighed amounts of lichen to the abrasion pH slurry. Lichen ground in water (1 g/40 cc) yields a solution of pH 4·8.

## REFERENCES

Garrels, R. M., and Christ, C. L. (1965) Solutions, Minerals, and Equilibria: Harper and Row, New York, 450 pp.

Graham, E. R. (1941) Acid clay, an agent in chemical weathering: *J. Geol.* **49**, 392–401.

Grant, W. H. (1963) Weathering of Stone Mountain Granite: *Clays and Clay Minerals* **11**, 65–73.

Grant, W. H. (1964) Chemical weatherng of biotite-plagioclase gneiss: *Clays and Clay Minerals* **12**, 455–463.

Kerr, P. F., and Kulp, J. L. (1948) Multiple differential thermal analysis: *Am. Mineralogist* **33**, 387–419.

Reiche, P. (1943) Graphic representation of chemical weathering: *J. Sediment. Petrol.* **13**, 58–68.

Reiche, P. (1950) A Survey of Weathering Processes and Products: University of New Mexico Press, Albuquerque.

Ruxton, B. P. (1968) Measures of the degree of chemical weathering of rocks: *J. Geol.* **76**, 518–527.

Stevens, R. E., and Carron, M. K. (1948) Simple field test for distinguishing minerals by abrasion pH: *Am. Mineralogist* **33**, 31–49.

**Résumé** – Si plusieurs échantillons de roches à texture granitique se trouvant à divers stades d'altération chimique sont broyés dans un mortier avec de l'eau distillée et le pH de la pâte obtenue determiné, on remarquera que le pH diminue au fur et à mesure que l'altération s'accentue. On réalise immédiatement tout le parti qui peut être tiré de cette relation en représentant de façon graphique l'abrasion pH par rapport à un autre index d'altération, tel que le pourcentage d'argile ou la densité de masse de la roche altérée. Les facteurs déterminant l'abrasion pH sont les cations, tels que K, Na, Ca, Mg, ainsi que la proportion d'argile présente.

**Kurzreferat** – Wenn eine Reihe von Gesteinsproben granitischer Struktur in verschiedenen Stadien chemischer Verwitterung in einem Mörser mit distilliertem Wasser vermahlen und das pH des erhaltenen Breies bestimmt wird, so findet man, dass bei fortschreitender Verwitterung das pH abnimmt. Aus dieser Beziehung kann Nutzen gezogen werden, indem man das Abrieb pH gegen einen anderen Verwitterungswert, wie z.B. den Prozentgehalt an Tonmineral oder das Raumgewicht des verwitterten Gesteins aufträgt. Die Faktoren, die das Abrieb pH bestimmen, sind Kationen wie z.B. K, Na, Ca and Mg sowie die vorhandene Menge an Tonmineral.

**Резюме**—Если измельчить в ступке с дистиллированной водой серию образцов пород с гранитной структурой, подвергшихся в различной степени химическому выветриванию и определить pH полученной тестообразной массы, то станет очевидно, что по мере усиления выветрелости образцов pH падает. Это может быть использовано для графического сопоставления pH истирания и других показателей выветривания, например, процентного содержания глинистого минерала или общей плотности выветрелой породы. pH истирания зависит от содержания в породе катионов (К, Na, Ca и Mg) и глинистого минерала.