

INTERNATIONAL SOCIETY FOR SOIL MECHANICS AND GEOTECHNICAL ENGINEERING



This paper was downloaded from the Online Library of the International Society for Soil Mechanics and Geotechnical Engineering (ISSMGE). The library is available here:

<https://www.issmge.org/publications/online-library>

This is an open-access database that archives thousands of papers published under the Auspices of the ISSMGE and maintained by the Innovation and Development Committee of ISSMGE.

The paper was published in the proceedings of the 8th Australia New Zealand Conference on Geomechanics and was edited by Nihal Vitharana and Randal Colman. The conference was held in Hobart, Tasmania, Australia, 15 - 17 February 1999.

Formulating an Index of Weathering for Karamu Basalt and Testing its Geotechnical Implications

M.P.J. Jayawardane

M.Sc., M.I.M.M. London, C.Eng.

Assistant Lecturer, University of Waikato, New Zealand

Summary This paper was a result of an attempt to formulate a weathering index and to determine its implications on the geotechnical properties of basalt. Samples were collected from an abandoned open cast basalt mine at Karamu, northern New Zealand, where a complete weathering profile was observed. Fresh and weathered rock and saprolites were tested in the field and in the laboratories both for chemical and geotechnical parameters. Chemical studies show that during weathering the contents of only four elements (Al, Fe, Mg, Ca), along with the structural water, change significantly. Based on the percentages of oxides of these elements and water, a weathering index was formulated. The good correlations between the weathering index and some of the geotechnical properties gave rise to a set of model equations given in the paper. This weathering index can serve as a good indicator of the geotechnical properties of Karamu basalt.

1. INTRODUCTION

Determination of the extent of weathering of rock material is very important since almost all geotechnical parameters alter along with weathering. The weathered nature of the ground can lead to special problems at every stage of an engineering project (Hencher & McNicholl, 1995).

This project was an attempt to formulate a weathering index based on the chemical composition of the weathered material and test its implications on the geotechnical parameters.

The history of weathering indices goes back to the 1940's when Reiche (1943) formulated a Weathering Potential Index, followed by Ruxton (1968), Parker (1970), Miura (1973) and Hodder (1984).

Since basalt is a very common rock type it was selected for this research. Due to the availability of exposed weathering profiles, basalt at Karamu was chosen for the study. Karamu lies 17 km Southwest of Hamilton and the Project Area is enclosed within longitudes 175° 5' to 175° 7' East and latitudes 37° 54' to 37° 55' South.

2. GEOLOGY OF THE PROJECT AREA

Karamu is a volcanic centre belonging to the Okete Volcanics which is part of the Alexandra Volcanics Group (AVG). Alexandra is the southern-most Pliocene-Quaternary (2.7 to 1.6 Ma) basalt field of northern North Island. The Okete volcanics form a basalt field of numerous monogenetic volcanoes that have a scattered distribution around Raglan – Pirongia. The Okete Volcanics have compositions which include basanites, alkali-olivine basalts and hawaiites (Briggs and Goles 1984).

The Karamu volcanic centre consists of basaltic lava flows and associated scoria material. The age of the lava flows is estimated at 2.03 Ma. The basaltic lavas are overlain by a thick sequence of weathered rhyolitic tephra ranging in age from 1.6 to 0.9 Ma. Tephra generally form layers which have a uniform thickness. When one such layer has formed, and before the formation of the next tephra layer, a soil layer has been formed. These soil layers have turned into dark coloured paleosols and now we see a series of alternating tephra and soil layers. Due to deep weathering, the tephra have turned into soil with high contents of clay.

3. OBSERVATIONS AND RESULTS

The study made use of an abandoned open-cast basalt mine at Karamu which showed a complete weathering profile starting from fresh basalt, through slightly weathered, moderately weathered, highly weathered to completely weathered basalt. The materials at different depths were observed and mapped (see Figure 1).

In-situ tests such as Schmidt Rebound Hammer Hardness Determination, Vane Shear Test and Standard Penetration Test were carried out in the field. Samples of each unit in the profile, in very large quantities, were then collected and prepared for further examination. In the laboratories, the following tests were carried out to determine geotechnical parameters: Uniaxial Compressive Strength Determination, Point Load Strength Index Determination, California Bearing Ratio, Water Content Determination, Dry Density, Particle Density, Direct Shear Test, and Atterberg Limits.

In order to evaluate the chemistry of these materials, the X-ray Fluorescence Method of Chemical

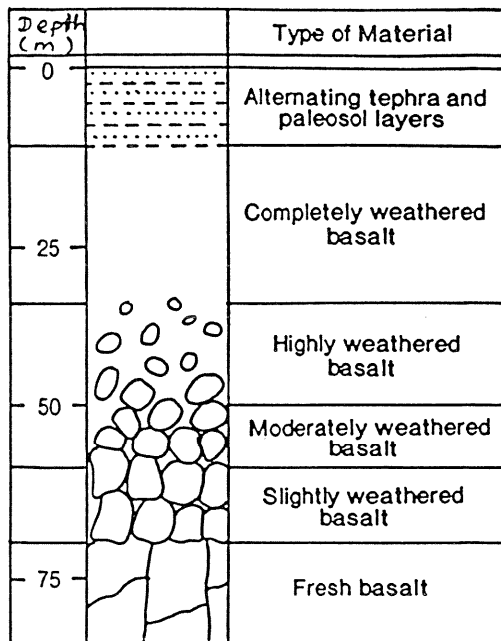


Figure 1. Weathering profile at Karamu.

Analyses was carried out. The major constituent oxides are given as percentages and trace elements as parts per million.

3.1 Weathering Profile

Figure 1 gives a description of the weathering profile. The bottom of the profile consists of black coloured, columnar jointed fresh basalt. Slightly weathered basalt with brown colour at the joints overlies that, followed by moderately weathered basalt with a visible brownish yellow clayey substance in thick layers at the joints. This in turn is overlain by highly weathered basalt which still has corestones in visible proportions in a matrix of clayey material. On top of it lies the brown coloured completely weathered basalt where the original structure could be seen but the minerals have altered beyond recognition, giving rise to a new set of minerals. Several thin layers of alternating weathered tephra and paleosols are covering these layers in some places.

3.2 Geochemical Information

For each layer with a different degree of weathering, some of the average values of the chemical analyses, obtained by X-Ray fluorescence method, are given in Table 1. The loss on ignition given as percentages in the chemical analysis is in reality the water retained within the mineral structures which is released on ignition at very high temperatures (over 900 degrees Celsius). It should not be mistaken for the physical water content, which is an assessment of externally retained water in the pores of the rock and soil material. The samples were oven dried before they were analysed for chemical composition.

The chemical composition of the samples is given as oxides, showing changes from fresh basalt to weathered. The calcium, bivalent iron and magnesium content decrease with the degree of weathering while the aluminium, trivalent iron and structural water content increase. Figure 2 shows this relationship.

Table 1. Mean values of test results.

	Fresh	Slight	Moderate	High	Complete
SiO ₂ %	45.92	35.69	31.87	28.22	25.82
Al ₂ O ₃ %	12.43	14.23	22.07	28.24	26.47
MnO %	0.18	0.19	0.32	0.36	0.23
MgO %	11.28	11.45	3.71	0.54	0.34
CaO %	10.18	6.11	0.64	0	0
Na ₂ O %	1.93	0.19	0	0	0
K ₂ O %	1.11	0.11	0.09	0	0
TiO ₂ %	2.18	3.01	3.94	3.58	4.94
P ₂ O ₅ %	0.38	0.33	0.57	0.83	0.51
Fe ₂ O ₃ %	2.91	3.75	19.11	18.01	23.03
FeO %	9.76	12.54	1.01	0.95	1.21
H ₂ O %	2.11	11.49	13.95	16.17	14.82
Reiche P.I.	3.69	2.51	1.44	1	0.97
Ruxton Ratio	0.649	0.516	0.409	0.357	0.317
Parker W.I.	0.185	0.111	0.012	0.0002	0.0001
Miura W.I.	1.97	1.04	0.11	0.04	0.02
New. W.I.	2	1	0.1	0.02	0.01
Dry Density	2902	2492	1845	1787	1502
kg/m ²					
Porosity%	0.31	1.42	13.34	21.38	27.19
Compressive	298.8	84.94	13.52	4.12	4.38
Strength MPa					
Cohesion KPa		0	1	2	7
Angle of Int.		35	33	33	33
Friction °					
Undr. Shear		183	112.8	146.6	94.8
Strength KPa					
California		45	30	15	1.5
Bearing Ratio					

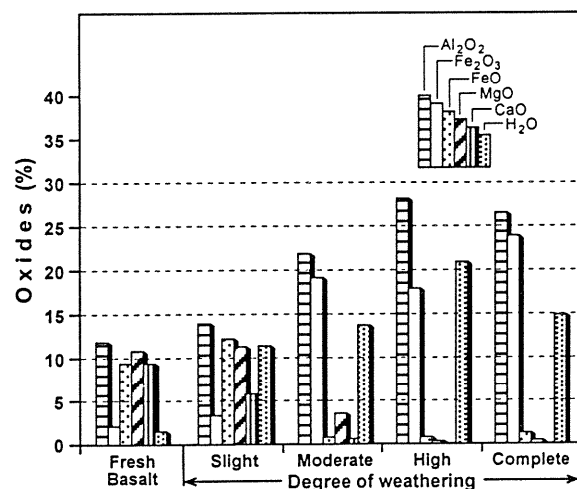


Figure 2. Changes in chemistry.

3.3 Weathering Indices

3.3.1 Previous work on indices

Reiche (1943) proposed the Weathering Potential Index (WPI) and a Product Index (PI):

$$PI = \frac{SiO_2}{SiO_2 + Al_2O_3 + Fe_2O_3 + FeO + TiO_2} \times 100 \quad (1)$$

Ruxton (1968) suggested the Ruxton's Ratio (RR).

$$RR = \frac{SiO_2}{Al_2O_3} \quad (2)$$

Parker (1970) proposed the Parker Weathering Index (W_p).

$$W_p = \frac{a_{Na}}{0.35} + \frac{a_K}{0.25} + \frac{a_{Mg}}{0.90} + \frac{a_{Ca}}{0.70} \quad (3)$$

where a_E is the atomic proportion of the element E. The denominators are the relative oxygen to element bond strength.

Miura (1973) came up with an alternative called the Miura Weathering Index (W_m).

$$W_m = \frac{MnO + FeO + CaO + MgO + Na_2O + K_2O}{Fe_2O_3 + Al_2O_3 + H_2O} \quad (4)$$

Reiche Product Index (P.I.), Ruxton's Ratio (RR), Parker Weathering Index (W_p) and Miura Weathering Index (W_m) were calculated based on the chemical analysis (see Table 1). These four weathering indices and ratio, on a logarithmic scale, show a gradual decrease upon weathering of basalt, and an increase with depth (see Figures 3-6).

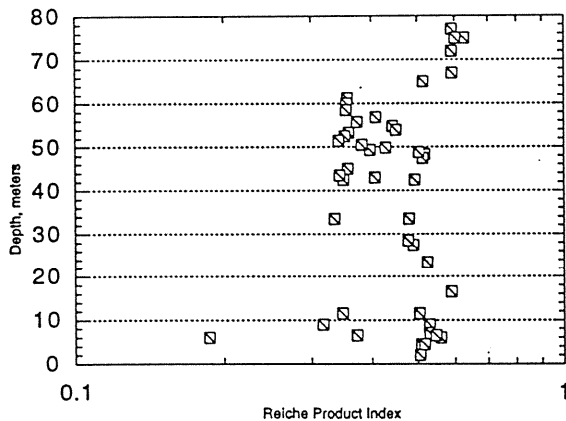


Figure 3. Plot of Reiche P.I. vs depth.

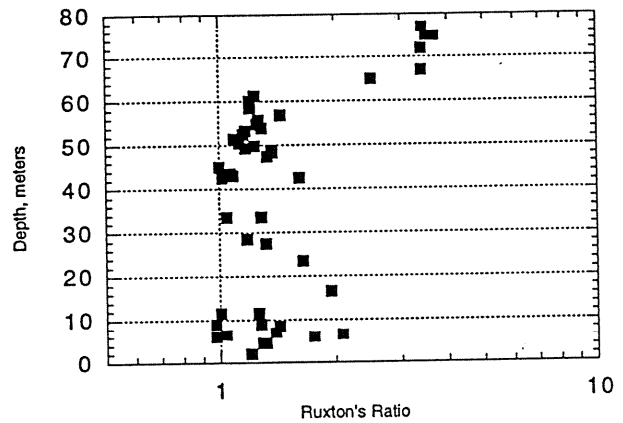


Figure 4. Plot of Ruxton's Ratio vs depth.

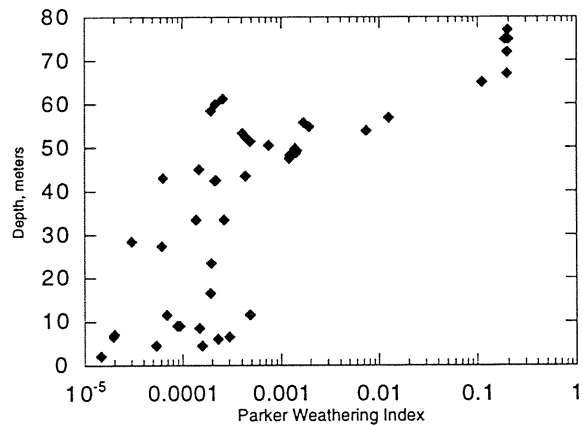


Figure 5. Plot of Parker W.I. vs depth.

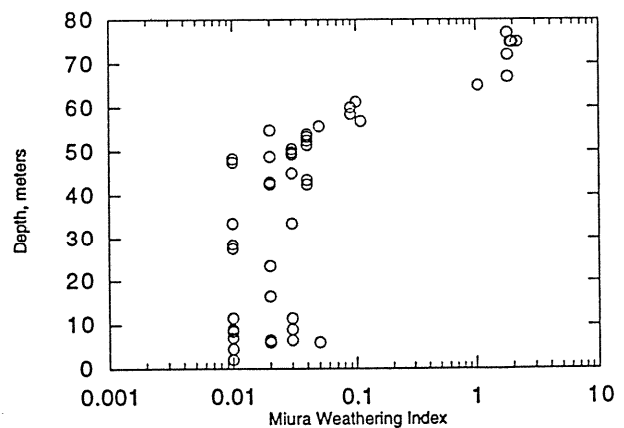


Figure 6. Plot of Miura W.I. vs depth.

3.3.2 New Weathering Index

Since manganese, sodium and potassium are available in negligible quantities this weathering index could be modified and written anew as:

$$\text{New W.I.} = \frac{\text{FeO} + \text{CaO} + \text{MgO}}{\text{Fe}_2\text{O}_3 + \text{Al}_2\text{O}_3 + \text{H}_2\text{O}} \quad (5)$$

This new weathering index on a logarithmic scale shows a decrease with weathering and an increase with depth (see Figure 7).

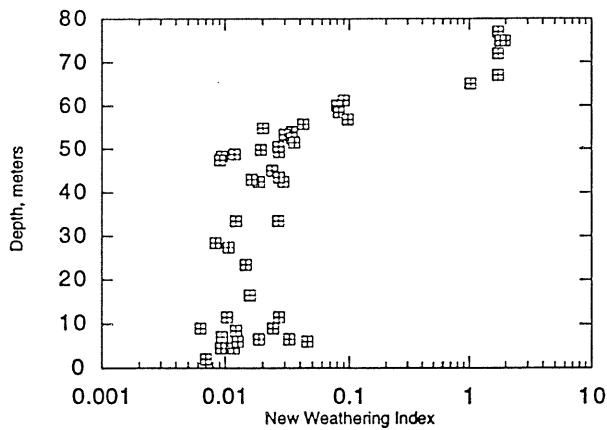


Figure 7. Plot of New Weathering Index vs depth.

3.4 Geotechnical Properties

One of the major problems of investigating weathered rocks is their possible susceptibility to disturbance during sampling and in-situ testing (Hencher & McNicholl, 1995). Extreme care was therefore taken in determining the geotechnical properties.

The average values of results of the tests Uniaxial Compressive Strength, Direct Shear (cohesion and angle of internal friction), Vane Shear, Porosity and Density and California Bearing Ratio values are given in Table 1.

4. IMPORTANT RELATIONSHIPS

Figures 8 to 12 show how Compressive Strength, Cohesion, Dry Density, Porosity and California Bearing Ratio change with the New Weathering Index.

New Weathering Index decreases with the intensity of weathering. Compressive Strength, Dry Density and California Bearing Ratio decrease, while Cohesion and Porosity increase with decreasing New Weathering Index.

$$\text{Compr. Strength, MPa} = -0.77 + 1.03 \log(\text{W.I.}) \quad (6)$$

$$\text{Dry Density, kg/m}^3 = 2587 + 547.33 \log(\text{W.I.}) \quad (7)$$

$$\text{Porosity, \%} = 2.46 + (-11.68 \log(\text{W.I.})) \quad (8)$$

$$\text{Cohesion, KPa} = -0.06 + (-2.34 \log(\text{W.I.})) \quad (9)$$

$$\text{CBR value, \%} = 47.2 + 20.7 \log \text{W.I.} \quad (10)$$

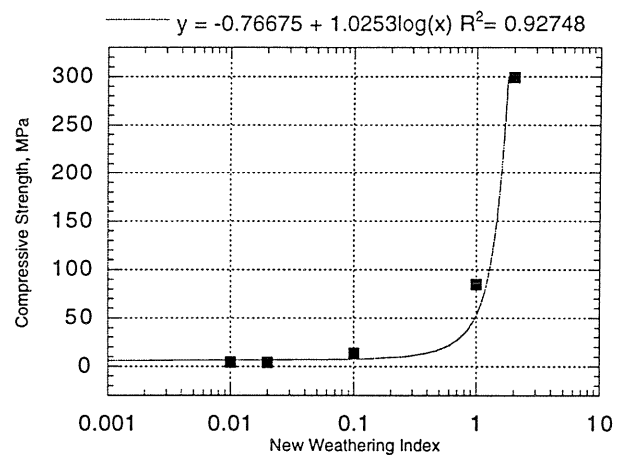


Figure 8. Plot of compressive strength vs New W.I.

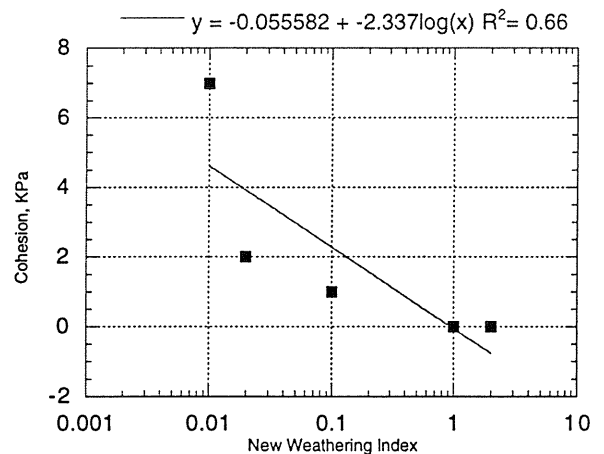


Figure 9. Plot of cohesion vs New W.I.

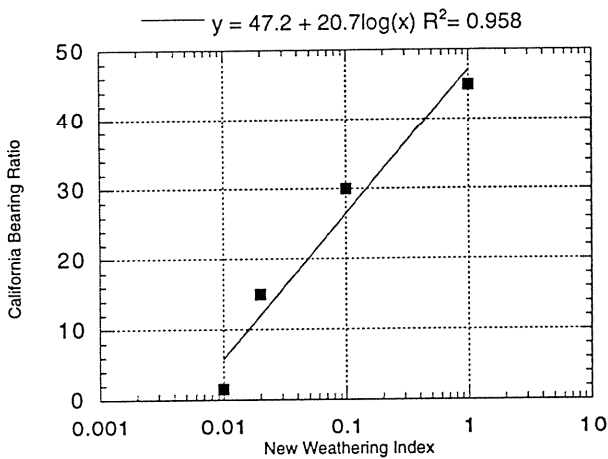


Figure 10. Plot of dry density vs New W.I.

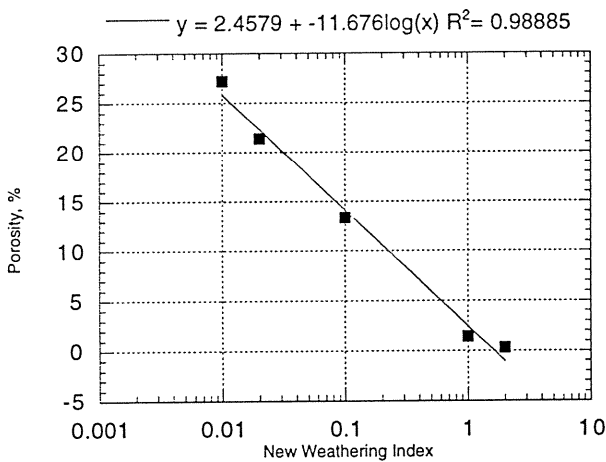


Figure 11. Plot of porosity vs New W.I.

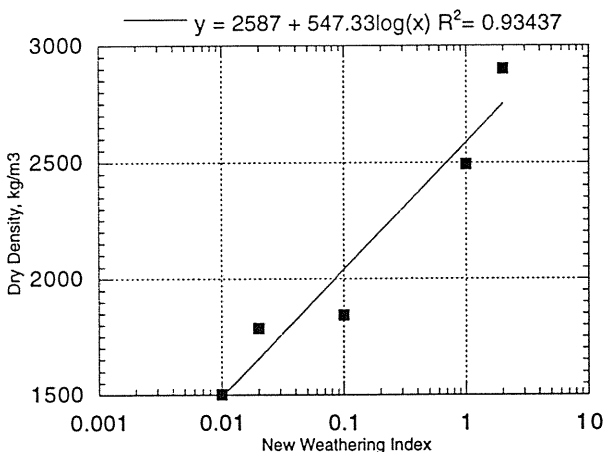


Figure 12. Plot of CBR values vs New W.I.

5. CONCLUSIONS AND RECOMMENDATIONS

- The weathering of Karamu basalt can be considered as a change in chemistry with the contents of aluminium, iron, magnesium, calcium and water playing major roles influencing geotechnical parameters.

- The New Weathering Index decreases with the intensity of weathering. While Compressive Strength, Dry Density and California Bearing Ratio decrease with the decrease in the weathering index, Cohesion and Porosity increase with the decrease in the weathering index.
- The model equations obtained can be used to predict geotechnical parameters of this particular basalt using the weathering index.
- These models are true for Karamu basalt but further research is recommended to test their applicability to basalt in other places.

6. ACKNOWLEDGEMENTS

The author is indebted to Prof. M.J. Selby, Prof. R.M. Briggs, Dr A.P.W. Hodder and Dr V.G. Moon (all of the Department of Earth Sciences, University of Waikato, Hamilton, New Zealand) for the support, advice and guidance given throughout this project.

7. REFERENCES

Briggs, R.M. and Goles, G.G. (1984). Petrology and Trace Element Geochemical Features of the Okete Volcanics, Western North Island, New Zealand, *Contributions to Mineralogy and Petrology*, No. 86, pp. 77-88

Brown, E.T. (1981). Rock Characterization, Testing and Monitoring, *ISRM suggested methods*, pp. 102-103.

Haskins, D.R. and Bell, F.G. (1995). Drakensberg Basalts: Their Alteration, Breakdown and Durability, *Quarterly Journal of Engineering Geology*, No. 28, pp. 287-302.

Hencher, S.R. and McNicholl, D.P. (1995). Engineering in Weathered Rock, *Quarterly Journal of Engineering Geology*, No. 28, pp. 253-266.

Hodder, A.P.W. (1984). Thermodynamic Interpretation of Weathering Indices and its Application to Engineering Properties of Rocks, *Engineering Geology*, No. 20, pp. 241-251.

Miura, K. (1973). Weathering in Plutonic Rocks, *Journal of the Society for Engineering Geology of Japan*, 14(3).

Pain C.F., Craig M.A. and Campbell I.D. (1994). Australian Regolith Conference, *Australian Geological Survey Organisation Record 1994/56*.

Parker, A. (1970). An Index of Weathering for Silicate Rocks, *Geological Journal*, 107, pp. 501-504.

Price, D.G. (1995). Weathering and Weathering Processes, *Quarterly Journal of Engineering Geology*, 28, pp. 243-252.

Reiche, P (1943). Graphic Representation of Chemical Weathering, *Journal of Sedimentary Petrology*, 13, pp. 53-68.

Ruxton, B.P. (1968). Measures of the Degree of Chemical Weathering of Rocks, *Journal of Geology*, 76, pp. 518-527.