

Andesites as resources for roading and concrete industries, North Island of New Zealand

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Abstract

Andesites are a major source of aggregate for much of the North Island of New Zealand. There are regional differences with respect to some important properties of the andesites. Some are reactive with cement and are designated as potentially deleterious or deleterious by the concrete industry. Other andesites, particularly those that are slightly altered or weathered, have rather high Plasticity or Clay Indices and perform poorly in road construction.

The performance of the andesites has been investigated and can be shown to be determined by: the chemistry of the rock which in turn determines the chemistry of the glass in the rock; the presence of large amounts of groundmass glass in the rock; and the nature of the superimposed alteration processes. Environment of extrusion and how rapidly the rock has been cooled or chilled are also important as they determine the fabric of the rock and how much glass will be present in the rock.

There are three main types of alteration that affect the quality of the aggregate: hydrothermal alteration, late magmatic alteration associated with the devitrification of glass, and weathering. Each of these alteration types produces different alteration minerals. In fresh andesites the devitrification of glass has an important affect on the rock's properties. The Taranaki andesites are shown to have unusually (in comparison with other North Island andesites) high Na₂O contents, held in the groundmass glass, which is the fundamental reason for the high alkali – silica reactivity of these andesites.

Keywords: *andesites, aggregates, volcanic glass, alkali reactivity*

Introduction

Andesites are widely used as aggregates in the central and northern parts of the North Island of New Zealand. Andesites that provide quality aggregates are all Cenozoic in age and sourced from either the Coromandel Volcanic Zone (eastern North Island), the Taupo Volcanic Zone (central North Island), or the Taranaki area (Figure 1). This paper reviews the properties of the andesites and the role that their glass and its chemistry plays in determining the performance of aggregates sourced from them.

The three groups of andesites can be distinguished in terms of their age, mineralogy and chemistry and in some cases by the properties of the aggregate produced.

The eastern North Island andesites have an age range of 18 to 2 million years although, because of the widespread hydrothermal alteration of older andesites in this zone, few rocks older than 7 million years are quarried. In the central North Island and the Taranaki region the andesites are less than 2 million years old. Andesite flows provide the resource for aggregates extracted from the Coromandel Volcanic Zone but in the central North Island, where andesites are a

minor component of the eruptives, and in the Taranaki area boulders and conglomerates from rivers and laha deposits are quarried. Erosion residuals tend to be hard and are always less vesicular than flow rocks; the vesicular nature of some flows reduces the strength and density of the rocks. Lavas that have strong flow banded textures, caused by alignment of groundmass crystals are platy with close spaced joints that impose limitations on the size of the aggregate that can be produced.

Primary petrologic and chemical features of the andesites

The andesites are all strongly porphyritic with plagioclase (andesine - labradorite) the major mineral constituent of the phenocryst and the groundmass assemblages. The groundmass texture of the andesites ranges from strongly glassy (c.30% by volume) to completely crystalline; flow orientation of groundmass feldspar needles is common.

In the central North Island andesites are dominantly two pyroxene (augite plus hypersthene) bearing (Graham et al, 1995) and so too are the eastern North Island Cenozoic andesites. In contrast the Taranaki low silica andesites are olivine - augite andesites and the higher silica andesites contain augite and hornblende (Price et al, 1999). All of the andesites also contain magnetite. The other major constituent of all the andesites is glass. The amount of glass is determined by cooling regime and the chemistry of the lavas. Generally speaking, the greater the SiO₂ content the higher the amount of glass in the rock and the more viscous the lava.

The three groups of andesites show very similar K₂O contents and all would be classified as medium-K arc volcanics (Le Maitre, 1989). While K₂O contents of the lavas overlap when plotted against silica, and most of the other oxides forming major constituents of the andesites have similar ranges (Price et al 1999), there is a notable difference between the Na₂O content of the Taranaki and the central and eastern North Island andesites. The Taranaki andesites consistently plot against silica showing that they have both a lower overall silica content and also higher contents of Na₂O

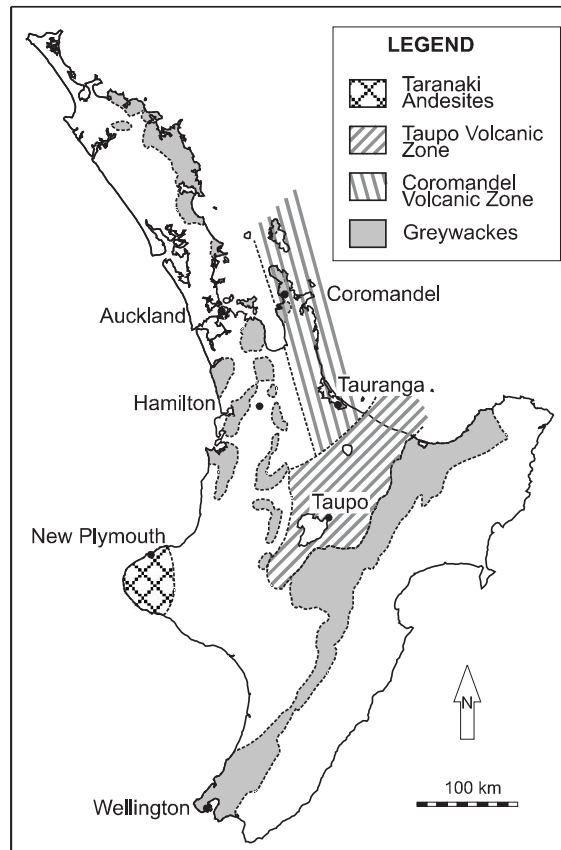


Figure 1: Location map showing the three zones of andesites discussed in this paper and the distribution of greywackes which are the other major aggregate resource of the region.

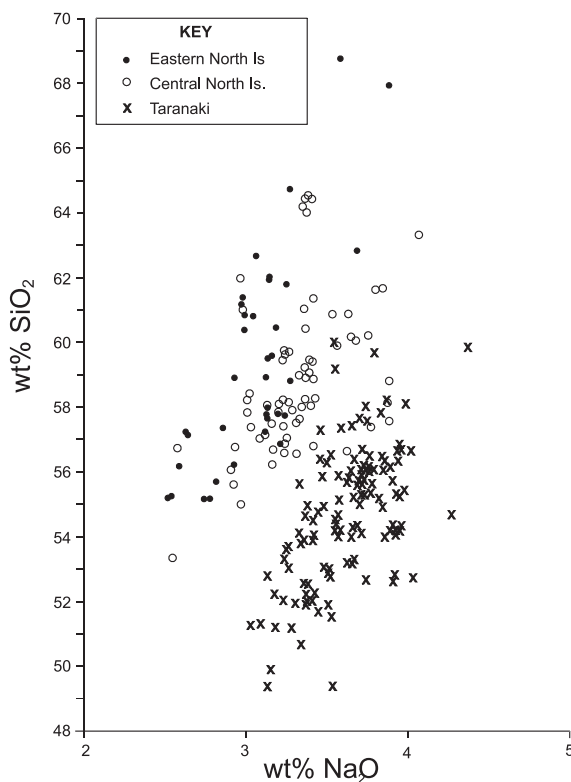


Figure 2: Plot of sodium versus silica for the andesites from the three North Island volcanic zones.

than do the central and eastern North Island andesites (Figure 2). There is no evidence from published mineral data that the Taranaki andesites contain more sodic plagioclases than do the eastern or central North Island andesites. Since the glass is the only other phase that can accommodate sodium it must be presumed that the Taranaki glasses are particularly rich in sodium.

Alteration of andesites and andesitic glass

The alteration of andesites is in a general sense predictable and alteration products have been described by many authors. Weathering will initially produce a smectite and then as weathering (leaching) progresses the smectite will be replaced by a kaolin mineral; high temperature hydrothermal alteration (ie temperatures in excess of 200°C) will result in chlorite, smectite and illite (usually interlayered), while simple devitrification of glass will produce either smectite or smectite and tridymite depending on the chemistry of the glass and conditions of devitrification. Correlation of chemical analyses and X-ray diffraction analysis of the glass (fine fraction) phase of andesites indicates that those with SiO₂ above 60% can be expected to have glass that is rich in both alkalis and silica which will devitrify into smectite with tridymite and occasionally zeolite, while those glasses in andesites with lower silica contents will devitrify to smectite.

In quarrying operations weathered rocks can be avoided and are not used to produce quality aggregates. Hydrothermal alteration that is pervasive affects very large volumes of rocks producing materials that have minerals and properties that are deleterious in aggregates (e.g. high pyrite content and high clay contents); rocks in areas of intense hydrothermal alteration are rarely, if ever, quarried.

It is understandable that if the main minerals in the andesites (plagioclase, augite and either hypersthene or olivine – which are CaO, FeO and MgO – bearing minerals) have a wide stability range then the variation in chemistry shown by the andesites will be located in the volcanic glass which contains most of the alkalis (Na₂O and K₂O) and excess silica in the rock plus minor amounts of aluminium and iron.

Devitrification is a very complex process that may occur any time during or after the cooling of the lava. The rate of devitrification and processes of devitrification have been the subject of many investigations.

All volcanic glasses contain primary fluids but the glasses also readily hydrate and acquire secondary fluids. Rate of hydration is dependent on the temperature, chemical composition of the glass and the relative humidity and chemistry of the environment.

Secondarily hydrated volcanic glasses have been long known to contain significantly lower amounts of sodium and silica than did the primary glass. In a subaerial environment both Na and K are lost from glasses while in the submarine environment there is significant introduction of potassium (Noble, 1967; Benartz & Schminke, 1989). The secondary hydration process ultimately leads to the formation of smectite and the liberation of alkalis by the process of H⁺ substituting for the alkalis in the glass.

In low temperature environments silica-rich volcanic glasses either hydrate, or leach by cation exchange, or the surface of the glass hydrolyses. All these processes are dependent on the hydration energies of cations involved. The alkalis, and particularly sodium, have notably high hydration energies (Lofgren, 1971; Cerling et al., 1985; Casey & Bunker, 1990; Friedman et al., 1997; Morgenstein et al., 1999). In all cases alkaline solutions are known to increase the rate of devitrification.

In thin sections all glassy rocks show some devitrification. In the minimal state of devitrification brown smectite rims vesicles and has formed directly from the hydrolysed glasses (Karakas & Kadir, 2000). In other rocks the glass may be entirely devitrified and replaced by smectite.

Andesites as roading aggregates

Most fresh andesites produce very good aggregates for roading. The abundance of volcanic glass provides strength and homogeneity to the andesite aggregate since glass is harder than pyroxenes and amphiboles (both Mohs hardness of 5 to 6) and just slightly harder than plagioclase feldspar (6-6.5). Glassy rocks produce very angular sharp edged chips with smooth fracture surfaces which do not provide the best adhesive surfaces for bitumen to adhere to. However, most andesites are not strongly glassy and produce angular chips with a more equidimensional shapes. On the negative side, glass is a component with the greatest capacity to reduce the quality of the aggregate since it is the most reactive component of the andesite and it always devitrifies or weathers to produce smectite clays which increase the Plasticity index of the rock; the strength of the rocks also decreases when clay content is high.

Andesites in concrete manufacture

Andesite aggregates provide good density and contribute to low coefficient of thermal expansion values in concrete (MacKechnie, 2004). While some andesites are used as aggregates in the concrete industry most are not as they are considered to be potentially harmful in terms of alkali silica reactions because of their glassy to cryptocrystalline matrices and the presence of cristobalite and tridymite which form from the alteration of the glass. Thus they provide a risk that neither the producer nor consumer is willing to take.

The major problem is with the devitrification products of the glass. Tridymite ($D= 2.18$) and cristobalite ($D= 2.33$), which are common products of devitrification of glass, have a much less dense structure than quartz ($D=2.65$) since they have structures with 6-loop open cavities which are sufficiently large to accommodate alkali ions that are needed maintain charge balance caused by Al^{3+} substituting for Si^{4+} in these silica polymorphs. The large structural cavities also allow ions, sodium in particular, to migrate into the structure and catalyse alkali silica reactions. Thus the process of devitrification both produces alkalies but also the mechanism for the alkalies to migrate and react with silica.

The ASTM C289 Test (the so-called quick chemical test) is widely used to determine the potential reactivity of NZ aggregates derived from volcanic rocks. Figure 3 shows plots of andesites from the three volcanic zones under consideration. The Taranaki andesites plot consistently in the deleterious area (C) of the diagram. The andesites from the eastern and central North Island, although showing wide scatter, plot in either the potentially deleterious or the innocuous fields (B or A respectively). When Figures 2 and 3 are compared it is clear that the high reactivity of the Taranaki andesites must be directly attributable to their high sodium content. The location of sodium is the glasses since there is no other major reservoir for sodium in andesite. Thus it seems that the fundamental, although as yet unexplained, high sodium content of the Taranaki rocks is a directly responsible for the problem of alkali reactivity that these andesites produce in

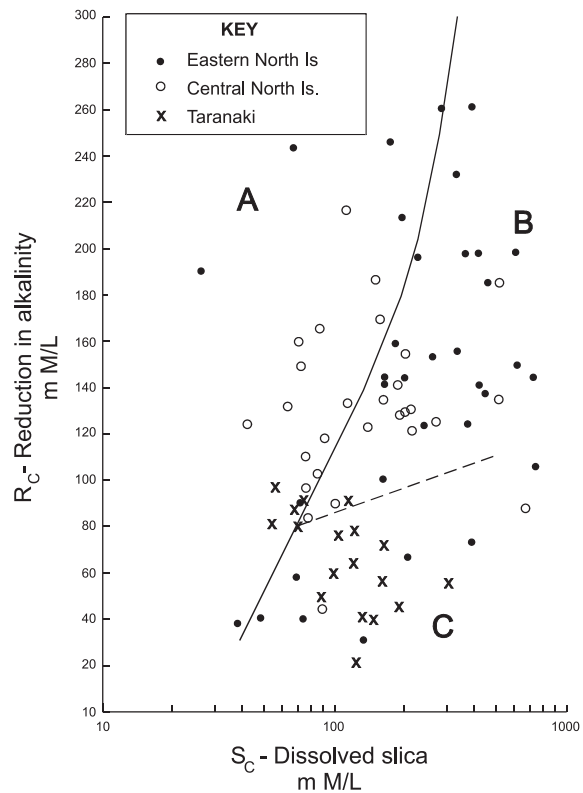


Figure 3: Results of testing various andesite aggregates from the North Island volcanic fields by ASTM C289. Fields on the diagram are : A = innocuous; B = potentially deleterious; C = deleterious. Data combined from Freitag et al., 2003.

concrete and which is less pronounced or absent in most other North Island andesites with similar or higher silica contents.

Conclusions

The glass content of andesites, the glass chemistry, and nature of the alteration and/or devitrification of the glasses are probably the most important factors in determining the quality and reactivity of North Island andesite aggregates. This preliminary study suggests that performance of andesite aggregates might be predicted from the properties, and particularly the chemistry of the glasses contained in them.

Acknowledgements

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