RGNZ/MGPB

Rudarsko-geološko-naftni zbornik
(The Mining-Geology-Petroleum Engineering Bulletin)
DOI: 10.17794/rgn.2026.1.8

Preliminary communication

A preliminary study of the effect of alteration on breakage properties of andesites from Tállya and Recsk (Hungary)

Izabella Rebeka Márkus[1]*, Gábor Mucsi[1], Ádám Rácz[1]

[1] *Institute of Raw Material Preparation and Environmental Technology, Faculty of Earth- and Environmental Sciences, University of Miskolc, 3515 Egyetemváros, Miskolc, Hungary.*

Abstract

This preliminary study investigates the influence of post-magmatic alteration on the breakage behaviour of andesitic rocks during comminution, with particular emphasis on the Chemical Index of Alteration (CIA) and smectite content. Six representative samples from two Hungarian quarries (Recsk and Tállya) exhibiting broadly similar mineralogical and textural properties but varying degrees of alteration were subjected to single particle breakage tests across multiple size fractions. Although the limited dataset does not allow for broad generalisation, the results provide a first indication that increased CIA values and higher smectite contents are associated with greater fragmentation susceptibility, as reflected by elevated A×b parameters. The study demonstrates that alteration indices can provide valuable predictive information on breakage response in andesitic rocks. These findings suggest the importance of integrating alteration metrics alongside traditional mineralogical and textural parameters when evaluating the breakage behaviour of andesitic rocks for aggregates production. While smectite quantification highlights the role of secondary phyllosilicate minerals in reducing the strength of andesitic rocks, CIA offers a more broadly applicable measure of alteration intensity that may be transferable across different volcanic contexts. The results are presented as a case study that highlights the potential of CIA and smectite quantification as predictive tools, while acknowledging the need for further research with larger datasets to confirm these trends.

Keywords:
andesite; aggregate production; drop weight test; alteration; smectite

1. Introduction

The optimisation of comminution processes – namely crushing and grinding – has been a central focus in mineral processing over the past few decades (**Napier-Munn et al., 1996, 2012; Morrell, 2004a; Dominy et al., 2018**), given their status as some of the most energy-intensive operations within the mining sector **(Howarth & Rowlands, 1987; Jeswiet & Szekeres, 2016)**. While numerous studies and industrial efforts have aimed to enhance the efficiency of comminution circuits in ore processing **(Pauw & Maré, 1988; Morrell, 2004b; Wills & Napier-Munn, 2006; Jankovic et al., 2015)**, similar advancements in the aggregate industry remain limited and underexplored **(Csőke et al., 1996; Adel et al., 2006)**. The limited progress in the aggregate sector can largely be attributed to the historically low energy costs, which permitted higher tolerances for by-products and reduced emphasis on end-product quality. However, rising energy demands, increasing costs, and stricter policies on waste reduction have created a pressing need for process optimisation in aggregate production. A key pathway toward cost-efficient production lies in model-based prediction of crushing behaviour, an area to which the present preliminary study seeks to contribute.

In terms of production volume, crushed aggregates constitute the largest segment of the mining industry, and they rank second in economic value (**Menegaki & Kaliampakos, 2010; Přikryl, 2021**). According to data from the European Aggregates Association (**URL 1**), a total of 4.35 billion tonnes of aggregates were produced across Europe in 2023 from 30116 extraction sites, of which crushed rock accounted for 2.13 billion tonnes. The types of rocks used for aggregate production largely depend on the geological characteristics of the production region (**McNally, 1998; Piasta et al., 2018**). In many areas, magmatic rocks such as andesite, granite, and basalt are the primary sources of aggregates. Metamorphic rocks, including quartzite and gneiss, are used less frequently, while sedimentary rocks, such as limestone and dolomite, are generally considered lower in priority but are still utilised where locally available. Due to having one of the lowest average values per unit weight among all mineral commodities, transportation

* Corresponding author: Izabella Rebeka Márkus
e-mail address: izabella.markus@uni-miskolc.hu
Received: 6 July 2025. Accepted: 28 August 2025.
Available online: 2 January 2026

plays a significant role in the overall cost of aggregates (**Drew et al., 2002; Přikryl, 2017**); as a result, extraction typically occurs near the point of use.

The rising energy costs and associated CO_2 emissions, coupled with the depletion of high-quality mineral resources for aggregate production, make process optimisation essential (**Legendre & Zevenhoven, 2014; Liu et al., 2018; Vasilyeva et al., 2023**). Achieving this requires a thorough understanding of the factors influencing crushing operations. The primary factors affecting the crushing processes are the type of equipment used for crushing (**Cleary & Sinnott, 2015; Sinnott & Cleary, 2015; Kamani & Ajalloeian, 2020**) and the geological characteristics of the materials (**Brattli, 1992; Akseli & Leinonen, 2015; Comakli & Cayirli, 2019**).

The influence of geological characteristics on the comminution of rocks has been extensively investigated in literature. These studies can be broadly categorised into two main groups. The first group focuses on ore-bearing rocks, examining their mineralogical composition and identifying the optimal degree of mineral liberation to enhance ore recovery. For example, **Oyarzún & Arévalo (2011)** demonstrated that mineralogical heterogeneity governs fragmentation pathways in porphyry ores**; while Mwaga et al. (2015)** reviewed how geometallurgical approaches integrate comminution testing with ore texture to predict processing performance. **Yuce (2017) and Abdelhaffez (2020)** similarly highlighted that fracture energy and breakage characteristics are strongly dependent on mineralogical composition and pre-existing microstructures**. More recently Semsari Parapari et al. (2020)** showed that ore texture exerts a stronger influence than stress loading conditions on breakage behaviour, while their follow-up study **(Semsari Parapari et al., 2022**) quantified how multivariate textural parameters control mineral liberation, fracture energy, and fragmentation outcomes. The second group addresses rocks used in aggregate production, analysing how mineralogical and microtextural features affect strength parameters and product quality. **Miskovsky et al. (2004)** showed that feldspar-rich granitoids display reduced resistance to impact, whereas fine-grained rocks with interlocked textures perform better under mechanical loading. **Zhang & Subasinghe (2012)** highlighted the importance of particle shape, angularity, and surface texture, showing that these factors control compaction and shear resistance in aggregate-based applications. **Akseli & Leinonen (2015) and Afolagboye et al. (2016)** confirmed that mineralogical variability and microstructural features directly affect crushing strength and long-term performance of construction aggregates.

The mechanical performance of aggregates is strongly controlled by their petrographic and textural attributes. **Ajalloeian & Kamani (2017)** showed that image-analysis-derived texture parameters (grain shape, circularity, orientation) influence Los Angeles abrasion results in carbonate aggregates. **Adomako et al. (2021)**, in a comprehensive review, further highlighted that mineralogy, porosity, and texture collectively govern Los Angeles and Micro-Deval outcomes. The importance of sample preparation and crushing conditions was demonstrated by **Räisänen & Mertamo (2003)**, who showed that laboratory crusher type and settings significantly affect aggregate shape and thereby test results. Similarly, **Hofer et al. (2013)** found that within railway ballast, petrographic variability plays a greater role in Los Angeles test values than particle geometry. **Köken (2020)** expanded this understanding by linking cone crusher size reduction ratios with Shore hardness, abrasion resistance, and textural characteristics across multiple rock types.

Beyond texture, the role of alteration has been repeatedly emphasised. **Török & Czinder (2017)** established correlations between strength parameters and abrasion resistance in Hungarian andesites, while **Czinder & Török (2019, 2021)** confirmed that petrographic variability and progressive alteration reduce both strength and durability indices. **Lampropoulou et al. (2020)** documented similar effects in Greek mafic and ultramafic rocks, where serpentinization and chloritization produced poorer quality aggregates, reflected in higher LA values and greater water absorption. In volcanic rocks, **Petrounias et al. (2018a, 2018b)** demonstrated that secondary phyllosilicate minerals, particularly smectite, are especially detrimental to mechanical behaviour. **Fournari & Ioannou (2019)** corroborated this relationship in crushed fine aggregates from Cyprus, reporting strong correlations between mineralogical composition and durability indicators such as soundness, Micro-Deval resistance, and water absorption.

At a broader scale, decision-support approaches such as the Analytic Hierarchy Process (**Köken et al., 2020**) integrate mineralogical, physical, and mechanical parameters to rank aggregate quality, showing that andesites tend to perform poorest among common igneous rock types. **Strzałkowski et al. (2021)** reviewed the Los Angeles and Micro-Deval methods, underscoring the combined role of petrography, particle morphology, and alteration in fragmentation and abrasion resistance. Site-specific investigations (**Åkesson et al., 2001; Apaydın & Yılmaz, 2021; Okogbue & Aghamelu, 2013; Pomonis et al., 2007; Urueña et al., 2022**) similarly confirm that aggregate quality cannot be decoupled from petrography, alteration, and microstructural attributes.

Magmatic rock quarries usually extract material from a single intrusive body, resulting in relatively uniform mineral composition and texture, although signs of post-magmatic or hydrothermal alteration are often present (**Pereira et al., 2024**). While the influence of mineral composition and texture on grindability and breakage properties has been widely studied, the effect of alteration – particularly the formation of smectite – has received comparatively less attention. Recent laboratory tests on altered andesite have shown that alteration can significantly weaken the rock and influence its failure

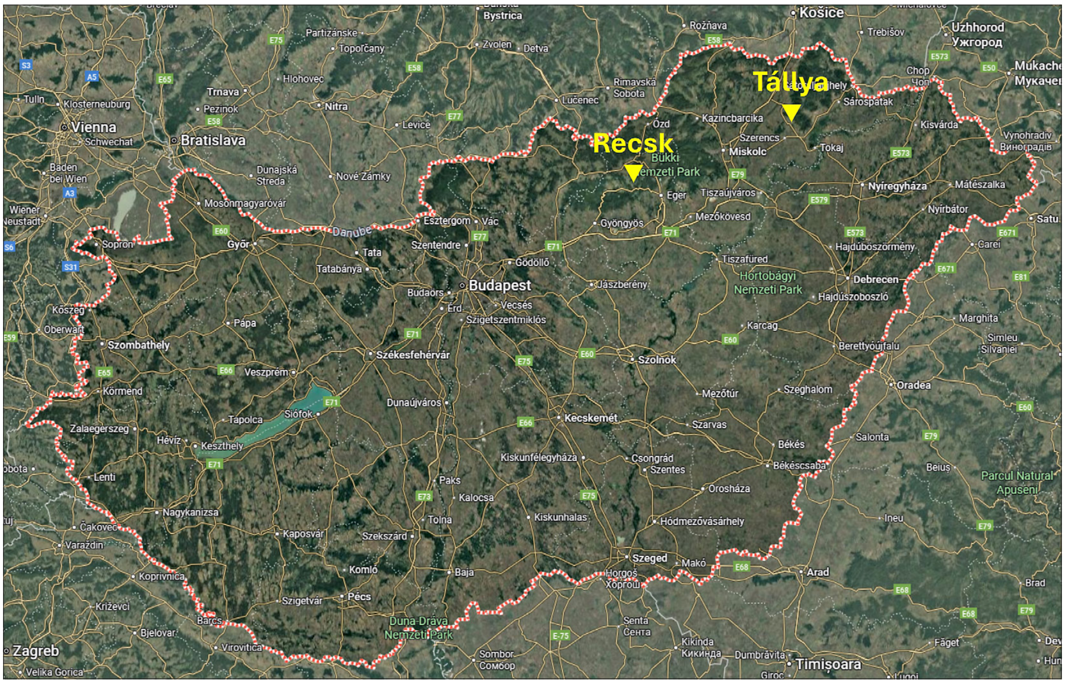

Figure 1. Geographical position of the two studied andesite quarries in Hungary (source: Google Maps)

behaviour (**Pola et al., 2014; Lampropoulou et al., 2020; Pereira et al., 2024**). Supporting this, studies in related fields highlight the importance of alteration intensity on comminution: **Yildirim et al. (2014)** developed the Process Alteration Index (PAI) to predict metallurgical responses linked to alteration, while **Darwish et al. (2025)** demonstrated that the Chemical Index of Alteration (CIA) effectively reflects mechanical weakening in hydrothermally altered uranium-bearing rocks. These findings underscore the need to consider alteration effects – alongside mineralogy and texture – in understanding grindability and breakage behaviour in aggregate production.

The present study provides a preliminary investigation into how alteration intensity and related mineralogical changes affect the breakage behaviour of andesitic rocks during comminution. Six representative samples from two Hungarian quarries were analysed; although limited in number, they were selected to capture a clear contrast in alteration state while keeping mineralogy and texture broadly comparable. The primary aim is to assess whether quantitative alteration indices – specifically the Chemical Index of Alteration (CIA) – and smectite content can be linked to the A×b breakage parameter obtained from drop-weight testing. By doing so, the research seeks to advance understanding of how post-magmatic alteration influences fragmentation susceptibility in volcanic rocks. Although exploratory in scale, this approach contributes new insight by testing the applicability of alteration indices as predictive tools for breakage properties, thereby opening pathway toward more efficient evaluation of crushing behaviour in industrial aggregate production.

2. Materials

For this study, samples were collected from two quarry sites: Recsk and Tállya (see **Figure 1**). Both locations extract andesite-type magmatic rocks formed during Neogene volcanic activity associated with the Inner Carpathian Volcanic Chain. The Tállya quarry is located within the Tokaj Mountains of northeast Hungary, where pyroxene-andesite was formed as a result of volcanic processes during the Sarmatian stage (approximately 12 million years ago) (**Haas et al., 2012**). The andesite quarried at Tállya is a porphyritic volcanic rock with a vitrophyric matrix, containing fine pyroxene needles and lamellar plagioclase. It exhibits columnar jointing, vesicular zones, and characteristic alteration near the margins, where the originally dark grey rock fades to greenish-grey due to hydrothermal processes. Secondary minerals such as spherosiderite, opal, smectites, and chalcedony frequently occur within the vesicles (**Cseh et al., 1990**).

The Recsk quarry, situated in the Mátra Mountains of northern Hungary, also extracts pyroxene-andesite, characterised by a light grey colour, carbonate-altered glassy matrix, unaltered hypersthene, and clinopyroxenes of diopside composition. These rocks originated from an Upper Tortonian volcanic event, dated to approximately 11.5 million years ago. The quarried material at Recsk is a light grey pyroxene-andesite with a carbonate-altered, microholocrystalline matrix containing plagioclase and carbonate minerals. The rock features unaltered hypersthene and clinopyroxenes of diopside composition, along with porphyritic plagioclase, siderite, and magnetite. The intrusive body is rich in

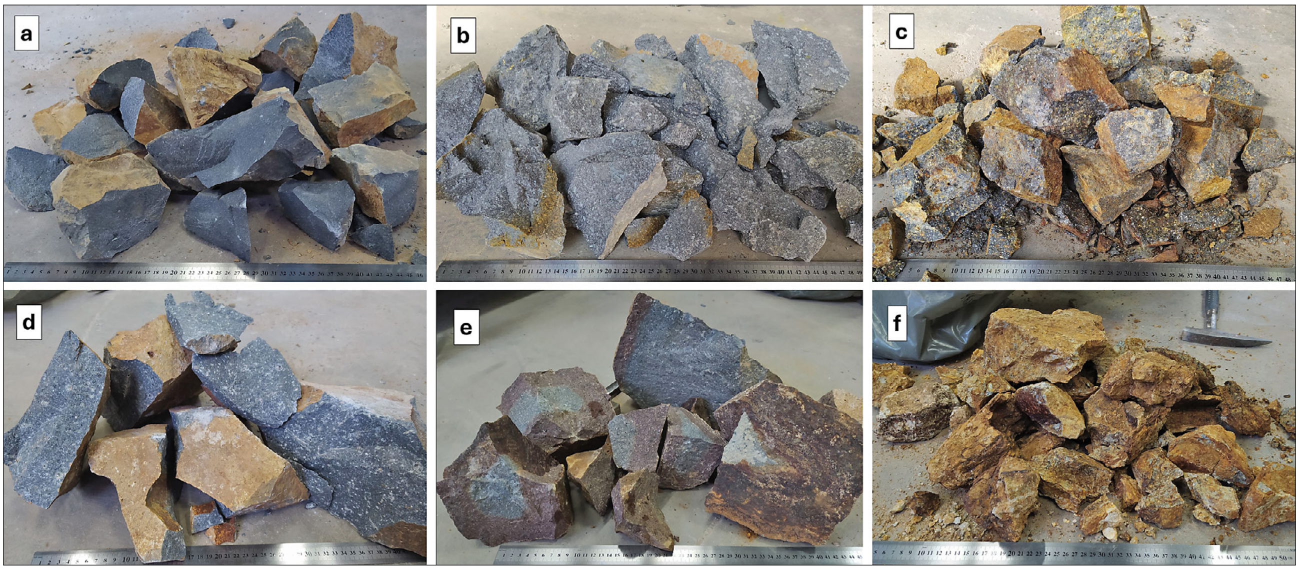

Figure 2. Photographs of the analysed rock samples. Samples labelled with "T" originate from the Tállya quarry, while those marked "R" are from the Recsk quarry. (a – T_1; b – T_2; c – T_3; d – R_1; e – R_3; f – R_4).

voids and secondary mineral fillings, resulting from volatile enrichment caused by the assimilation of Mesozoic carbonate rocks during magma ascent (**Budai et al., 2015**). Despite differences in the timing and location of the volcanic events, the andesite types extracted from the two sites are comparable, exhibiting only minor variations in geochemistry and post-volcanic alteration processes.

Three andesite types were distinguished within the Tállya quarry, from which representative samples were collected. The first sample (T_1) comes from the lower quarry levels and consists of dark grey, microcrystalline andesite with plagioclase phenocrysts (0.5–1 mm), minimal vesicles, and negligible alteration (see **Figure 2a**). The second sample (T_2) was taken from intermediate levels, characterised by lighter grey, moderately vesicular andesite with larger plagioclase crystals (1–2 mm) and signs of moderate alteration (see **Figure 2b**). The third sample (T_3) originates from the upper levels, where strongly altered, vesicle-rich andesite with iron oxide crusts and secondary mineral fillings are present (see **Figure 2c**).

Three andesite types with varying alteration levels were also sampled from the Recsk quarry. The first sample (R_1) originates from the lower quarry levels and consists of medium grey, dense andesite with a microcrystalline matrix, feldspar, quartz, and biotite phenocrysts, and carbonate-filled vesicles (see **Figure 2d**). Alteration is minimal, appearing as scattered greenish-yellow spots. The second sample (R_3) was collected from mid-levels and shows distinct greenish-grey and purplish-brown zones, with biotite and occasional quartz phenocrysts preserved mainly in the less altered areas (see **Figure 2e**). The third sample (R_4) comes from the upper quarry levels and represents strongly weathered, friable andesite with yellowish-brown iron oxide coatings and spheroidal weathering structures; feldspar phenocrysts are present but heavily altered (see **Figure 2f)**.

3. Methods

The mineralogical composition of samples was determined by X-ray powder diffraction (XRD) on a Bruker D8 Discover instrument (Cu-Kα radiation, 40 kV, 40 mA generator settings) in Bragg-Brentano geometry. Recording was done with a LynxEye XE-T position sensitive detector (PSD), 2° window opening. Crystalline phases were identified by Search/Match, on the ICDD PDF2 (2005) database (Bruker DiffracPlus EVA), and phase amounts were calculated with Rietveld refinement in Bruker TOPAS4.

Bulk chemical composition was determined by wavelength dispersive X-ray Fluorescence Spectrometry (WD-XRF) on Cereox cemented powder pellets on a Rigaku Supermini200 type instrument with the Pd-source operated at 50 kV and 4 mA.

The textural features were observed with transmitted light optical microscopy on rock polished thin section in polarised light, using a Zeiss AXIO Imager.M2m microscope equipped with an AxioCam MRc 5 digital camera.

Single particle breakage tests are widely applied to investigate the breakage behaviour of rocks, as they eliminate the machine-induced effects typical of conventional crushing equipment. Among these, the Drop Weight Test (DWT) is a standard method for determining the relationship between applied impact energy and particle size reduction. In this method, a mass is dropped from a controlled height onto a single particle, inducing breakage through compressive and tensile stresses, which allows for the assessment of specific breakage energy and fragmentation characteristics. For this study, a laboratory device operating on the principles of the

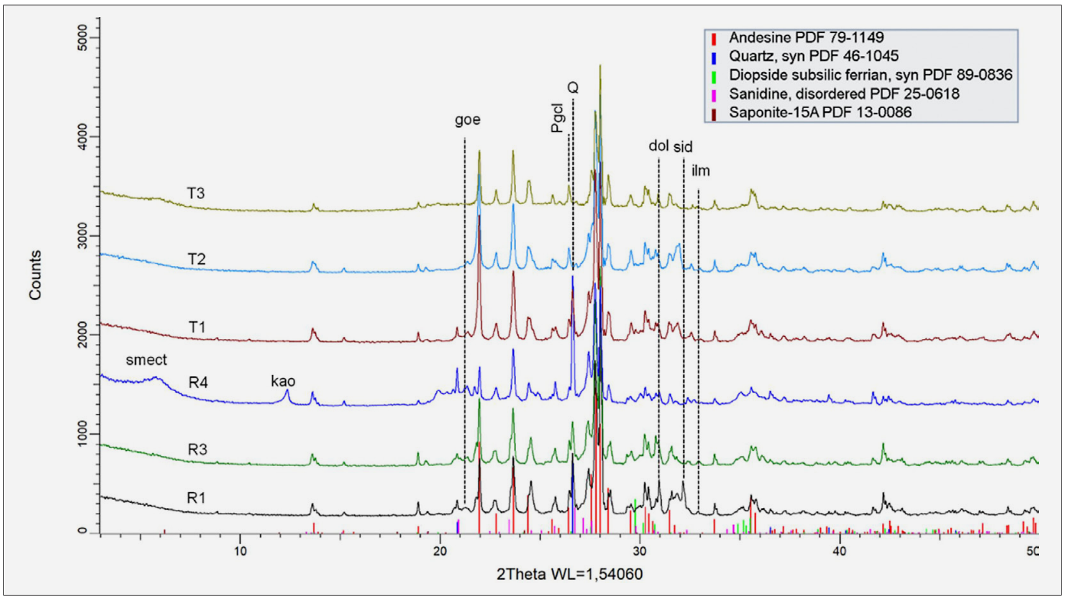

Figure 3. XRD diffractogram of the samples

DWT was constructed and utilised to perform controlled impact tests on the rock samples.

The breakage energy applied during the tests was determined from the mass of the falling weight and the drop height, as expressed by the following equation:

$$E_a = m_w * g * \left(h_i - h_f\right) \quad (1)$$

Where:

- E_a – the breakage energy (m^2 kg/sec^2),
- m_w – weight of the drop weight (kg),
- g – the gravitational acceleration (9.81 m/s²),
- h_i – initial height of the drop weight (m),
- h_f – final height (after breakage) of the drop weight (m).

The specific breakage energy was calculated by relating the applied impact energy to the mass of the tested particle, as shown in the following equation:

$$E_{cs} = E_a / m_p \quad (2)$$

Where:

- E_{cs} – specific breakage energy (kWh/t),
- E_a – the breakage energy (m^2 kg/sec^2),
- m_p – mass of the particle (g).

For breakage energy calculations, the difference between the initial and final drop heights in **Equation 1** was defined using the mean particle size. For the specific breakage energy, the particle mass in **Equation 2** was not measured individually; instead, the total mass of the test sample was recorded and divided by the number of particles to obtain an average particle mass.

Breakage tests were conducted on five specific particle size fractions: 40–45 mm, 25–31.5 mm, 20–22.5 mm, 12.5–16 mm, and 8–11.2 mm. The size fractions were produced by crushing the quarry samples with a jaw crusher, followed by dry sieving. To minimise the influence of particle shape, flaky fragments were removed using a bar sieve with an aperture equal to half the upper size limit (D_i/2) of each fraction. For every andesite type, fraction size range, and impact energy level (levels 1, 2, and 3), a defined number of particles were tested – more for smaller fractions (up to 70) and fewer for larger ones (minimum 20), in total approximately 1900 particles were tested. Each particle was broken individually, the fragments appertaining to one setup were collected, and the resulting size distribution was determined. The entire procedure was repeated three times for each parameter set to ensure reproducibility.

4. Results

4.1. Mineralogical composition

The mineral composition of the samples was analysed by X-ray powder diffraction (XRD), with the results shown in **Figure 3**. Both quarry sites display similar mineralogical characteristics, dominated by plagioclase feldspars (andesine, oligoclase, labradorite), potassic feldspars (sanidine, microcline), quartz, and pyroxenes (diopside, enstatite). Accessory minerals include titanomagnetite and ilmenite, while alteration products such as dolomite, siderite, and smectite were also identified. Amorphous phases, likely linked to both volcanic glass and secondary alteration, were present in all samples. Notable differences include goethite in the Recsk samples and kaolinite in R_4.

Quantitative mineralogical analysis (see **Table 1**) confirmed overall compositional similarities between the sites but also revealed significant variations in individual mineral proportions. These differences reflect both distinct rock genesis and post-intrusion processes,

Table 1. Quantitative mineralogical composition of samples (weight percent, error +/- 5 relative percent)

Sample	T_1	T_2	T_3	R_1	R_3	R_4
Andesine	8.1	8.8	33.3	6,7	23.4	7.9
Quartz	4.2	1	0.6	4.6	3.5	8.5
Sanidine Na0.35	14.4	11.7	0.1	12.3	11.0	7.9
Smectite	1.4	1.4	5.7	2.3	3.1	11.9
Diopside	4.1	5	1.1	4.0	3.2	0.4
Titanomeg-netite	0.3	0.2	0.5	0.2	0.3	0.3
Oligoclase An25	27.8	24.5	22.1	15.3	12.0	9.5
Dolomite	0.6	1.1	0.5	0.74	0.3	0.7
Labradorite An55	13.2	16.1	8.4	29.1	17.7	9.2
Ilmenite	1.2	0.8	0.5	0.3	0.4	1.0
Microcline	2.6	1.2	0.4	0	3.6	8.2
Cristobalite	5.8	6.6	1.2	1.2	1.8	1.0
Enstatite	3.4	3.3	4.9	6.4	7.1	0
Siderite	3.2	3.8	0	5.23	0	0
Kaolinite	0	0	0	0	0	21.0
Geothite	0	0	0	0.82	1.9	2.9
amorphous	9.7	14.8	20.7	10.3	10.7	9.5

including alteration. Feldspar minerals – andesine, sanidine, oligoclase, and labradorite – occur in varying amounts across the samples. In the Tállya quarry samples, andesine increases toward the intrusion margins (8.1–33.3%), while the Recsk quarry samples show no clear trend (6.7–23.4%). Sanidine content rises toward the intrusion margins for samples from both sites (Tállya: 0.1–14.4%; Recsk: 7.9–12.25%). Labradorite varies between 8.4–16.1% in Tállya and 9.2–29.1% in Recsk samples. Total plagioclase content is higher in Tállya samples (49.1–64.2%) compared to those from Recsk (26.6–53.1%). Potassium feldspars (sanidine and microcline), linked to autometasomatic processes, show contrasting trends near intrusion margins, with lower contents in Tállya samples and variable amounts in those from Recsk.

4.2. Textural observations

The Tállya quarry samples (T_1, T_2, and T_3) all exhibit characteristic porphyritic textures, with phenocrysts of plagioclase, pyroxene, amphibole, and occasional alkali feldspars set in a microcrystalline to

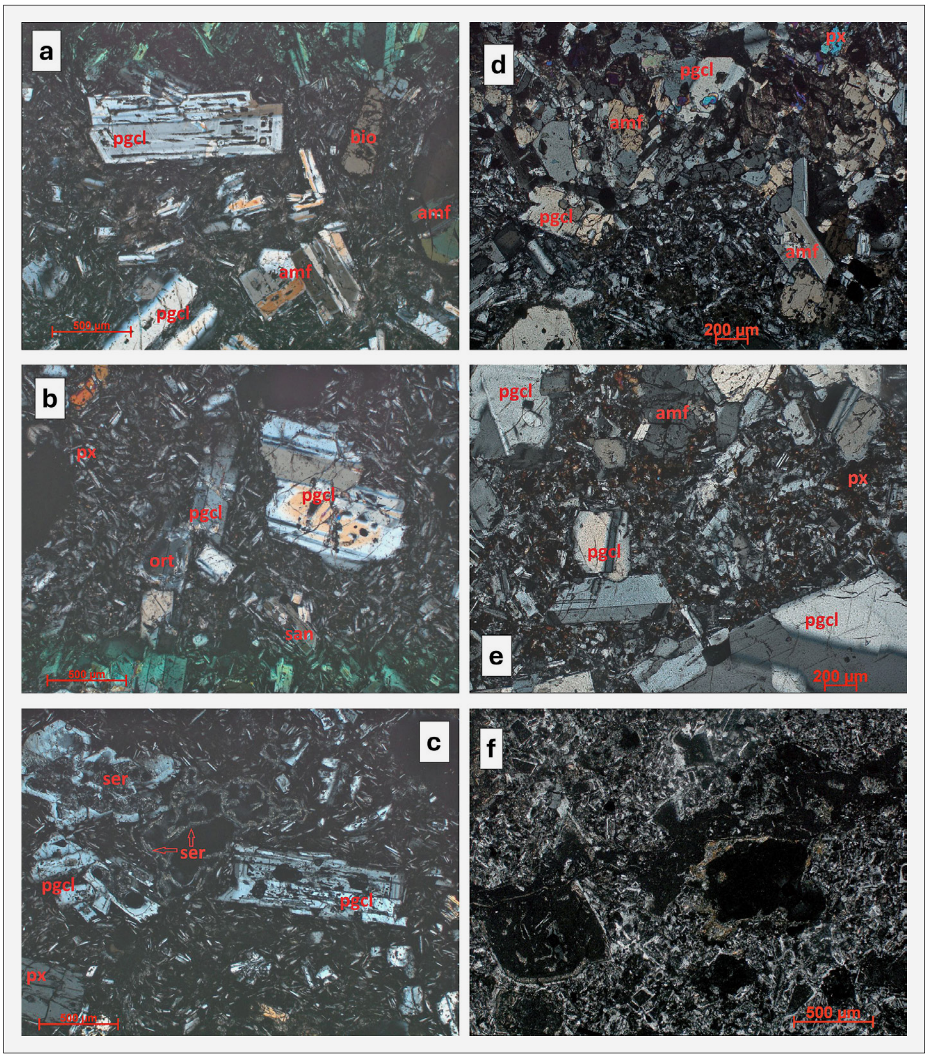

Figure 4. Photomicrographs illustrating the representative textures of the investigated samples. Samples labelled with "T" originate from the Tállya quarry, while those marked "R" are from the Recsk quarry. (a – T_1; b – T_2; c – T_3; d – R_1; e – R_3; f – R_4

cryptocrystalline groundmass. In the least altered sample, T_1, the phenocrysts are well-formed, idiomorphic (see **Figure 4a**). Sample T_2 shows moderate alteration, the phenocrystals being idiomorphic and hypidiomorphic, with slightly rounded edges, although the overall texture remains largely intact (see **Figure 4b**). In the most altered samples, T_3, a reduction in phenocryst size can be observed. The phenocrystals are altered and the presence of alteration products, such as smectite, can be identified. The groundmass remains consistently fine-grained across all three samples, with only minor variations in its grain size; sample T_3 shows a slight increase (see **Figure 4c**).

The Recsk quarry samples present more pronounced textural differences. Sample R_1, sourced from deeper levels of the quarry, displays a coarser texture with abundant, well-preserved phenocrysts, some forming aggregates, set in a relatively fine-grained matrix (see **Figure 4d**). Sample R_3, originating from the intermediate quarry levels, contains notably coarser phenocrysts, particularly plagioclase, while the groundmass grain size remains comparable to that of R_1. However, alteration is more irregular, with Fe-oxide phases partially masking the matrix and signs of phenocryst edge degradation becoming apparent (**Figure 4e**). The uppermost and most altered sample, R_4, differs markedly; phenocrysts are fewer, highly weathered, and reduced in size, recognisable only based on their outline. The groundmass is overprinted by pervasive iron oxide alteration, resulting in a more heterogeneous texture and generally finer matrix compared to the less altered samples (see **Figure 4f**).

Table 2. Chemical index of alteration (CIA) values of the samples

Sample	Chemical Index of Alteration
T_1	58.91
T_2	59.50
T_3	63.99
R_1	58.93
R_3	59.83
R_4	76.41

4.3. Alteration index

Chemical alteration indices are widely used tools for assessing the intensity and nature of rock alteration based on major element geochemistry. Since they rely only on major element compositions, alteration indices can be easily applied to a wide range of geological datasets. The Chemical Index of Alteration (CIA), introduced by **Nesbitt & Young (1982)**, is a widely recognized geochemical metric for quantifying the degree of chemical weathering in rocks:

$$CIA = \left[\frac{Al_2O_3}{Al_2O_3 + CaO^* + Na_2O + K_2O} \right] *100 \qquad (3)$$

Calculated using the molar proportions of major oxides, specifically Al_2O_3, the amount of CaO incorporated in silicates, Na_2O, and K_2O, the CIA provides insight into the extent of feldspar decomposition and the relative enrichment of alumina due to the leaching of mobile cations during weathering processes. This index can sensitively capture subtle variations in alteration degree, even in rocks where mineralogical composition appears broadly consistent.

The Chemical Index of Alteration (**Equation 3**) was calculated from the XRF-derived major element compositions; the results can be found in **Table 2**. Samples from Tállya present slight variation, the T_3 sample being the most altered. In the case of samples from Recsk, sample R1 and R3 present similar alteration, while R4 is strongly altered.

4.4. Breakage properties

Breakage test results were evaluated using the t_n model introduced by **Narayanan & Whiten** (**1983**). The response of a rock to a given energy input can be described with the following equation:

$$t_n = A * \left(1 - e^{-b*E_{cs}}\right) \qquad (4)$$

Where:

A – represents the asymptotic limit to the t_{10} value with increasing impact energy,

b – the curvature of the exponential decay,

E_{cs} – the applied specific energy (kWh/t).

The most commonly used parameter to describe particle breakage is the t_{10} value, which expresses the percentage of product particles passing a size corresponding to one-tenth of the initial mean particle size of the tested material. This breakage index is widely applied in comminution studies as it provides a simple yet effective way to quantify the extent of fragmentation resulting from impact forces. In this study, the t_{10} parameter was determined for each sample based on the post-breakage size distribution. The relationship between the t_{10} values and the applied specific breakage energy, which reflects the energy input per unit mass of the particles, is presented in **Figure 5**.

The A and b values obtained from the model fitting (**Equation 4**) can be used to calculate the A×b value, which represents a single value that represents the susceptibility of a rock to impact breakage (**Powell et al., 2014**). In this study, the results were evaluated separately for each initial particle size fraction (see **Figure 5**), with the t_{10} model fitted individually to each size range. The corresponding A×b values for the samples are summarised in **Table 3**. The obtained A×b values clearly reflect the influence of both particle size and material properties on the breakage behaviour of the tested samples. The A×b values generally decrease with decreasing particle size across all samples, which aligns with typical breakage behaviour, where smaller particles show

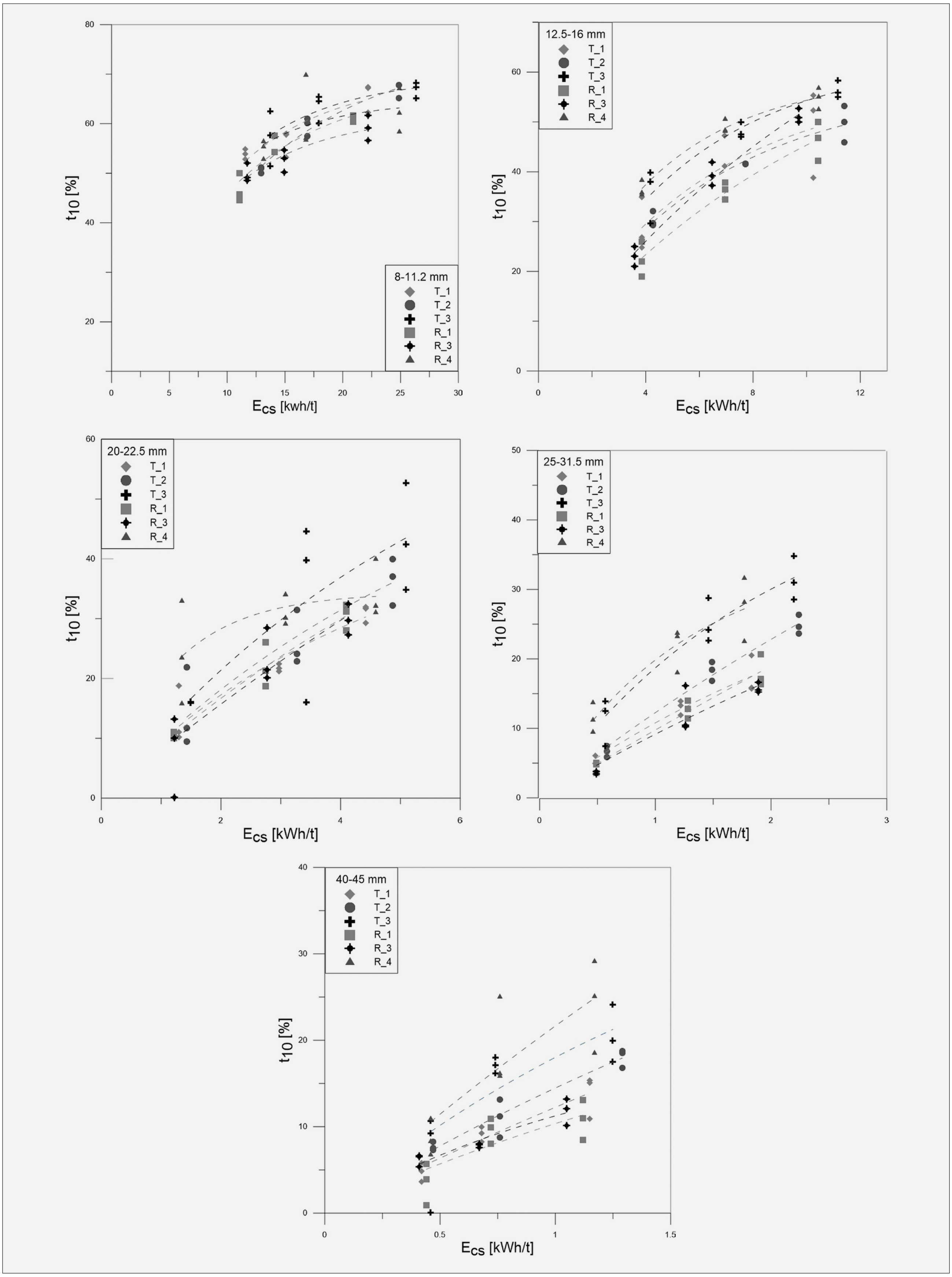

Figure 5. Relationship between t_{10} and specific breakage energy (E_{cs}) for the samples, grouped by initial particle size fraction

Table 3. The A×b value of the samples

Sample	Fraction size	A×b	Fraction size	A×b	Fraction size	A×b	Fraction size	A×b	Fraction size	A×b
T_1	40 – 45 mm	13.24	25 – 31.5 mm	12.58	20 – 22.5 mm	10.62	12.5 – 16 mm	10.28	8 – 11.2 mm	8.44
T_2		16.70		13.21		10.58		9.87		6.62
T_3		28.59		23.79		17.36		12.42		8.94
R_1		15.01		10.06		9.35		6.67		7.62
R_3		16.12		9.91		10.61		6.75		8.36
R_4		24.24		28.98		29.84		14.21		9.77

higher resistance. However, some deviations from this trend were observed. For instance, in the 12.5–16 mm and 20–22.5 mm fractions, sample T_2 exhibited lower A×b values than the less altered T_1, suggesting localized heterogeneities or mineralogical variations influencing breakage susceptibility. Similarly, in the 25–31.5 mm fraction, R_1 showed a lower A×b value compared to R_3, despite both representing relatively unaltered to moderately altered samples.

Overall, the most altered samples (T_3 and R_4) consistently showed the highest A×b values across fractions, highlighting the dominant effect of alteration on increasing breakage susceptibility. Conversely, the least altered samples (T_1 and R_1) mostly exhibited lower A×b values, indicating greater resistance. The intermediate alteration samples (T_2 and R_3) displayed variable behaviour in some size ranges, which may reflect subtle microstructural or compositional differences.

5. Discussion

The influence of mineral composition and texture on particle breakage has been extensively discussed in literature (**Lindqvist et al., 2007; Tavares & das Neves, 2008; Wang, 2015**). However, the present study revealed only minor variations in the mineralogical composition across the investigated samples, largely associated with localised differences in alteration intensity rather than fundamental changes in the primary rock-forming minerals. All samples exhibited broadly similar mineral assemblages typical of andesitic rocks, dominated by plagioclase, pyroxenes, amphibole, and potassium feldspars. Similarly, while porphyritic textures with idiomorphic to hypidiomorphic plagioclase, pyroxene, and amphibole phenocrysts embedded in a microcrystalline to cryptocrystalline groundmass were consistently observed, only subtle textural variations related to alteration progression were present. These included the rounding of phenocryst edges, partial degradation of crystal boundaries, and, in the most altered samples, the near-complete loss of original mineral shapes.

In contrast, the degree of post-magmatic alteration showed a measurable effect on breakage behaviour. To quantify alteration intensity, the Chemical Index of Alteration (CIA) was applied, providing a geochemical proxy based on the depletion of mobile elements (Ca, Na, K) relative to immobile aluminium. Although widely used in geochemistry, sedimentology, and weathering studies, CIA remains relatively underutilised in research focused on the mechanical performance of aggregates.

In this study the relationship between the Chemical Index of Alteration (CIA) and the A×b breakage parameter was examined to explore weather alteration intensity influences fragmentation behaviour (see **Figure 6**). Scatter plots comparing CIA with A×b breakage parameter revealed a consistent tendency for samples with higher CIA values to exhibit greater susceptibility to fragmentation. This trend was clearest in the 20-22.5 mm and 25-31.5 mm fractions, while it was less distinct in the finest and coarsest fractions. These observations suggest that increasing alteration, reflected by higher CIA values, weakens the rock and enhances breakage efficiency, although the strength of the effect appears to vary by particle size. Where the trend was weaker, additional geological factors such as microcracks, porosity or subtle microstructural variability may also have influenced the breakage response. Although the dataset is limited, the observed tendencies are in agreement with broader studies showing that alteration indices provide meaningful predictors of rock behaviour. **Yildirim et al. (2014)**, for example, introduced the Process Alteration Index (PAI) as a geometallurgical tool for linking alteration to comminution response in porphyry copper systems, while **Darwish et al. (2025)** demonstrated that CIA effectively reflects mechanical weakening in hydrothermally altered uranium-bearing rocks. **Pereira et al. (2024)** further emphasised that post-magmatic alteration in volcanic rocks – particularly the formation of secondary clays – reduces their mechanical performance. Taken together, these findings indicate that CIA can serve as a useful geochemical proxy for evaluating the breakage response of altered andesites.

Scatter plots comparing smectite content with the A×b breakage parameter showed similar overall tendency: higher smectite contents were consistently associated with increased fragmentation susceptibility (see **Figure 7**). The effect was particularly noticeable in the coarser fractions, where even modest smectite enrichment corresponded to pronounced increases in A×b values. In finer fractions, the influence appeared less distinct, suggesting that additional geological factors may also contribute to the breakage response. Smectite, a

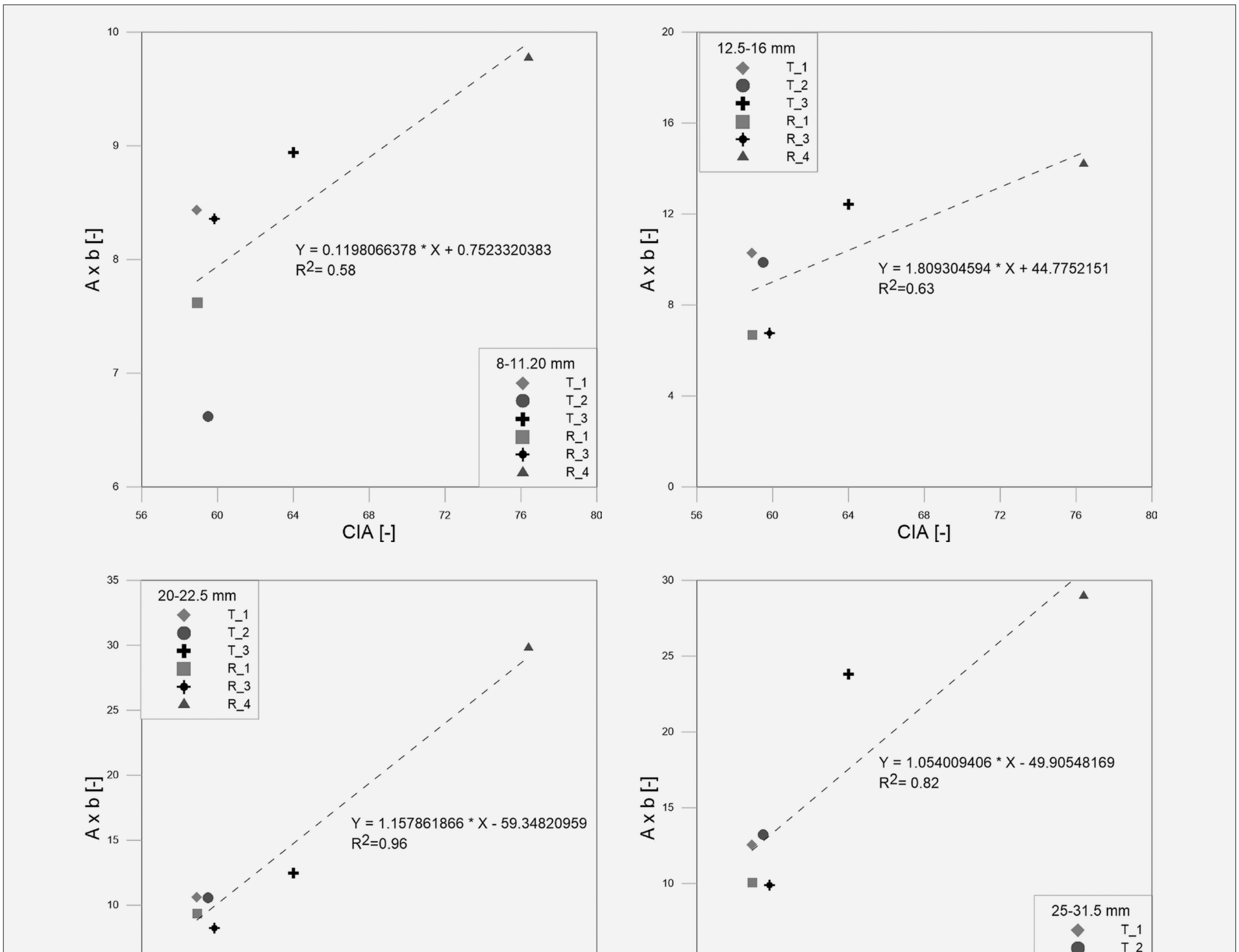

Figure 6. Plots showing the relationship between the Chemical Index of Alteration (CIA) and the A×b breakage parameter for different particle size fractions. The dashed lines are visual aids only, intended to emphasise the overall trend of increasing fragmentation susceptibility with higher smectite content.

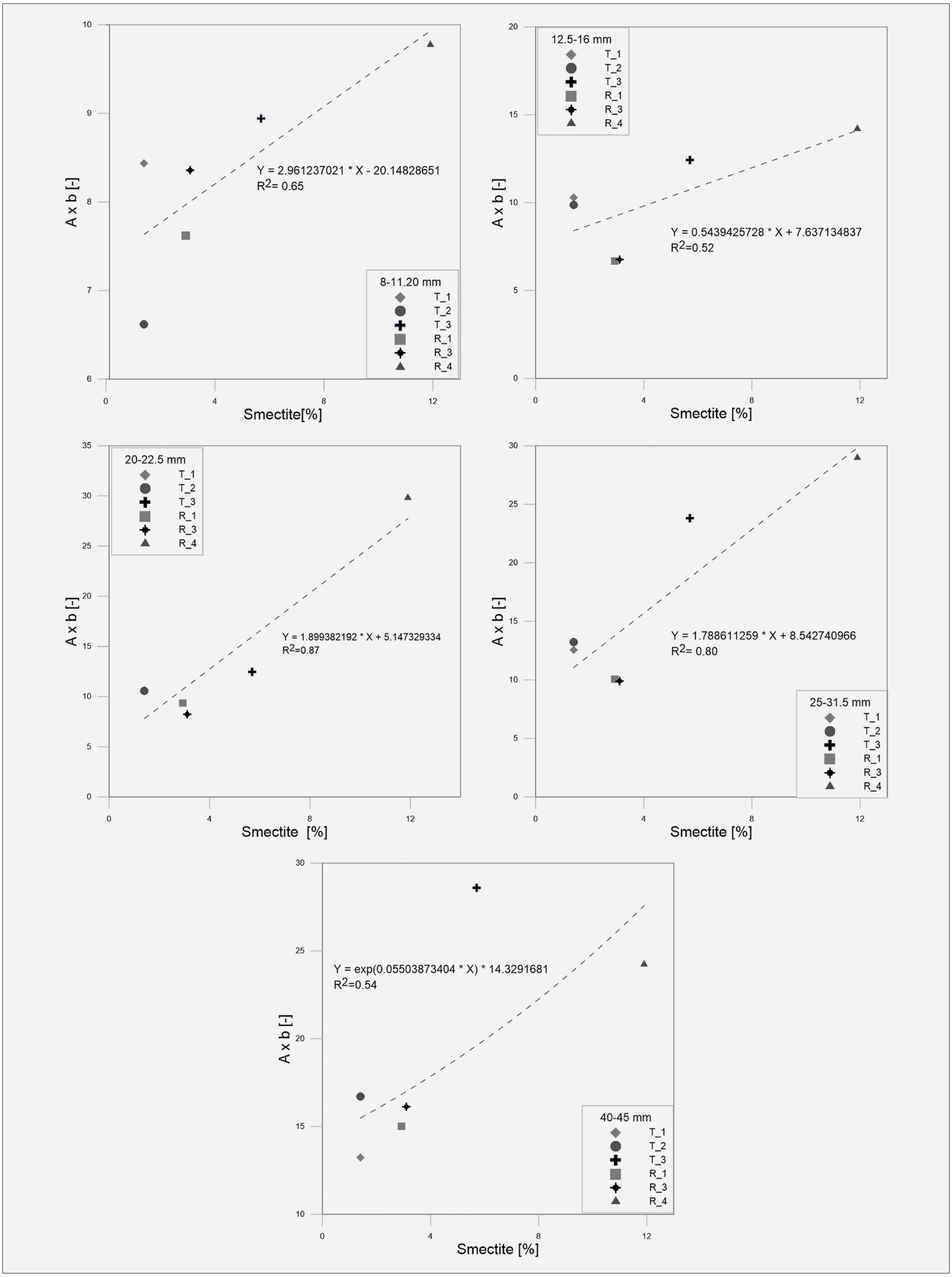

Figure 7. Plots illustrating the relationship between smectite content and the A×b breakage parameter across the investigated particle size fractions. The dashed lines are visual aids only, intended to emphasise the overall trend of increasing fragmentation susceptibility with higher smectite content.

secondary clay mineral formed mainly through low-temperature hydrothermal or weathering processes (**Marfil & Maiza, 2012**), is well known for weakening rock strength, promoting disintegration, and reducing durability due to its swelling properties and high water retention (**Petrounias et al., 2018a**). Even small amounts were linked in our dataset to noticeably higher A×b values, emphasising its disproportionate influence on fragmentation behaviour. These observations are consistent with previous work demonstrating that smectite and other phyllosilicates reduce strength and durability indices in volcanic aggregates (**Petrounias et al., 2018b; Pola et al., 2014**). The present results extend this evidence to controlled comminution testing, confirming the critical role of smectite in rock weakening.

Although smectite quantification captured a clear weakening tendency in our samples, a practical advantage of CIA is its broader applicability across alteration styles. CIA reflects the progressive depletion of mobile cations (Ca, Na, K) regardless of which specific secondary minerals form, making it suitable for felsic, intermediate, and mafic rocks (**Choi et al., 2012**). In contrast, clay-specific metrics (e.g. smectite content) are alteration-pathway dependent and may be less transferable where other assemblages (e.g. chlorite, kaolinite, carbonate) dominate (**Mathieu, 2018**). Given that andesitic systems can host multiple low-temperature assemblages – commonly smectite ± silica ± Fe-sulfates in acid-sulfate settings (**Salaün et al., 2011**) – CIA offers a more general first-order proxy for predicting breakage susceptibility across varied volcanic contexts, while mineralogical quantification remains valuable for mechanistic interpretation.

These exploratory findings complement earlier studies on volcanic and other magmatic rocks, which consistently report that alteration and secondary mineralisation lower aggregate quality and mechanical strength (**Pola, 2014; Czinder & Török, 2019, 2021; Lampropoulou et al., 2020**). They also align with reviews of aggregate performance tests, which highlight petrography, alteration, and microstructure as key determinants of fragmentation and abrasion resistance (**Strzałkowski et al., 2021**). By explicitly linking geochemical and mineralogical alteration indices to drop-weight test results, the present study contributes to bridging a gap between geological characterisation and comminution behaviour.

Although based on a limited dataset, the observed tendencies suggest that alteration indices such as CIA and smectite quantification could serve as first-order indicators of comminution performance. If validated on larger datasets, such metrics could provide quarry operators with practical tools to forecast crushing response before production, thereby supporting process optimisation, energy efficiency, and improved aggregate quality assessment. This preliminary contribution highlights the value of incorporating alteration parameters alongside mineralogical and textural descriptors in evaluating the mechanical response of volcanic rocks.

6. Conclusions

Given the overall uniformity of mineralogical and textural properties across the investigated andesite samples, alongside clear variations in alteration intensity and secondary mineral formation, a focused evaluation of alteration effects on breakage behaviour is particularly justified. While the influence of mineralogical composition and textural properties on fragmentation has been extensively studied, the role of alteration has received far less attention in context of comminution. The present study shows that incorporating alteration parameters such as the Chemical Index of Alteration (CIA) and smectite content provides valuable complimentary information on the weakening mechanism that governs rock breakage. The CIA quantitatively captures the progressive chemical weathering, while smectite content directly reflects the presence of swelling clay minerals that weaken rock strength and promote fragmentation.

The observations indicate that both CIA and smectite exhibit consistent tendencies toward increased fragmentation susceptibility under impact loading. These results are in line with previous findings that emphasised the detrimental effect of alteration and phyllosilicate formation on the mechanical behaviour of volcanic rocks. However, detailed experimental approaches to quantify these effects, such as the one presented here, remain scarce and need to be pursued more extensively in future research.

Although the dataset is limited to six samples from Hungarian quarries – and the findings should therefore be regarded as a preliminary case study rather than representative of all volcanic aggregates – the applied methodology provides a foundation for future large-scale measurement campaigns and points toward the development of machine learning–based predictive approaches.

Despite these limitations, the study highlights the potential value of integrating alteration indices into the evaluation of comminution behaviour. Similar to geometallurgical approaches developed in ore processing, alteration metrics could, if confirmed on larger and more diverse dataset, serve as a practical predictive tool for assessing crushing performance in andesitic rocks. Such an approach would complement traditional petrographic methods, supporting more reliable aggregate quality assessments, better resource management, and improved process efficiency in industrial application.

Acknowledgement

The authors express their gratitude to Richárd Tompa, Quality Control Manager at Colas Északkő Ltd., for his invaluable assistance in sample collection. The authors also wish to extend their thanks to Dr. Ferencz Móricz of the Institute of Exploration Geosciences, University of Miskolc, for conducting the XRF measurements and to

Dr. Kristály Ferenc of the Institute of Exploration Geosciences, University of Miskolc for conducting and evaluating the XRD measurements.

Funding

No funding was received to assist with the preparation of this manuscript.

7. References

Abdelhaffez, G. S. (2020). Studying the effect of ore texture on the bond work index at the Mahd Ad Dahab gold mine: A case study. *Rudarsko Geolosko Naftni Zbornik*, *35*(1), 111–121. https://doi.org/10.17794/rgn.2020.1.9

Adel, G., Kojovic, T., & Thornton, D. (2006). Mine-to-Mill Optimization of Aggregate Production. *2005 SME Annual Meeting: Got Mining - Preprints*. 763-769. DOI: 10.2172/889024

Afolagboye, L. O., Talabi, A. O., & Akinola, O. O. (2016). Evaluation of selected basement complex rocks from Ado-Ekiti, SW Nigeria, as source of road construction aggregates. *Bulletin of Engineering Geology and the Environment*, *75*(2), 853–865. https://doi.org/10.1007/s10064-015-0766-1

Åkesson, U., Lindqvist, J., Göransson, M., & Stigh, J. (2001). Relationship between texture and mechanical properties of granites, Central Sweden, by use of image-analysing techniques. *Bulletin of Engineering Geology and the Environment*, *60*(4), 277–284. https://doi.org/10.1007/s100640100105

Akseli, T., & Leinonen, S. (2015). Influence of Geological Characteristics on Mechanical Properties of Crushed Stone Aggregates Produced from Meta-Volcanic Rocks in Finland. In M. A. Lollino G., Guzzetti F., Culshaw M., Bobrowsky P., & Luino F. (Eds.), *Engineering Geology for Society and Territory - Volume 5,* 111–114. Springer International Publishing. https://doi.org/10.1007/978-3-319-09048-1_22

Apaydın, Ö. F., & Yılmaz, M. (2021). Correlation of petrographic and chemical characteristics with strength and durability of basalts as railway aggregates determined by ballast fouling. *Bulletin of Engineering Geology and The Environment*, *80*, 4197–4205. https://doi.org/10.1007/s10064-019-01654-4

Brattli, B. (1992). The influence of geological factors on the mechanical properties of basic igneous rocks used as road surface aggregates. *Engineering Geology.* 33(1). 31-34 https://doi.org/10.1016/0013-7952(92)90033-U

Budai, T., Csillag, G., Kercsmár, Z., Selmeczi, I., & Sztanó, O. (2015). Magyarország felszíni képződményeinek földtana magyarázó Magyarország földtani térképéhez (1:500 000). (*Surface geology of Hungary: Explanatory notes to the Geological map of Hungary (1:500 000)* Magyar Földtani és Geofizikai Intézet. 62 ISBN 978-963-671-301-0 *(in Hungarian*)

Choi, E.-K., Kim, S.-W., Kim, I.-S., Park, D.-H., & Kim, J.-G. (2012). A study on the Chemical Index of Alteration of igneous rocks. *Journal of the Korean Geotechnical Society, 28*(5), 41–54. https://doi.org/10.7843/kgs.2012.28.5.41

Cleary, P. W., & Sinnott, M. D. (2015). Simulation of particle flows and breakage in crushers using DEM: Part 1 - Compression crushers. *Minerals Engineering*, *74*, 178–197. https://doi.org/10.1016/j.mineng.2014.10.021

Comakli, R., & Cayirli, S. (2019). A correlative study on textural properties and crushability of rocks. *Bulletin of Engineering Geology and the Environment*, *78*(5), 3541–3557. https://doi.org/10.1007/s10064-018-1357-8

Cseh, Z., Daragó, I., Encsy, G., Kozák, E., Mátyás, E., Mészáros, I., Szentmarjai, G., & Zagata, F. (1990). A tállyai kőbánya 60 éve. (*The Tállya quarry – 60 years*) Tokaji Nyomda. Tokaj (*in Hungarian*)

Csőke, B., Pethő, S., Földesi, J., & Mészáros, L. (1996). Optimization of stone-quarry technologies. *International Journal of Mineral. Processing*, *44–45*, 447–459. https://doi.org/10.1016/0301-7516(95)00051-8

Czinder, B., & Török, Á. (2019). Effects of long-term magnesium sulfate crystallisation tests on abrasion and durability of andesite aggregates. *Bulletin of Engineering Geology and the Environment*, *80*, 8891–8901. https://doi.org/10.1007/s10064-019-01600-4

Czinder, B., & Török, Á. (2021). Strength and abrasive properties of andesite: relationships between strength parameters measured on cylindrical test specimens and micro-Deval values-a tool for durability assessment. *Bulletin of Engineering Geology and the Environment*, *80*, 8871–8889. https://doi.org/10.1007/s10064-020-01983-9

Darwish, Y. Z., Embaby, A., Selim, S. M., El Kholy, D. M., Sharafeldine, H. E., & Farag, H. A. (2025). Chemical Index of Alteration and its relation to mechanical properties of hydrothermally uranium-mineralized rocks in Gabal Gattar Area, Northern Eastern Desert, Egypt. *Journal of Mining and Environment*, *16*(1), 75–96. https://doi.org/10.22044/jme.2024.14535.2737

Dominy, S. C., O'Connor, L., Parbhakar-Fox, A., Glass, H. J., & Purevgerel, S. (2018). Geometallurgy – A route to more resilient mine operations. *Minerals,* 8(12). 560. https://doi.org/10.3390/min8120560

Drew, L. J., Langer, W. H., & Sachs, J. S. (2002). Environmentalism and Natural Aggregate Mining. *Natural Resources Research, 11(1),*19-28. https://doi.org/10.1023/A:1014283519471

Fedo, C. M., Nesbitt, H. W., & Young, G. M. (1995). Unraveling the effects of potassium metasomatism in sedimentary rocks and paleosols, with implications for paleoweathering conditions and provenance studies. *Geology, 23*(10), 921–924, DOI:10.1130/0091-7613(1995)023<0921:UTEOPM>2.3.CO;2

Haas, J., Hámor, G., Jámbor, Á., Kovács, S., Nagymarossy, A., & Szederkényi, T. (2012). Geology of Hungary *Regional Geology Reviews* (J. Haas, ed.). Springer Berlin, Heidelberg. 246 https://doi.org/10.1007/978-3-642-21910-8

Howarth, D. F., & Rowlands, J. C. (1987). Quantitative Assessment of Rock Texture and Correlation with Drillability and Strength Properties. *Rock Mechanics and Rock Engineering*, *20*, 57–85. https://doi.org/10.1007/BF01019511

Jankovic, A., Valery, W., & Duffy, K. (2015). Advances in ore comminution practices over the last 25 years. XIV Balkan Mineral Processing Congress, Belgrade, Serbia, 17-19 June 2015. 123-130

Jeswiet, J., & Szekeres, A. (2016). Energy Consumption in Mining Comminution. *Procedia CIRP*, *48*, 140–145. https://doi.org/10.1016/j.procir.2016.03.250

Kamani, M., & Ajalloeian, R. (2020). The effect of rock crusher and rock type on the aggregate shape. *Construction and Building Materials*, *230*. 117016. https://doi.org/10.1016/j.conbuildmat.2019.117016

Lampropoulou, P., Petrounias, P., Giannakopoulou, P. P., Rogkala, A., Koukouzas, N., Tsikouras, B., & Hatzipanagiotou, K. (2020). The effect of chemical composition of ultramafic and mafic aggregates on their physicomechanical properties as well as on the produced concrete strength. *Minerals*, *10*(5). 406. https://doi.org/10.3390/min10050406

Legendre, D., & Zevenhoven, R. (2014). Assessing the energy efficiency of a jaw crusher. *Energy*, *74*(C), 119–130. https://doi.org/10.1016/j.energy.2014.04.036

Lindqvist, J. E., Åkesson, U., & Malaga, K. (2007). Microstructure and functional properties of rock materials. *Materials Characterization*, 58(11-12 SPEC. ISS.), 1183–1188. https://doi.org/10.1016/j.matchar.2007.04.012

Liu, R., Shi, B., Li, G., & Yu, H. (2018). Influence of operating conditions and crushing chamber on energy consumption of cone crusher. *Energies*, *11*(5). 1102. https://doi.org/10.3390/en11051102

Marfil, S., & Maiza, P. (2012). Geochemistry of Hydrothermal Alteration in Volcanic Rocks (D. Panagiotaras, Ed.). InTech Open, London. 514. DOI: 10.5772/1880

Mathieu, L. (2018). Quantifying hydrothermal alteration: A review of methods. *Geosciences, 8*(7), 245. https://doi.org/10.3390/geosciences8070245

McNally, G. (1998). Soil and Rock Construction Materials (1st ed.). London CRC Press. London. 416 https://doi.org/10.4324/9780203476574

Menegaki, M. E., & Kaliampakos, D. C. (2010). European aggregates production: Drivers, correlations and trends. *Resources Policy*, *35*(3), 235–244. https://doi.org/10.1016/j.resourpol.2010.01.003

Miskovsky, K., Taborda Duarte, M., Kou, S. Q., & Lindqvist, P. A. (2004). Influence of the Mineralogical Composition and Textural Properties on the Quality of Coarse Aggregates. *Journal of Materials Engineering and Performance*, *13*(2), 144–150. https://doi.org/10.1361/10599490418334

Morrell, S. (2004a). An alternative energy-size relationship to that proposed by Bond for the design and optimisation of grinding circuits. *International Journal of Mineral Processing*, *74*(1–4), 133–141. https://doi.org/10.1016/j.minpro.2003.10.002

Morrell, S. (2004b). A new autogenous and semi-autogenous mill model for scale-up, design and optimisation. *Minerals Engineering*, *17*(3), 437–445. https://doi.org/10.1016/j.mineng.2003.10.013

Mwaga, A., Rosenkranz, J., & Lamberg, P. (2015). Testing of Ore Comminution Behavior in the Geometallurgical Context - A Review. *Minerals*, *5*, 276–297. https://doi.org/10.13140/RG.2.1.1048.4640

Napier-Munn, T., Drinkwater, D., & Ballantyne, G. (2012). The CEEC Roadmap for Eco-Efficient Comminution. *CEEC/JKTech workshop on eco-efficient comminution. Coalition for Eco-Efficient Comminution https://www.ceecthefuture.org/media/downloads/CEECRoadmap.pdf*

Napier-Munn, T., Morrell, J., Morrison, S., Robert, D., & Kojovic, T. (1996). Mineral comminution circuits: Their operation and optimisation (Volume 2). Julius Kruttschnitt Mineral Research Center. University of QueenslandIndooroopilly, Qld Australia. 413

Narayanan, S., & Whiten, W. J. (1983). Breakage characteristics for ores for ball mill modelling. *Australas Inst. Min. Metall. Bull. Proc*, *286*, 31–39.

Nesbitt, H. W., & Young, G. M. (1982). Early Proterozoic climates and plate motions inferred from major element chemistry of lutites. *Nature*, *299*, 715–717. https://doi.org/10.1038/299715a0

Okogbue, C. O., & Aghamelu, O. P. (2013). Performance of pyroclastic rocks from Abakaliki Metropolis (southeastern Nigeria) in road construction projects. *Bulletin of Engineering Geology and the Environment*, *72*(3–4), 433–446. https://doi.org/10.1007/s10064-013-0489-0

Oyarzún M, & Arévalo A. (2011). Rock Texture and BWi Relationships, El Teniente Ore Deposit, Chile. The First AusIMM International Geometallurgy Conference, 5-7 September 2011 Brisbane, Australia, 181–186.

Pauw, G., & Maré, M. S. (1988). The Determination of Optimum Impact-Breakage Routes for an Ore. *Powder Technology*, *54*, 3–13. https://doi.org/10.1016/0032-5910(88)80043-3

Pereira, M. L., Zanon, V., Fernandes, I., Pappalardo, L., & Viveiros, F. (2024). Hydrothermal alteration and physical and mechanical properties of rocks in a volcanic environment: A review. *Earth-Science Reviews,* 252, 104754. https://doi.org/10.1016/j.earscirev.2024.104754

Petrounias, P., Giannakopoulou, P. P., Rogkala, A., Lampropoulou, P., Koutsopoulou, E., Papoulis, D., Tsikouras, B., & Hatzipanagiotou, K. (2018a). The impact of secondary phyllosilicate minerals on the engineering properties of various igneous aggregates from Greece. *Minerals*, *8*(8). 329 https://doi.org/10.3390/min8080329

Petrounias, P., Giannakopoulou, P. P., Rogkala, A., Stamatis, P. M., Tsikouras, B., Papoulis, D., Lampropoulou, P., & Hatzipanagiotou, K. (2018b). The influence of alteration of aggregates on the quality of the concrete: A case study from serpentinites and andesites from central Macedonia (North Greece). *Geosciences (Switzerland)*, *8*(4). 115 https://doi.org/10.3390/geosciences8040115

Piasta, W., Budzynski, W., & Góra, J. (2018). Properties of Coarse Mineral Aggregates Against Properties of Concrete. *Architecture, Civil Engineering, Environment*, *11*(3), 97–105. https://doi.org/10.21307/acee-2018-042

Pola, A., Crosta, G. B., Fusi, N., & Castellanza, R. (2014). General characterization of the mechanical behaviour of different volcanic rocks with respect to alteration. *Engineering Geology*, *169*, 1–13. https://doi.org/10.1016/j.enggeo.2013.11.011

Pomonis, P., Rigopoulus, I., Tsikouras, B., & Hatzipanagiotou, K. (2007). Relationship between petrographic and physicomechanical properties of basic igneous rocks from the Pindos Ophiolitic Complex, NW Greece. *Bulletin of the Geological Society of Greece*, *40 (2)*, 947–958. https://doi.org/10.12681/bgsg.16778

Powell, M. S., Hilden, M., Ballantyne, G., & Marcelo Tavares, L. (2014). The appropriate, and inappropriate, application of the JKMRC t10 relationship. XXVII International Mineral Processing Congress - IMPC 2014, Santiago, Chile, 20-24 October 2014. Santiago, Chile: Gecamin Digital Publications

Přikryl, R. (2017). Constructional geomaterials: versatile earth resources in the service of humankind – introduction to the thematic set of papers on challenges to supply and quality of geomaterials used in construction. *Bulletin of Engineering Geology and the Environment*, *76*(1), 1–9. https://doi.org/10.1007/s10064-016-0985-0

Přikryl, R. (2021). Geomaterials as construction aggregates: a state-of-the-art. *Bulletin of Engineering Geology and the Environment*, *80*(12), 8831–8845. https://doi.org/10.1007/s10064-021-02488-9

Rigopoulos, I., Tsikouras, B., Pomonis, P., Hatzipanagiotou, K., & Christaras, B. (2017). The influence of alteration on the engineering properties of ultrabasic and basic rocks used as aggregates: The ophiolite complexes of Pindos and Vourinos (Greece). *International Journal of Rock Mechanics and Mining Sciences*, *47(1)*, 69-80. https://doi.org/10.1016/j.ijrmms.2009.04.003

Rigopoulos, I., Pomonis, P., Tsikouras, B., & Hatzipanagiotou, K. (2019). Alteration and mineralogical heterogeneity as key factors controlling the mechanical behaviour of ophiolitic aggregates. Bulletin of Engineering Geology and the Environment, 78, 4379–4395. https://doi.org/10.1007/s10064-018-1374-0

Salaün, A., Villemant, B., Gérard, M., Komorowski, J.-C., & Michel, A. (2011). Hydrothermal alteration in andesitic volcanoes: Trace element redistribution in active and ancient hydrothermal systems of Guadeloupe (Lesser Antilles). *Journal of Geochemical Exploration, 111*(3), 589-83. https://doi.org/10.1016/j.gexplo.2011.06.004

Semsari Parapari, P., Parian, M., & Rosenkranz, J. (2020). Breakage process of mineral processing comminution machines - An approach to liberation. *Advanced Powder Technology*, *31*(9), 3669–3685. https://doi.org/10.1016/j.apt.2020.08.005

Semsari Parapari, P., Parian, M., & Rosenkranz, J. (2022). Quantitative analysis of ore texture breakage characteristics affected by loading mechanism: Fragmentation and mineral liberation. *Minerals Engineering*, *182*. 107561 https://doi.org/10.1016/j.mineng.2022.107561

Sinnott, M. D., & Cleary, P. W. (2015). Simulation of particle flows and breakage in crushers using DEM: Part 2 - Impact crushers. *Minerals Engineering*, *74*, 163–177. https://doi.org/10.1016/j.mineng.2014.11.017

Strzałkowski, P., Duchnowska, M., Kaźmierczak, U., Bakalarz, A., Wolny, M., Karwowski, P., & Stępień, T. (2021). Evaluation of the structure and geometric properties of crushed igneous rock aggregates. *Materials*, *14*(23). 7202. https://doi.org/10.3390/ma14237202

Tavares, L. M., & das Neves, P. B. (2008). Microstructure of quarry rocks and relationships to particle breakage and crushing. *International Journal of Mineral Processing*, 87(1–2), 28–41. https://doi.org/10.1016/j.minpro.2008.01.007

Török, Á., & Czinder, B. (2017). Relationship between density, compressive strength, tensile strength and aggregate properties of andesites from Hungary. *Environmental Earth Sciences*, *76*(18). 639. https://doi.org/10.1007/s12665-017-6977-y

Urueña, C., Möller, C., Andersson, J., Lindqvist, J. E., & Göransson, M. (2022). The effect of metamorphism on the aggregate properties of gabbroic rocks. *Bulletin of Engineering Geology and the Environment*, *81*(5). 231. https://doi.org/10.1007/s10064-022-02718-8

Vasilyeva, N., Golyshevskaia, U., & Sniatkova, A. (2023). Modeling and Improving the Efficiency of Crushing Equipment. *Symmetry*, *15*(7). 1343. https://doi.org/10.3390/sym15071343

Wang, Y. (2015). Numerical modelling of heterogeneous rock breakage behaviour based on texture images. Minerals Engineering, 74, 130–141. https://doi.org/10.1016/j.mineng.2014.12.030

Wills, B. A., & Napier-Munn, Tim. (2006). Wills' mineral processing technology: An introduction to the practical aspects of ore treatment and mineral recovery. Elsevier Science & Technology Books. 444 p. https://doi.org/10.1016/B978-0-7506-4450-1.X5000-0

Yildirim, B. G., Bradshaw, D., Powell, M., Evans, C., & Clark, A. (2014). Development of an effective and practical Process Alteration Index (PAI) for predicting metallurgical responses of Cu porphyries. *Minerals Engineering*, *69*, 91–96. https://doi.org/10.1016/j.mineng.2014.07.009

Yuce, A. E. (2017). Grinding size estimation and beneficiation studies based on simple properties of ore components. *Physicochemical Problems of Mineral Processing*, *53*(1), 541–552. https://doi.org/10.5277/ppmp170142

Zhang, J., & Subasinghe, N. (2012). Extracting ore texture information using image analysis. *Transactions of the Institutions of Mining and Metallurgy, Section C: Mineral Processing and Extractive Metallurgy.* 121(3), 123–130. https://doi.org/10.1179/1743285512Y.0000000011

URL 1: https://www.aggregates-europe.eu/facts-figures/figures/ (accessed 30th June 2025).

SAŽETAK

Preliminarno istraživanje utjecaja alteracije na svojstva usitnjavanja andezita iz kamenoloma Tállya i Recsk (Mađarska)

Ova preliminarna studija istražuje utjecaj postmagmatske alteracije na ponašanje andezitnih stijena tijekom usitnjavanja s posebnim naglaskom na kemijski indeks alteracije (CIA) i sadržaj smektita. Šest reprezentativnih uzoraka iz dvaju mađarskih kamenoloma (Recsk i Tállya), koji pokazuju uglavnom slična mineralna i teksturna svojstva, ali različite stupnjeve alteracije, podvrgnuto je ispitivanjima lomljenja pojedinačnih čestica u više granulometrijskih frakcija. Iako ograničen broj podataka ne omogućuje široke generalizacije, rezultati pružaju početne pokazatelje da su viši CIA indeksi i veći sadržaji smektita povezani s povećanom sklonošću fragmentaciji, što se očituje kroz povišene A×b parametre. Studija pokazuje da indeksi alteracije mogu pružiti vrijedne prediktivne informacije o odgovoru andezita na usitnjavanje. Dobiveni rezultati upućuju na važnost uključivanja parametara alteracije uz tradicionalne mineralne i teksturne karakteristike prilikom procjene ponašanja andezitnih stijena u proizvodnji agregata. Kvantifikacija smektita naglašava ulogu sekundarnih filosilikatnih minerala u smanjenju čvrstoće andezitnih stijena, dok CIA predstavlja šire primjenjivu mjeru intenziteta alteracije koja se može primijeniti u različitim vulkanskim kontekstima. Rezultati se predstavljaju kao studija slučaja koja ističe potencijal CIA indeksa i kvantifikacije smektita kao alata za procjenu, uz naglasak na potrebu za dodatnim istraživanjima s većim brojem uzoraka radi potvrde uočenih trendova.

Ključne riječi:
andezit, proizvodnja agregata, ispitivanje lomljivosti udarnim opterećenjem, alteracija, smektit

Author’s contribution

Izabella Rebeka Márkus (PhD candidate): methodology, investigation, data curation, formal analysis, and writing – original draft. **Ádám Rácz** (Associate Professor): conceptualization, methodology, supervision, and writing – review & editing, **Gábor Mucsi** (Professor): conceptualization, and writing – review & editing.
All authors have read and agreed to the published version of the manuscript.