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INVESTIGATION OF THE PETROLOGICAL PROPERTIES OF ANDESITES FROM TÁLLYA QUARRY, HUNGARY AND THEIR INFLUENCE ON THE RESISTANCE TO WEAR AND FRAGMENTATION

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Abstract: The two most common used mechanical test in the aggregate industry for quality control are the resistance to wear (micro-Deval) and resistance to fragmentation (Los Angeles) tests. The quality of aggregates strongly depends on the textural, structural, and mineralogical features of the crushed material. These rock properties were experimentally studied on andesite samples from Tállya quarry. The mineralogical and chemical composition of samples were determined, textural observations were made on thin sections. The alteration was quantified using the chemical composition and mineralogical data. Micro-Deval and Los Angeles tests were conducted on the samples. The micro-Deval indices and the Los Angeles values showed similar trends, although the different type of stresses. The results showed that the examined mechanical properties of the Tállya andesites are complexly influenced by the textural and structural features, mineralogical composition, and alteration, however alteration has one of the most significant effects.

Keyword: *Rock texture, mineralogical composition, weathering index, micro-Deval, Los Angeles*

1. INTRODUCTION

The quality standards for mining aggregates are constantly becoming stricter in the EU therefore it is very important for the processing plant to produce the best quality products with the highest possible yield. The quantity of the good quality resources is decreasing, while the sustainable raw material management requires the utilisation of the low-quality raw materials with the compliance to the quality requirements for the products. The quality requirements of aggregates can be achieved by crushing and screening technology, for which it is essential to explore the relationship between the feed quality and the crushing and screening process. This depends on a lot of factors, such as the textural, structural, and mineralogical features of the feed material and the operating conditions and machine parameters of the crushers. In this paper the term texture is referred to the mineralogical composition, distribution, grain, shape, size, mode of interlocking, while the term structure to the mineral grain orientation, cracks and any other voids, and visible sign of alteration.

The relationships between petrological and mechanical properties of rocks have been investigated by numerous authors [1, 2]. The mechanical properties are mainly influenced by the mineral association, their distribution, shape, size, orientation or in other words the texture and the degree of alteration, cracks, and porosity.

There are conflicting findings on the effect of primary minerals such as quartz and feldspar contents on the mechanical strength of rock aggregates [3]. Secondary minerals, such as clay minerals and micas contribute to a decrease of rock strength, along with the altered plagioclase. The effect of alteration and the type of alteration, beyond the fact that behaves as a plain of weakness, can be significant. For example, an alteration zone abundant in potassium feldspar will be much harder to crush than a phyllic alteration zone that is rich in sericite [4].

In the case of similar mineralogical composition, the effect of the rock texture is more significant than the mineralogy itself [5, 6]. Akseli and Leinonen [7] emphasizes that the resistance to wear depends more on mineralogical composition, while the resistance to fragmentation depends more on the changes of the texture. The decrease in grain size of the minerals results in the increase of its specific surface, which leads to an increase of bond strength and hardness. If a mineral occurs as larger aggregates composed of several smaller grains, these may interact as a larger grain and give properties that compare with a coarser-grained rock, phase contact may act as discontinuities having an influence on fragmentation [8]. The shape and roughness of mineral grains influences the contact surface between the grains. The grain boundary irregularity results in extent intergrowth and strong bond between minerals which has a great impact on crack formation and on the strength properties [9]–[11]

A significant part of the presented studies focuses on magmatic rocks and ores. The presented petrological features and their effect on mechanical properties of rocks are relevant in the case of rocks of magmatic origin. However, the systematic study of one rock type, for example andesite, with different textural and structural properties is scarce in the international literature. The scope of our study was to examine the petrological properties of andesites from the Tállya quarry (Hungary) and their effect on mechanical properties of aggregates.

2. MATERIAL AND METHODS

Samples were collected from three different operation levels within the Colas Északkő Ltd. operated Tállya quarry. The locations were selected based on the quality of quarried material, the sample Tállya_1 representing a good quality finely grained, dark grey coloured columnar andesite, without signs of alteration or cracks. The sample Tállya_2 constitutes of finely grained, light purplish-grey vesicular andesite, . The third sample Tállya_3 was consists of altered, poor quality andesite with visible signs of alteration and oxidation *(Figure 1)*.

Figure 1
The collected samples from the Tállya quarry, from the left to right: Tallya_1, Tallya_2 and Tállya_3

X-ray powder diffraction analysis were carried out at the Institute of Mineralogy and Geology on a Bruker D8 Discover instrument, with Cu-Kα radiation (40 kV, 40 mA generator settings).

Chemical analysis was carried out at the Institute of Mineralogy and Geology by X-ray fluorescence spectroscopy on Cereox cemented powder pellets by wavelength dispersive measurement (WD-XRF) on a Rigaku Supermini200 type instrument. The chemical composition was used for the quantification of the alteration of the samples. Weathering indices measure the degree of depletion of mobile components relative to immobile components caused by the weathering.

Nesbitt and Young [12] proposed the following equation for the quantification of weathering, which they named Chemical Index of Alteration (CIA):

$$CIA = \left[\frac{Al_2O_3}{Al_2O_3+CaO^*+Na_2O+K_2O}\right] * 100 \quad (1)$$

where CaO^* is the amount of CaO incorporated in the silicate fraction of the rock, a correction is made for the carbonate and apatite content. The resultant value is a measure of the proportion of Al_2O_3 versus the labile oxides in the analysed sample. Harnois [13] proposed the following modified Chemical Index of Weathering (CIW) equation:

$$CIW = \left[\frac{Al_2O_3}{Al_2O_3+CaO+Na_2O}\right] * 100 \quad (2)$$

During the weathering Si, Mg, Ca and Na are leached, Al and Ti remain essentially in the system, iron and potassium have more complicated behaviour. Both indices increase with the degree of alteration, the range of the values depends on the mineralogical composition of individual samples, thus it can range from 0 to 100.

The thin section used for the polarized optical microscopy observation was prepared in the laboratory of the Institute of Mineralogy and Geology. The polarized optical microscopy observation was made in the Optical Microscopy Laboratory of

the Institute of Mineralogy and Geology on a Zeiss Axio Imager A2m optical microscope equipped with AxioCam MRc 5 digital camera for image acquisition.

The resistance to wear was determined in accordance with the MSZ EN 1097-1:2012 standard Tests for mechanical and physical properties of aggregates- Part 1: Determination of the resistance to wear (micro-Deval) [14] in the laboratory of the Institute of Raw Material Preparation and Environmental Processing. The test consists of measuring the wear produced by friction between the aggregates and an abrasive ball charge in a rotating drum under defined conditions. The test is conducted in a typical micro-Deval apparatus which consists of a hollow drum and rotated on a horizontal axis. The test is carried out on aggregate with the particle size between 14 mm and 10 mm. 500 ±2 g sample is placed in the drum with 5000 ±5 g of steel balls and 2,5 ±0,05 l of water, and rotated at a speed of 100 ±5 min^{-1} for 12000 ±10 revolutions. After the required revolution number, the material is emptied and the quantity of material retained on the +1,6 mm sieve is dried at 110 ±5°C and the mass is determined. The micro-Deval coefficient is calculated with the following equation:

$$M_{DE} = \frac{500-m}{5} \quad (3)$$

where m is the mass of the oversize fraction retained on a 1,6 mm sieve in grams.

The resistance to fragmentation was determined in compliance with the MSZ EN 1097-2:2020 standard Tests for mechanical and physical properties of aggregates- Part 2: Methods for the determination of resistance to fragmentation[15]. The test is conducted in a Los Angeles test machine, which consists of a hollow drum made of steeland rotates on a horizontal axis. The ball load consists of 11 spherical steel balls, the total load weighting between 4690 g and 4860 g. The test is caried out on an aggregate with the particle size between 14 mm and 10 mm 5000 ±5 g of sample is placed in the drum with the ball load, then the drum is rotated for 500 revolutions at a constant speed between 31 min^{-1} and 33 min^{-1}. The material is emptied on a 1.6 mm sieve and carefully washed. After drying it at 110 ±5 °C the mass of the retained material is weighted. The Los Angeles coefficient is calculated with the following formula:

$$LA = \frac{5000-m}{50} \quad (4)$$

where m is the mass retained on the 1,6 mm sieve in grams.
Lower M_{DE} and LA values representing better quality rock, and higher resistance against the stress.

3. RESULTS

3.1. Mineralogical composition

The XRD results did not show major differences in the type of rock forming minerals, just in their amount *(Table 1)*. The primary rock constituent minerals are intermediate plagioclases, mainly the oligoclase variety. The ratio of oligoclase

shows no significant changes in the sample being between 27,8–22,1 %. The group of intermediate plagioclases, alongside the oligoclase comprises the andesine and labradorite. This varieties form a solid-solution series with different ratios of Na-Ca content, but with similar mineralogical properties, thus treating the group as one mineral is more practical from the point of view of our study. The K-feldspars, sanidine and microcline in the case of the studied samples, are the products of the auto metasomatism occurring during the cooling phase of the magma, a faster decrease in temperature near the surface results in a decrease in the amount of K-feldspars as it can be seen in the case of sample Tállya_3 compared to the other two samples. Similar to the plagioclase feldspars, the K-feldspars have almost identical composition and properties, which results in similar properties, thus treating them as one is practical in the case of our samples. The amorphous content shows an inverse relationship with the depth related to the surface. The sample Tállya_1 has the lowest quantity of amorphous material resulting from the slower solidification and cooling of magma, while the sample Tállya_3 has the highest amount of amorphous material being at the marginal region of the rock body, cooling down faster resulting in an increase of glassy phase.

Table 1

Quantitative mineralogical composition of the samples (weight percent, error +/–5 relative percent)

Sample	Andesine	Quartz	Sanidine Na0.35	Smectite	Diopside	Titano-magnetite	Oligoclase An25	Dolomite	Labradorite An65	Ilmenite	Microcline	Cristobalite	Enstatite	Siderite	amorphous
Tállya_1	8.1	4.2	14.4	1.4	4.1	0.3	27.8	0.6	13.2	1.2	2.6	5,8	3.4	3.2	9.7
Tállya_2	8.8	1	11.7	1.4	5	0.2	24.5	1.1	16.1	0.8	1,2	6.6	3.3	3.8	14.8
Tállya_3	33.3	0.6	0.1	5.7	1.1	0.5	22.1	0.5	8.4	0.5	0,4	1.2	4.9	0	20.7

3.2. Chemical composition and alteration indices

The major element composition from the XRF analysis is presented in *Table 2*. Similar to the mineralogical composition, the results show no significant differences between the samples, variations can be seen in their amount. The increase in SiO_2 and Al_2O_3 is in correlation with the increase in the amorphous material. The difference up to 100% of the total is mainly the loss on ignition resulting from dehydration (amorphous material, smectite) and carbonate decomposition (siderite, dolomite). The minor amount of S is indicative for presence of sulphides, observed as rare pyrite grains.

Table 2

Chemical composition of the samples (weight percent, error +/–1 relative percent)

Sample	SiO_2	Al_2O_3	MgO	CaO	Na_2O	K_2O	Fe_2O_3	MnO	TiO_2	P_2O_5	S	Σ
Tállya_1	58,0	16,0	1,63	6,15	3,13	2,05	6,86	0,15	1,13	0,28	0,18	95,5
Tállya_2	57,3	15,9	1,33	6,08	2,95	2,10	7,09	0,18	1,16	0,29	0,13	94,5
Tállya_3	59,1	17,2	0,96	5,23	2,24	2,35	5,79	0,07	1,26	0,28	0,01	94,5

A direct relationship between the chemical composition of the material and the mechanical features cannot be drawn based on the earlier literature review, but it can be used for quantifying the degree of the weathering of the samples [16]. There are several calculation modes applied in the literature as presented previously by *Equation (1)* and *(2)*.

$$[12]CIA = \left[\frac{Al_2O_3}{Al_2O_3+CaO^*+Na_2O+K_2O}\right] * 100[14][14][14][14][14][14][14][14][14][14]CIW =$$

$$CIA = \left[\frac{Al_2O_3}{Al_2O_3 + CaO^* + Na_2O + K_2O}\right] * 100[14][14][14][14][14][14][14][14][14][14]CIW$$

$$= \left[\frac{Al_2O_3}{Al_2O_3 + CaO + Na_2O}\right] * 100\text{The}$$

$$CIW = \left[\frac{Al_2O_3}{Al_2O_3 + CaO + Na_2O}\right] * 100\text{The}$$

Table 3

Calculated alteration indices of the samples (dimensionless values)

Sample	CIW	CIA
Tállya_1	63,26	58,91
Tállya_2	63,72	59,50
Tállya_3	69,70	63,99

Based on the nature of our samples, the dolomite [$CaMg(CO_3)_2$] content which contributes to the amount of CaO, and the K content, we considered more appropriate the use of the CIA proposed by Nesbitt and Young for the quantification of alterations

3.3. Textural properties

Based on the polarized light microscopy observation made on the thin sections the three samples have slightly different texture. The sample Tállya_1 has the largest phenocrystals and the finest grained matrix *(Figure 2)*. The phenocrystals are mainly plagioclase, which are generally idiomorphic, without signs of alteration, the size of individual minerals ranging from 200 μm up to 1000 μm, frequently forming aggregates with pyroxene and amphiboles. Beside the plagioclase, pyroxenes phenocrystals and rarely amphiboles can be observed which are slightly resorbed and altered. The matrix consists of finely grained acicular plagioclase, amorphous

material, and opaque minerals, which based on the XRD results are probably titano-magnetite and ilmenite.

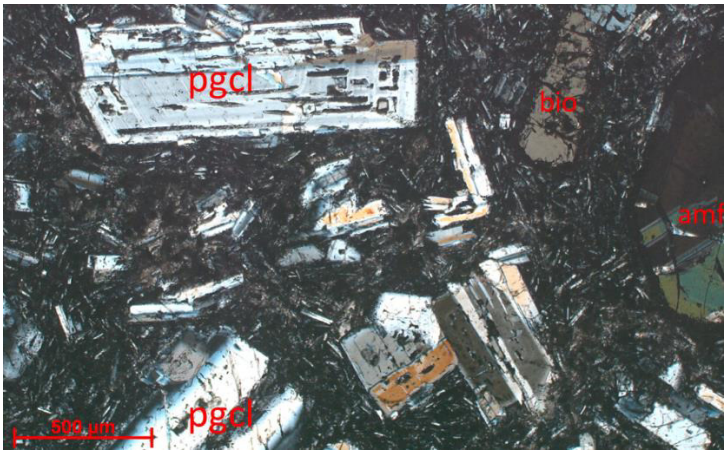

Figure 2

Polarized light optical microscopy image (+N) of the sample Tállya_1 (pgcl-plagioclase, amf- amphibole, bio- biotite)

In the sample Tállya_2 the size of the phenocrystals decreases, appearing mostly as anhedral to subhedral crystals with resorbed margins. The amount of amphibole and pyroxene phenocrystals decreases and they appear strongly fractured, altered. In the pores 150–500 µm radial siderite aggregates could be identified. The composition of matrix is similar to the previous sample but shows a significant increase in the grain size and extensive patches of carbonatization (dolomite based on the XRD results) could be identified *(Figure 3)*.

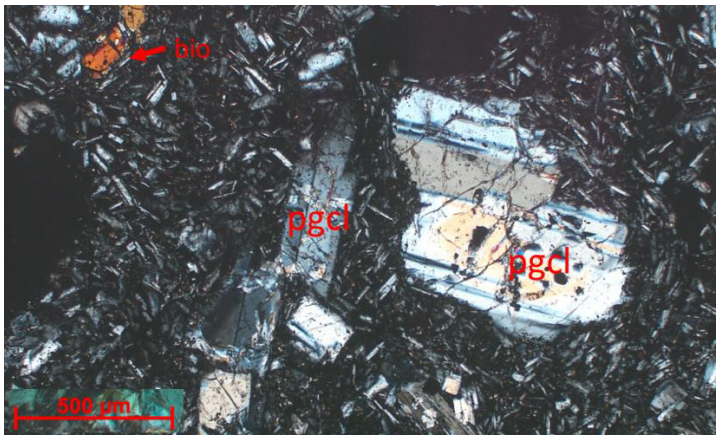

Figure 3

Polarized light optical microscopy image (+N) of the sample Tállya_2 (pgcl-plagioclase, bio- biotite)

The sample Tállya_3 is strongly altered which is in relationship with the increased amount a smectite detected by the XRD. The grain size of the phenocrystals and matrix is similar to the previously described Tállya_2 sample. The phenocrystals have a hypidiomorphic appearance, presenting strong signs of alteration. In the matrix the frequent presence of opaque and isotropic patches is related to the presence of amorphous materials, such as Fe-oxide-hydroxides and glass *(Figure 4)*.

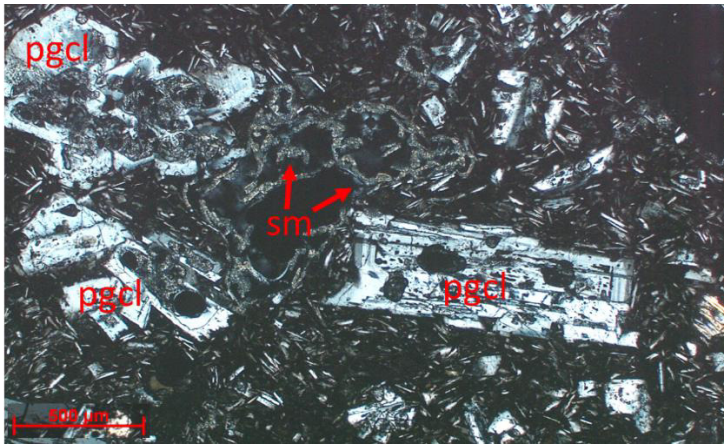

Figure 4

Polarized light optical microscopy image (+N) of the sample Tállya_3 (pgcl-plagioclase, bio- biotite, sm- smektite)

3.4. Resistance to wear

The resistance to wear was measured in the case of all three samples in accordance with the standard MSZ EN 1097-1:2012 and calculated with the formula given in *Equation (3)*. The samples showed an increase in the M_{DE} value, being least resistant to wear with the increasing degree of alteration *(Table 4)*. The M_{DE} values were plotted versus the alteration indices *(Figure 5)*. The change in the M_D values is not linear with the change in the alteration indices, which leads us to the conclusion that other petrological and mechanical factors have an effect, especially in the case of the difference between sample Tállya_1 and Tállya_2. The K-feldspar content has a negative correlation, while the amorphous material content has a positive correlation with the M_{DE} values *(Table 4)*.

Table 4

M_{DE} values of the samples and the K-feldspar and amorphous material content

Sample	M_{DE}	K-feldspar	amorphous
Tállya_1	3.94	17%	9.7%
Tállya_2	8.79	12.9%	14.8%
Tállya_3	20.66	0.5%	20.7%

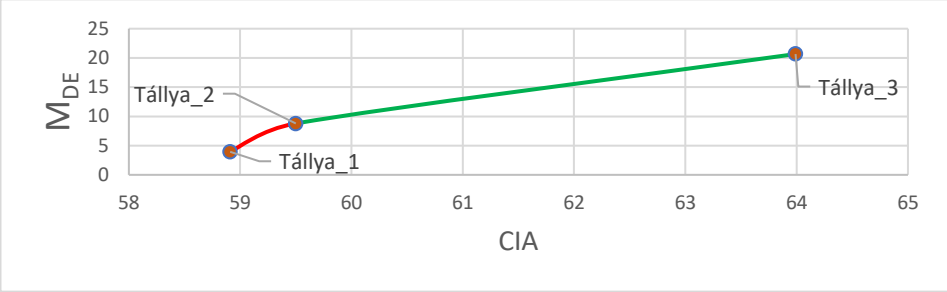

Figure 5
The relationship between M_{DE} indices and CIA

3.5. Resistance to fragmentation

Measuring of the resistance to fragmentation was carried out according to the standard MSZ EN 1097-2:2020 and *Equation (4)* presented before in the case of all three samples. The LA values showed similar trend to the M_{DE} values, the difference between the samples being even more significant *(Table 5)*. Plotting the LA values versus the CIA *(Figure 6)*, the change in the LA is not linear with the change in the CIA indices. Similar to the M_{DE} indices, the LA values show negative correlation with the K-feldspar and positive correlation with the amorphous material content.

Table 5
LA indices of the samples and the K-feldspar and amorphous material content (wt%)

Sample	LA	K-feldspar	amorphous
Tállya_1	14.85	17%	9.7%
Tállya_2	23.05	12.9%	14.8%
Tállya_3	37.2	0.5%	20.7%

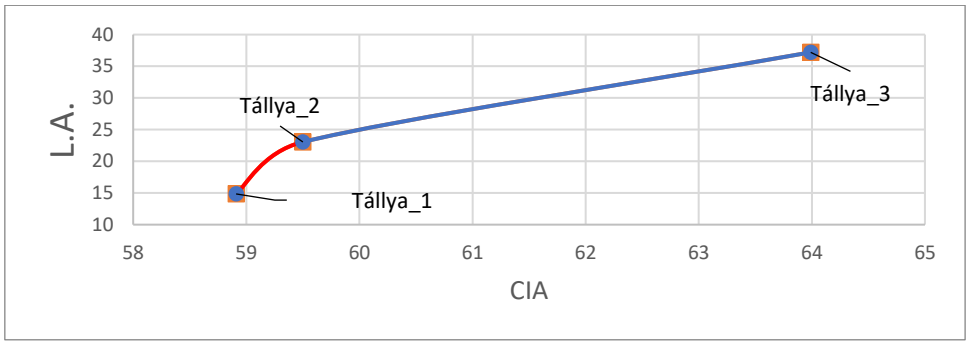

Figure 6
The relationship between LA values and CIA

4. DISCUSSION

In the present study, the relationship between mineral composition, texture, alteration and mechanical properties of andesites was investigated.

The mineralogical composition of the samples determined with XRD did not show significant difference in the case of rock forming minerals. The amount of K-feldspars showed an increase with the degree of alteration and a decrease with the decrease of the depth of the sample related to the surface and thus within the rock body. The amorphous content showed an inverse trend.

Based on the mineralogical results the positive influence of the quartz and the low quantity of amorphous material in the case of sample Tállya_1 is expected on the resistance to wear. The higher smectite content of the Tállya_3 sample has a negative influence on the mechanical properties of the sample. The increase of the K-feldspar and quartz content and decreasing smectite and amorphous content resulted in increasing resistance to the wear and LA values, thus the effect of the mineralogical composition is evident.

The optical microscopic observations revealed differences in the particle size and shape of phenocrystals. A decrease in the size of phenocrystal and the loss of their own shape could be observed with the increase of alteration, while an increase of the grain size of the matrix could be observed. The XRD and XRF result were used in the quantification of the alteration of the samples, complemented with the optical microscopic observation for the identification of the smectite type. The CIW and CIA are appropriate tools for quantifying the state of the alteration of samples, however we find the CIA to be more applicable in the case of our samples because of K content and Ca content in form of carbonates. The resistance to wear and fragmentation showed positive correlation with the alteration indices, but the change in the M_{DE} and LA values was not linear with the change in alteration indices. In the case of samples Tállya_1 and Tállya_2 the changes in the M_{DE} and LA values are also influenced by other petrological factors as the mineralogy and texture.

The grainsize of the matrix is the smallest in the Tállya_1 and the largest in the sample Tállya_3, which results decreasing cohesion between the grains [2], [9], as it is reflected in the results of the resistance to wear and fragmentation tests. The presumption that the irregular grain contact surface results in stronger intergranular bond [10], [11] was not supported by our results. Based on our optical microscopic observations the sample Tállya_2 should have resulted the highest M_{DE} and LA values. In the case of sample Tállya_3 the grain boundaries present greater irregularity then in the case of Tállya_2, but the alteration and the presence of smectite mineral plays a key role in the low resistance to wear and fragmentation.

The results showed that the examined mechanical properties of the Tállya andesites are complexly influenced by the textural and structural features, mineralogical composition, and alteration.

5. SUMMARY

The petrological properties of samples collected from Tállya quarry were determined. The XRD was used for the identification and quantification of mineralogical composition. The chemical composition was determined using XRF, from the results alteration indices were calculated for the quantification of the alteration. Polarised optical microscopy observations were made on thin section with the purpose of identifying main textural features and the type of alteration of the samples.

The resistance to wear was measured using the micro-Deval method recommended by the MSZ EN 1097-1 standard. The resistance to fragmentation was measured based on the MSZ EN 1097-2 standard using the Los Angeles method. The two methods apply different type of stresses, the Los Angeles test creates mainly impact stress, while the micro-Deval creates attrition. The two different stresses could result in different results, but the finding of our examination gave similar trends, the Tállya_1 sample representing the lowest M_{DE} and L.A. value, while the Tállya_3 the highest.

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