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Feldspar Potential in Namibia
– Evaluation of Economic Suitability

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Cover photo: © BGR-GSN-Project
Pegmatite of the De Rust pegmatite swarm northeast of the Brandberg massif, Namibia. These pegmatite bodies, which intruded into metasediments of the Amis River Formation, may host considerable amounts of tin, tantalum as well as lithium-bearing minerals and feldspar.

Feldspar Potential in Namibia

– Evaluation of Economic Suitability

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List of Abbreviations

BGR	Bundesanstalt für Geowissenschaften und Rohstoffe (Federal Institute for Geosciences and Natural Resources)
BGS	British Geological Survey
BMZ	Bundesministerium für wirtschaftliche Zusammenarbeit und Entwicklung (Federal Ministry of Economic Cooperation and Development)
EGD	Economic Geology Division
GSN	Geological Survey of Namibia
RTS	Reverse trade statistics
SADC	Southern African Development Community
USGS	United States Geological Survey

1 Introduction

In 2019, mining contributed 9.3 % to the Namibian gross domestic product and more than 50 % to its export revenues. The mining industry also has a significant impact on Namibian society through its potential to enhance local value addition and job creation. However, as in other sectors of Namibian industry, the mining sector faces a number of challenges and there remain untapped opportunities to bolster the Namibian economy, notably, concerning non-metallic commodities other than diamonds.

In order to expedite its growth potential, the Namibian Government, in 2015, launched the “Growth at Home” strategy for industrialisation. The “Growth at Home” strategy focusses on domestic value addition and mineral beneficiation figures prominently within this context. It is against this background that the Federal Institute for Geosciences and Natural Resources (BGR), on behalf of the Federal Ministry of Economic Cooperation and Development (BMZ) of Germany, cooperates with the Geological Survey of Namibia (GSN).

In 2017, BGR and GSN jointly implemented a project entitled “Sustainable Use of Namibia’s Mineral Potential” that contributes to the “Growth at Home” strategy by focussing on non-metallic commodities. The objective of this ongoing project is to support the Economic Geology Division (EGD) staff in taking custody and exploring potentials of local value addition of Namibia’s non-metallic minerals. These include industrial minerals, with feldspar being one facet among this wide spectrum of commodities.

The BGR-GSN-Project investigated various pegmatites in central and southern Namibia regarding their mineral potential during several field campaigns. Representative feldspar grab samples were taken from these pegmatite occurrences for subsequent chemical analysis and interpretation regarding their suitability for economic application. There is considerable economic potential for feldspars as a constituent in the production of ceramics and glass, among others.

This study aims to illustrate the potential of feldspar occurrences in Namibia and thus promote local value addition. It shall be of value to the Namibian government, to potential investors, to mining and exploration companies, as well as to the general public.

2 What is feldspar

Feldspar minerals make up 60 – 65 % of the Earth's crust and are thus the most important rock forming minerals. They belong to the group of silicates and are commonly expressed as three endmembers: potassium/potash feldspar (varieties orthoclase, sanidine, microcline, adular; $KAlSi_3O_8$), sodium/soda feldspar (albite, $NaAl_2Si_2O_8$) and calcium feldspar (anorthite, $Ca_2AlSi_30_8$; cf. Figure 1). Barium feldspar, celsian, occurs only rarely. Pure endmember compositions are only infrequently found in nature, whereas a wide range of solid solution compositions are common between potassium and sodium endmembers, called alkali feldspars and between sodium and calcium endmembers, called plagioclases. There is a considerable miscibility gap between potassium and calcium endmembers, i.e. there is no solid solution between them. The specific density of alkali feldspar ranges between 2.55 and 2.63 g/cm^3, while that of plagioclase varies between 2.62 and 2.76 g/cm^3 (Deer et al. 1992).

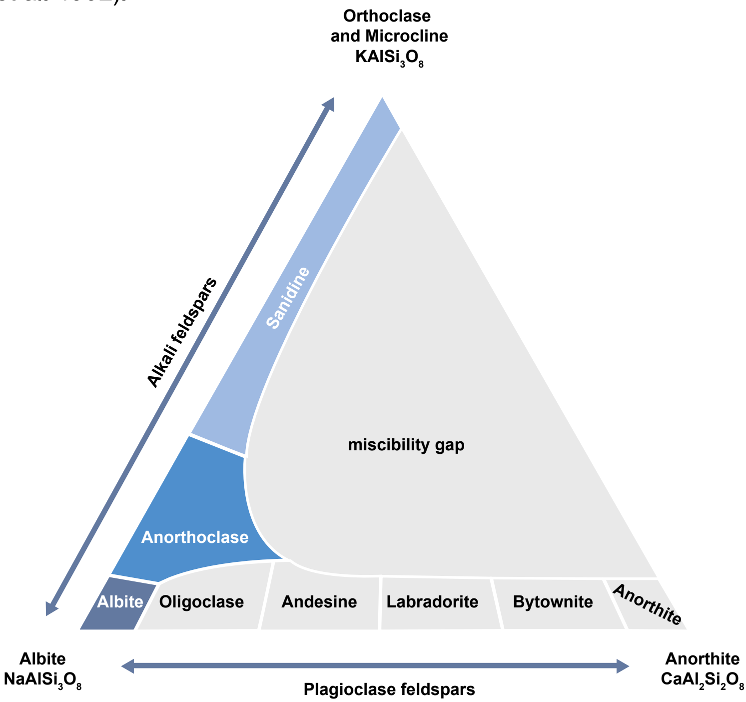

Figure 1: Feldspar triangle indicating solid solution compositions of plagioclases and alkali feldspars feldspars (after Deer et al. 1992).

Feldspars are not water-soluble, but will transform through hydrothermal and weathering processes into a variety of secondary minerals such as kaolinite, zeolite, and sericite. Plagioclases weather more readily than alkali feldspars, which results in a higher portion of potassium feldspars in weathered residues, such as feldspar sands.

2.1 Feldspar deposits

Generally, feldspars form through magmatic and metamorphic processes, of which the former is more relevant for the formation of potential feldspar deposits. Feldspars occur in the following primary and secondary context:

Pegmatites or **aplites** are very coarse or finer grained felsic dykes, respectively and develop as highly differentiated magma intrudes into the country rock, crystallizing either very slowly (pegmatites) or quite fast (aplites). Because of their fractionation processes, pegmatites carry not only quartz, feldspar and mica, but may also be considerably enriched in incompatible elements, rare metals and gemstones. Because of their intrusive character, pegmatites are of limited three-dimensional extent from a few meters to several hundred meters or even kilometres in length. Pegmatites represent the most important host for feldspar deposits in Namibia.

Some extrusive **igneous (rhyolite, trachyte) rocks** and their intrusive equivalents (granite, syenite) are particularly rich in feldspars. They form as felsic magma either erupts on earth's surface or intrudes into the bedrock, subsequently solidifying into volcanic and plutonic rocks, respectively. Thoroughly weathered deposits (usually under humid conditions) play a key role for the recovery of feldspar as unfavourable elements were removed and plagioclases transformed to kaolinite.

Pegmatite or feldspathic sand refers to feldspar-rich and kaolinite-bearing quartz sands that originate from (also in-situ) weathering processes.

Feldspar-bearing quartz sands may show varying, but typically minor amounts of feldspar and usually only traces of kaolinite. They are predominantly exploited for their silica content, but the presence of feldspar allows for special applications.

As Namibia has been subject to an extremely arid climate since the emplacement of feldspar-bearing magmas, significant weathering processes leading to the formation of weathered or secondary feldspar deposits are not known. Pegmatites on the other hand bear significant potential for feldspar deposits in Namibia (Figure 2).

Figure 2: Large feldspar crystals within pegmatite in central Namibia (hammer for reference) (Photo: BGR-GSN-Project 2019).

2.2 Classification of resource size

Pegmatitic feldspar deposits can be classified regarding their resource size (Table 1). After Lorenz (1991) and Orris & Bliss (1992), the following reference values can be applied [run-of-mine ore]:

Table 1: Reference values (run-of-mine ore) for resource size classification after Lorenz (1991) and Orris & Bliss (1992).

Size	Lorenz (1991)	Orris & Bliss (1992)
small	50,000 – 100,000 t	< 400,000 t
medium	100,000 - 1 Mt	400,000 - 4 Mt
large	1 - > 10 Mt	> 4 Mt

3 Application

Of economic interest are mainly the potash and soda feldspars due to their chemical composition, i.e. potassium and sodium content. Plagioclases on the other hand, are only rarely required by the industry. Feldspar as an industrial mineral is primarily used by the ceramics industry and subordinately in the glass industry. Different chemical compositions go along with different sintering and melting properties, which results in numerous applications.

In the **ceramics and porcelain industry**, alkali feldspars are used as a flux, i.e. their addition reduces the onset temperature of yielding/melting point (transition to melt phase) as well as the sintering point (transition partial melting/agglomeration) of the raw materials (other constituents: clays, kaolin, quartz sand; Figure 3) and enamel/glaze. This is mainly induced by the alkali ratio of the feldspars and thus contributes significantly to energy reduction during the firing process. An interlocked glass matrix forms while cooling, resulting in specific product attributes such as porosity, water absorption, transparency and impermeability.

Figure 3: Several raw materials such as feldspar, quartz and kaolin serve as feedstock for ceramic masses (Photo: BGR).

For the production of ceramic masses (Figure 4), which are a mixture of raw materials, as well as in **glazes** and in **enamel** mainly soda and potash feldspars are used. “Impure” feldspars that contain both endmembers are also valuable because of their aluminium content. It reduces tension in the crystal lattice and thus reduces fire cracks and improves evenness, chemical durability and rupture strength of the final product.

Figure: 4: Before application in the final stage, feldspar raw material passes through various intermediate processing steps from filter cake to ceramic masses (Photo: BGR).

Figure 5: Application of glaze on ceramic product. (Photo: with kind permission of KPM Berlin).

Figure 6: Feldspar is an important constituent in tableware (Photo: BGR).

Masses for ceramic products and porcelain on average contain the following portions of feldspar:

• Wall tiles:	0 – 10 %
• Floor tiles (interior):	15 – 25 %
• Stone ware (exterior):	30 – 50 %
• Ceramics (e.g. vase):	0 – 52 %
• Sanitary ware (e.g. sink):	20 – 30 %
• Dental ceramics:	70 – 85 %
• Electrotechnical porcelain:	20 – 28 %
• Bone china (best quality):	20 – 30 %
• Glaze (Figure 5):	12 – 36 %
• Tableware (Figure 6):	20 – 25 %
• Meissen porcelain:	25 – 26 %
• Bisque ware (e.g. sculpture):	45 %
• Enamel:	0 – 30 %
• Soft paste porcelain:	30 – 35 %

High quality or pure feldspars serve as feedstock for **dental prostheses** (filling, crown, veneers, Figure 7). The feldspars are first milled and subsequently cleaned and annealed. Dental ceramics show very similar physical properties as natural dentition, enabling ideal insertion. Nowadays so-called composite dental prostheses are preferred, which also contain compound/composite material along the ceramic raw materials. Ultrapure feldspars are still required for UV-hardening fillings and artificial dentition.

Figure 7: Dental prostheses (Photo: dental-inno/Pixabay).

For the production of clear and coloured container **glass** (Figure 8), as well as float glass, mirrors, crystal glass, optical and technical glass, and glasses used in the automobile industry or in laboratories alkali feldspars are preferred because of their potassium, sodium, aluminium and silica content.

Potassium (K_2O) fosters the dissolution of raw materials and together with sodium (Na_2O) also influences the expansion coefficient of glass. Aluminium (Al_2O_3) impedes devitrification and increases the durability as well as the viscosity of the melt, facilitating mechanical moulding during the production of container glass. Feldspars are a favourable source for silica as they have

Figure 8: Feldspar is an important component for the production of clear and coloured container glass (Photo with kind permission of Aktionsforum Glasverpackung).

a significantly lower melting point as quartz sand (SiO_2), which would only slowly dissolve in the glass melt. This accelerates the melting process and thus decreases the energy required.

Glasses not based on recycled glass on average contain the following amounts of feldspar:

- float glass: < 1 %
- technical glass: 2 %
- clear container glass: 7 – 9 %
- cosmetic glass: 8 – 9 %
- crystal glass: 9 – 11 %
- coloured glass bottles: 10 – 15 %

The production of coloured, e.g. brown or green glass does not demand high purity feldspars. On the contrary, predominantly recycled glass is used as well as low quality feldspars, feldspathic sands or rocks.

Finely ground feldspars are increasingly applied as white fillers in the production of varnish, paint, plastering, adhesives, rubber and plastics.

In pigment paste, feldspars are used as basis **filler** to dilute pigments, which facilitates the dosage in application. The excellent weatherability of feldspars results in a preferable application in exterior paint (0 – 15 % feldspar), particularly durable marking paint (20 – 40 % feldspar) or anticorrosive (10 – 30 % feldspar).

Other (subordinate) fields of application include:

- Homogeneously ground for roof tiles to reduce abrasion during processing and enhanced desiccation
- Coarsely ground for brick industry (10 – 25 % feldspar, Figure 9)
- In furnaces to improve flux of slag
- Finely ground as binding material for the production of ceramic grinding disks (10 – 15 % feldspar)
- In abrasives and cleaning paste due to medium hardness and tabular crystal habit
- Concrete blocks

Figure 9: Coarsely ground feldspar is essential in the manufacture of bricks (Photo with kind permission of Dr. Krakow Rohstoffconsult GmbH).

4 Specifications and beneficiation

4.1 Chemical requirements

The industry seeks preferably pure potash feldspars, raw materials rich in potash feldspars or pure alkali feldspars. In trading, potash feldspar contains more than 10 % potassium oxide (K_2O), whereas sodium feldspar contains more than 7 % sodium oxide (Na_2O) as opposed to chemically pure endmembers with 16.9 % K_2O and 11.8 % Na_2O respectively.

Besides high portions of K_2O and Na_2O, it is essential for all feldspars or feldspathic raw materials to contain very little or no iron oxide (Fe_2O_3). Furthermore, even traces of copper (Cu) and manganese (Mn) are undesirable and only small amounts of chromium (Cr_2O_3) and titanium (TiO_2) acceptable as they all influence the colour of the final product.

Feldspathic concentrates for the application in the ceramics industry must contain > 85 % feldspar and in the glass industry > 90 % feldspar. Fe_2O_3 should not exceed 0.3 % for ceramic masses, 0.1 % for glazes and 0.08 % for high-quality glass.

Each industry has their unique requirements when it comes to the desired chemical composition or grain size of the processed feldspars. All reference values are indicated in Table 2. It should be noted that these represent a guideline of internationally traded and accepted compositions, whereas locally feldspars of “inferior” quality might successfully be integrated into the manufacture of various products because of lower transportation costs.

*Table 2: Specifications/reference values of feldspars in different industries compiled by LORENZ & GWOSDZ (1999) and ELSNER (2017). * Typical composition of a feldspar kindly provided by Fine Industrial Minerals CC, South Africa which is used by Peralin Paints, Namibia for floor paint.*

<table>
<tr><th></th><th></th><th>Clear container glass</th><th>Float glass</th><th>Coloured container glass</th><th>Ceramic</th><th>Pottery</th><th>Enamel</th><th>Glaze</th><th>Filler</th><th>Floor Paint in Namibia *</th></tr>
<tr><td rowspan="10">Chemical Composition</td><td>SiO_2</td><td colspan="2">65 – <69</td><td><69</td><td>65 – <69</td><td>65 – 67</td><td>65 – 66.5</td><td></td><td></td><td>65.8</td></tr>
<tr><td>TiO_2</td><td colspan="2">0.04 – <0.05</td><td>0.04 – <0.5</td><td><0.1</td><td>0.04 – <0.5</td><td></td><td>0.1 – <0.3</td><td></td><td>0.0</td></tr>
<tr><td>Al_2O_3</td><td colspan="2">>17 – <19</td><td>>17.0 – <19.0</td><td>>17.0 – <19.0</td><td></td><td>>18.75 – <19.75</td><td></td><td></td><td>18.8</td></tr>
<tr><td>Fe_2O_3</td><td colspan="2"><0.035</td><td><0.3</td><td><0.2</td><td>0.05 – <0.3</td><td><0.1</td><td><0.15 – (<1.0)</td><td></td><td>0.05</td></tr>
<tr><td>MgO</td><td colspan="2"><0.04</td><td><0.04</td><td>0.02 – 0.04</td><td></td><td><0.1</td><td></td><td></td><td>0.3</td></tr>
<tr><td>CaO</td><td colspan="2"><0.03</td><td><1.5</td><td>0.02 – <0.5</td><td></td><td><0.5</td><td></td><td></td><td>0.09</td></tr>
<tr><td>Na_2O</td><td colspan="2">0.6 – 0.8</td><td>5.0 – 7.0</td><td>3.0 – 10.0</td><td>1.5 – 3.0</td><td>>2 – 3</td><td rowspan="2">Sum $K_2O + Na_2O$ >13.0 – (15.0)</td><td></td><td>2.1</td></tr>
<tr><td>K_2O</td><td colspan="2">>12.0</td><td>4.0 – 6.0</td><td>8.0 – 14.0</td><td>10.5 – 12.5</td><td>12.0 – 13.0</td><td></td><td>12.1</td></tr>
<tr><td>Cr_2O_3</td><td colspan="2"><0.0005</td><td></td><td><0.0005</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Other</td><td colspan="2">no Cu, Mn</td><td></td><td>no Cu, Mn</td><td></td><td>no Cu, Mn</td><td></td><td></td><td>no Cu, Mn</td></tr>
</table>

Table 2:

		Clear container glass	Float glass	Coloured container glass	Ceramic	Pottery	Enamel	Glaze	Filler	Floor Paint in Namibia *
Mineralogical Composition	K-Feldspar	76	87				K-Feldspar preferred	K-Feldspar and Na-Feldspar		
	Na-Feldspar	5	7							
	Quartz	12	4	<6	<5, <25 – (30)			n.s.	degree of whiteness >90 %, oil adsorption + surface 0.8 – 4.0 m²/g, humidity <0.1 %	
	Clay	7	2							
	Mica	<1	<1							
	Other	no corundum, Ti-minerals					no garnet, hornblende, biotite, tourmaline			moisture <0.25 %
	Grain size	75 – 600 µm, max. 10 %<>			bulk < 63 µm			bulk <63 µm, at least 40 % <40 µm	average 3 – 12 µm	93 % <45µm

4.2 Beneficiation

Most feldspathic raw materials need further processing before introduction into the market (Figure 10). Several techniques such as hand picking, milling, sieving, washing, grading, magnetic separation (to dispose of heavy metals) or air separation (to dispose of mica) are applied. Flotation is used to consecutively separate mica, quartz, other accompanying minerals and feldspar and further separate potash from sodium feldspar. Nevertheless, it is still crucial that the raw material is high in feldspar with a negligible iron content.

Figure 10: Feldspar raw material requires processing before introduction to the market. Customers are supplied with milled feldspar of different mesh sizes (Photo: BGR).

Feldspathic hard rocks should contain feldspar crystals that are medium to coarse grained (> 5 mm), enabling the separation of unfavourable minerals (e.g. Fe-rich micas) already after milling. Quartz content in the final product is an advantage, as silica is essential for the production of glass and enamel.

The main difference in producing feedstock for the ceramic industry versus the glass industry (besides the chemical requirements) lies in the desired grain size fractions. Screening units and sifters are commonly used to remove unwanted size fractions.

Glass grade feldspar is typically traded with a grain size between 75 – 600 µm. Smaller grain size fractions are unfavourable during the blending process. Therefore, a gyratory crusher is needed to produce the required grain size range. Iron abrasion is usually not an issue except for the application in special industries, e.g. technical glass.

Ceramic grade feldspar is characterized by a bulk grain size of less than 63 µm. This requires additional processing with a ball mill. The mill lining and grinding balls should be composed of quarzitic, ceramic or aluminous material to keep iron contamination low.

4.3 Further tests and quality control

Chemical and mineralogical composition are the most important parameters when evaluating the suitability of feldspar. Furthermore, the grain size distribution may be of interest as well as specific tests to evaluate melting and sintering behaviour. For the application as filler, the degree of whiteness, oil adsorption and specific surface area are critical parameters.

The industry favours a long-term homogeneous product that exhibits unchanged chemical and physical properties. Therefore, continuous quality control including chemical analyses and blending of the extracted material is essential. Resource size may also play a role in this context.

5 Mining, import and export of feldspar raw materials in the SADC region

5.1 Current feldspar production

Each year, every mining country of the world is urged to share production statistics regarding their mining activity. These statistics are compiled and published by the British Geological Survey (BGS) and the United States Geological Survey (USGS) among others. If a country does not appear in these lists, there was either no mining activity for this specific commodity, the country might not publish any statistics or the production data is not known. To evaluate Namibia's position in the context of feldspar-producing or consuming countries in Southern Africa, it is compared to the 16 member countries of the Southern African Development Community (SADC).

Of the SADC countries, only South Africa publishes statistics on feldspar production. In 2018, five active mining operations recovered feldspar from pegmatites mainly located in the Province of Limpopo but also Northern Cape, Western Cape, Gauteng and Kwa Zulu Natal (DMR Republic of South Africa). During the past years, South Africa's annual feldspar raw material production varied between 70,000 and 190,000 tons. The majority of the recovered feldspar is used in domestic ceramic tile, porcelain, glass and paint industries etc. predominantly located in Cape Town or Johannesburg and its surroundings. Final products, e.g. paint, are exported.

Even though Zimbabwe and Zambia do not publish any feldspar production data, feldspar mining is likely to take place on a minor scale (Barry 2016; Minerals Marketing Corporation of Zimbabwe). Zambian feldspar production of a few thousand tons per year may originate from two pegmatite deposits (one partly altered to kaolinite) in central and southern Zambia, mainly feeding the local industry. Zambia's only glass factory closed down a few years ago, but there are plans to restart its operation. New demand for feldspar also arises through the establishment of ceramic tile production (Mitchell & Muibeya 2000; Gov. of Southern Zambia). Zimbabwe's feldspars originate from pegmatites that are either associated with Archean Greenstone Belts or hosted within the Magondi and Zambezi metamorphic belts (MMMD Zimbabwe). The feldspathic products are used by a domestic glass-packaging factory and by a newly established ceramic tile and porcelain manufacturing company. Mozambique has mined feldspar on a minor scale from pegmatites in the Zambezia Province destined for export, but production has ceased some years ago.

In contrast, Namibia did not extract any feldspar systematically since the 1970s.

Feldspar production in the SADC region is comparably small on a global scale. In 2019, Turkey, Italy and China are the largest feldspar producers in the world, each producing several million tons per year.

5.2 Past feldspar production in Namibia

In Namibia, only small quantities of feldspars were mined as a by-product in the 1960s and 1970s (cf. Figure 11), because there was no major feldspar-consuming industry (Schneider 1992). This has not changed since.

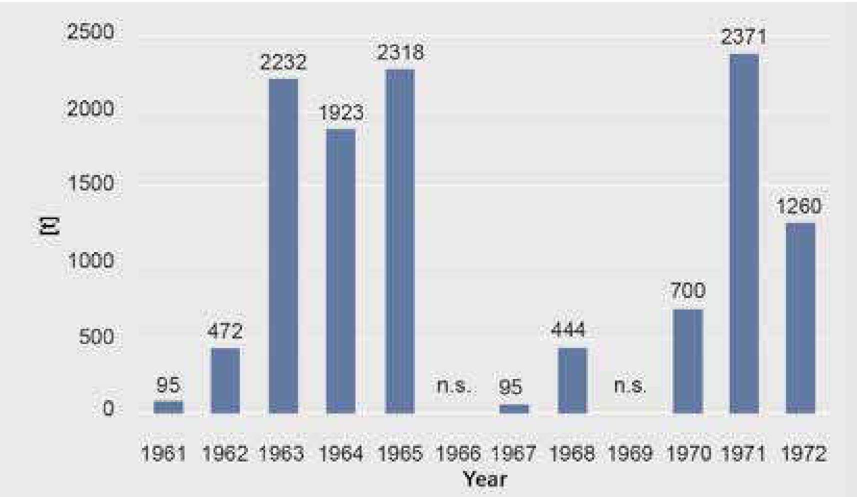

Figure 11: Feldspar production in Namibia in [t] per year (Schneider 1992).

5.3 Trade data

Trade data is retrieved from the commercial IHS Markit - Global Trade Atlas® (IHS GLOBAL SA). The database provides both import and export data for more than 90 countries based on customs data of individual countries. Data is primarily classified through Harmonised System (HS) product codes by the WCO (World Customs Organization). Feldspar is generally traded under HS2529.10.

There are certain general limitations to global trade data. The most prominent issue arises with data availability since many countries do not publish trade data at all. Especially export data is an issue among many countries. There may also be challenges due to mislabelled products (wrong HS codes), product baskets, data entry errors or missing data in general.

Where export data is not available the so-called reverse trade statistics (RTS) may be useful. If a country does not state any exports, cumulative global imports from that particular country may be used as a rough, yet incomplete estimate of exports. It should be noted that these statistics do not represent absolute, but rather minimum values as trade between two non-reporting countries will not be reflected.

The majority of the SADC countries do not report their import and export statistics.

6.4 Import

For most of the SADC countries, the statistics retrieved though the Global Trade Atlas do not necessarily represent reliable trade data for feldspar raw materials due to above-mentioned reasons. This is especially true when only small import numbers (usually in tons) are listed as these are supposedly artefacts or errors in declaration (e.g. Botswana imported 1 ton of feldspar from South Africa in 2019).

During the past ten years, Namibia sporadically imported small quantities of feldspar (RTS). Sporadic import means that for some years, no import is inferred for Namibia at all. In 2014 and 2017-19 on the other hand, 3 to 9 tons of feldspar per year were imported from South Africa.

Subordinate or sporadic import of feldspar is typical for several SADC countries (RTS), ranging between a few tons to several tens of tons per year (Angola, Botswana, Malawi, Mozambique, Zambia, Zimbabwe). In 2018 and 2019, the Democratic Republic of Congo imported a few hundred tons of feldspar per year from South Africa.

Significant import (comparing the SADC countries over the past ten years), however, is executed by South Africa (500 – 21,000 t/a) and Tanzania (2,000 – 5,000 t/a), indicating larger feldspar-consuming industries. A simple trade flow for feldspar focusing on SADC member countries is illustrated in Figure 12. Tanzania imports feldspar mainly from Turkey, which is used in the glass and ceramic tile production. South Africa (application see Chapter 5.1) imports feldspar predominantly from Spain, but in previous years, a minor share came also from Turkey and Zambia.

Similar to previous years, the top three feldspar importers in 2019 were Italy (2.7 Mt/a), Spain (2.7 Mt/a) and Russia (650,000 t/a).

Figure 12: Feldspar trade flows to and from the SADC countries. Dark blue colours mark the exporting country and light blue the importing country. Thickness of arrows indicates relative size of trade volume. Trade data is retrieved from the IHS Markit - Global Trade Atlas®.

5.5 Export

Similar to the size and importance of the feldspar mining sector in Southern Africa, the export of feldspar from these countries is comparably small on a global scale. Nonetheless, during the past ten years, Zimbabwe (RTS) and South Africa exported minor amounts of feldspar to various countries in the world. The vast majority of Zimbabwe's exported feldspar (13,000 – 33,000 t/a) is shipped to China, whereas South Africa's feldspar (60 – 100,000 t/a) is predominantly transported to India. In 2018 and 2019, Zambia exported 8,000 and 12,000 t of feldspar respectively to South Africa. It cannot be discerned whether the feldspar is used in the local South African industry or transported to the closest harbour for export (trade through).

During the past ten years, Madagascar, Mauritius and Mozambique sporadically exported up to a few hundred tons of feldspar per year to Asia (RTS). The inferred (RTS) sporadic and subordinate export of feldspar from Namibia (1 t/a) and Malawi (1 – 6 t/a) is considered as error in declaration as no feldspar mining activity is known in these countries.

In 2019, Turkey (6.3 Mt/a), Thailand (825,000 t/a) and India (636,000 t/a) were the globally largest feldspar exporters.

6 Feldspar demand in Namibia

6.1 Direct demand

The demand for feldspar in Namibia has been limited in the past. This is mirrored by the non-existent feldspar mining activity as well as very low import figures. It mainly results from the lacking downstream industries that require large amounts of feldspar in their production processes. As of 2020, there is no ceramic or glass factory established in Namibia.

Namibia is home to a few companies offering a wide range of paint products like floor and wall paints, primers, lacquers, roof and special coatings, as well as plasters. Some companies import their products from abroad, others produce locally. Only some of the locally manufactured products require feldspar fillers. As of 2020, Windhoek-based **Peralin Paints** uses feldspar fillers only in the manufacture of floor paints. The raw material is currently sourced from a South African supplier in the Gauteng Province (Peralin Paints 2020, personal communication). In recent years, the demand for these floor paints has decreased in Namibia, resulting in the use of 2 – 6 tons of feldspar per year. These amounts are in line with inferred trade data.

6.2 Indirect demand

At present, Namibia largely relies on international imports of a variety of glass and ceramic products. Import data is retrieved from the Global Trade Atlas. In 2019, Namibia imported glass and glassware with a value of approximately 35 million US$ and ceramic products with an approximate value of 22 million US$. This also includes a broad variety of specialized products. Examples of selected products and their estimated feldspar ratio are given below. These rough estimates should be considered as minimum values.

Floor tiles

In 2019, Namibia imported around 17,000 t of ceramic floor tiles from South Africa and subordinately from Asia. Assuming a feldspar ratio of 15 – 25 %

in the final product (see Chapter 3), this translates to roughly 2,500 – 4,200 t of processed feldspar.

Bottles

Namibia imported 84,500 bottles of coloured container glass from the EU in 2019, mainly from Germany. Prior to that, Italy was the main trading partner in the EU regarding bottles of clear container glass. As imports of bottles from the EU are unit-based without weight or volume reference, it is not possible to estimate the exact tonnage and thus potential feldspar content.

Furthermore, Namibia imported 45,800 tons of glass bottles from South Africa in 2019. No differentiation is made between bottles of coloured or clear container glass. Assuming a feldspar content of a minimum of 7 % to a maximum of 15 % for clear and coloured container glass, respectively (see Chapter 3), this equals to 3,000 – 7,000 t of feldspar per year.

Ceramic sanitary ware

In 2019, Namibia imported about 120,000 ceramic sinks, wash basins and water closet bowls from South Africa. Typical sinks weigh around 10 – 15 kg, closet bowls range between 20 – 25 kg. One item is therefore estimated to weigh 18 kg on average, thus resulting in approximately 2,160 t in total. Assuming a feldspar ratio of 20 – 30 % (see Chapter 3), this translates to 430 – 650 t of feldspar in the final product.

6.3 Potential demand

In recent years, there have been plans by **Groot Suisse Ltd.** to develop various infrastructure projects to serve the demand of local and regional markets (Groot Suisse Ltd. 2020). Among others, two glass factories are envisioned to manufacture container glass, float glass and fibre glass. Additionally, a ceramic factory is targeted to produce premium ceramics, porcelain stoneware, floor tiles, sanitary ware, tableware and faucets. As of 2020, these projects are in a pre-construction stage. An additional demand of several ten thousand tons of feldspar could possibly arise if said projects are realized.

7 Feldspar occurrences in Namibia

Significant amounts of feldspar occur in Namibia only within pegmatites. These Precambrian and early Namibian pegmatites are restricted to two different areas respectively, the Damara Orogen in north-central Namibia and the Namaqua Metamorphic Complex in southern Namibia (cf. Figure 13).

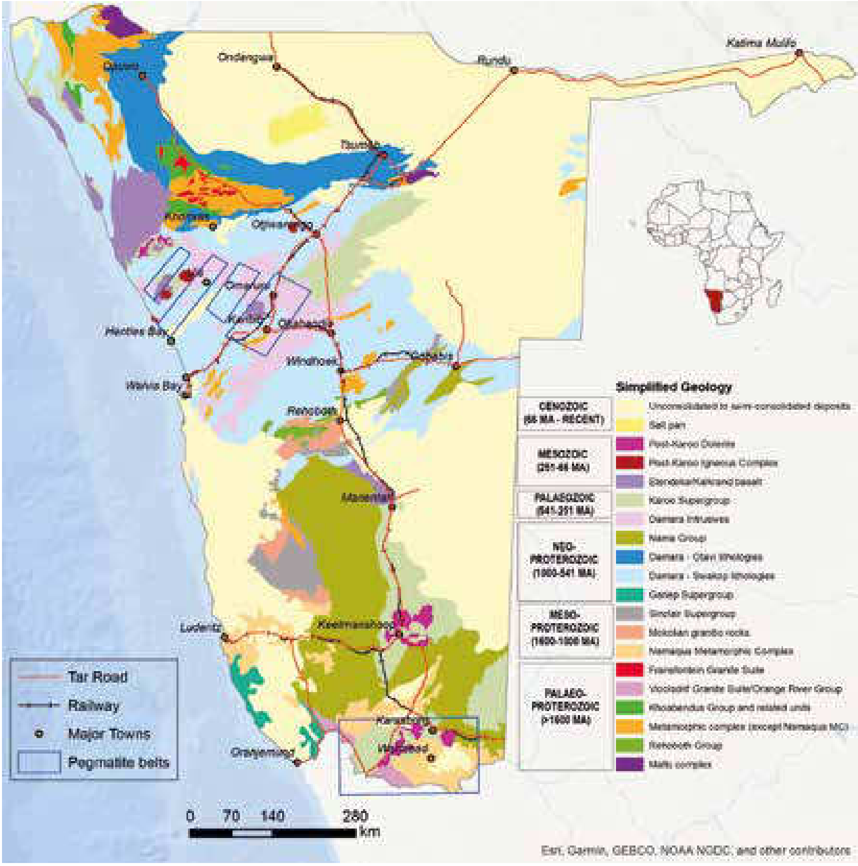

Figure 13: Simplified geology of Namibia with major towns as well as railway and tar roads. Blue polygons indicate pegmatite belts and districts in central and southern Namibia. Data source: GEOLOGICAL SURVEY OF NAMIBIA 2020.

Within the Damara Orogen, four linear pegmatite belts are found, all of which strike northeast – southwest (cf. Figure 14): Brandberg West – Goantagab, Cape Cross – Uis, Nainais – Kohero and Sandamap – Erongo, with the latter connected to the Karibib Pegmatite District (SCHNEIDER 1992).

Each of these pegmatite belts exhibit numerous individual pegmatite swarms that occur zoned or unzoned and may carry significant amounts of rare metals or semi-precious stones. In the south, Lithium-Caesium-Tantalum (LCT) pegmatites occur in two areas: Tantalite-Valley, south of Warmbad in close proximity to the northwest-trending Tantalite Valley Shear Belt and the Sandfontein-Ramansdrift area close to the Orange River.

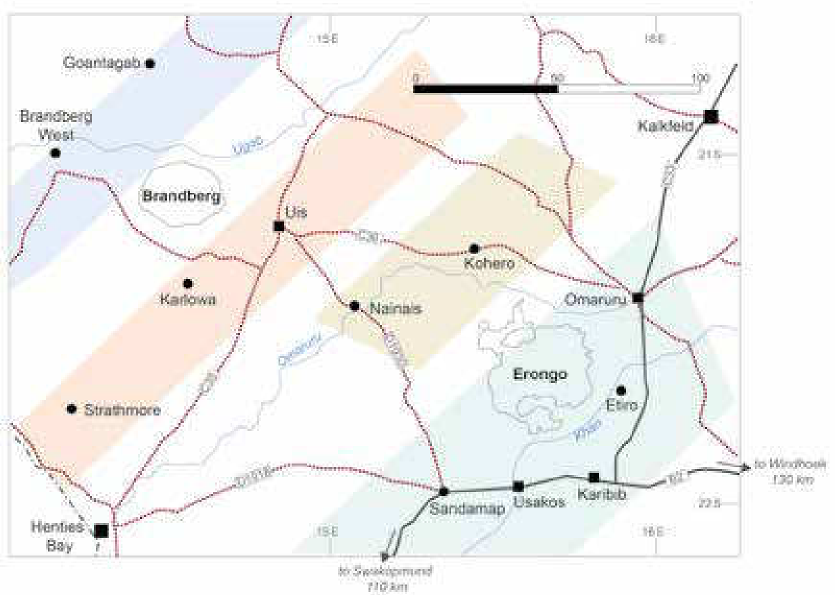

Figure 14: Pegmatite belts in north-central Namibia from west to east: Brandberg West – Goantagab, Cape Cross – Uis, Nainais – Kohero and Sandamap – Erongo as well as the Karibib Pegmatite District after GEOLOGICAL SURVEY OF NAMIBIA (2002).

7.1 Significant deposits

Etiro

The Etiro Pegmatite belongs to the Karibib Pegmatite District and is situated on farm Etiro, 20 km north of Karibib. It is 850 m long and between 4 and 28 m wide, dipping steeply with well-developed internal zoning (Miller 1969). The wall zone consists of microcline-perthite, quartz, biotite, muscovite, schorl, albite and apatite, which grades into a 0.3 to 5 m wide intermediate zone comprising plagioclase, quartz, microcline-perthite, beryl, muscovite, biotite, schorl, apatite, and accessory columbite-tantalite, monazite and topaz. The mineral assemblage of the core zone is characterised by microcline-perthite (exsolution lamellae of albite in alkali-feldspar/intergrowth of two chemically different alkali-feldspars), quartz, apatite, cleavelandite, amblygonite, columbite-tantalite, tourmaline and native bismuth. Lithium-muscovite (lepidolite), fluorite and monazite are found as replacement minerals in some areas of the intermediate and core zone. Past mining activity in several open pits focused on beryl, feldspar and lepidolite with accessory columbite-tantalite and bismuth minerals.

Helikon/Rubicon

The Helikon and Rubicon pegmatites consist of several zoned Li-Cs-Be-Rb pegmatites that belong to the Karibib Pegmatite District. They are situated on farm Okongava East, about 30 km south of Karibib. They were previously mined in open casts and by room and pillar mining on lepidolite, amblygonite, petalite, beryl, bismuth and columbite (Figure 15 and Figure 16). Potash feldspar was recovered as a by-product from Rubicon.

The Rubicon pegmatite forms a 900 m long prominent ridge with a width of 25 to 35 m that strikes northwest, dipping with 45° to northeast near surface and flattening to 18 – 25° at depths (Diehl 1992a). It consists of an inner core zone (quartz core, high grade petalite zone, perthite zone) (Figure 17), outer core zone (high grade lepidolite zone, low grade lepidolite zone, low grade petalite zone, beryl zone) and the potash feldspar-bearing intermediate, wall and border zone (Diehl & Schneider 1990).

Currently, significant exploration activity is carried out at the Rubicon and Helikon deposits (currently known as Karibib Lepidolite Project) to revive lithium mining in Namibia. The closest railhead is located in Karibib and the deep-water port of Walvis Bay is 120 km to the southwest. Windhoek lies about 180 km to the southeast. NamPower connects the town of Karibib to electricity and the project utilizes generators for that matter. Water is provided via boreholes.

Figure 15: Open pit of Rubicon pegmatite south of Karibib (Photo: BGR-GSN-Project 2019, with kind permission of Lepidico Chemicals Namibia (Pty) Ltd.).

Figure 16: Remnants of room and pillar mining at historic mine site at Rubicon pegmatite (Photo: BGR-GSN-Project 2019, with kind permission of Lepidico Chemicals Namibia (Pty) Ltd.).

Figure 17: Massive perthite (alkali feldspar) crystals at Rubicon pegmatite (Photo kindly provided by Lepidico Chemicals Namibia (Pty) Ltd.).

Uis

The Uis tin mine is situated in the town of Uis, 30 km southeast of the Brandberg Complex. The tin deposit is hosted within a series of cassiterite-bearing pegmatites (Uis pegmatite swarm) that belong to the Cape Cross – Uis Pegmatite belt. Some of these are up to 1 km long and 50 m wide, striking northeast and dipping steeply. The pegmatites are unzoned, coarse-grained and generally contain very low concentrations of tin, niobium, tantalum and lithium (Diehl 1990c). Major minerals are quartz, microcline to microcline-perthite, albite and muscovite. Disseminated cassiterite particularly occurs in irregular greisen zones that consist of lepidolite, quartz and albite.

The deposit at Uis was discovered in 1911. Considerable quantities of tin were extracted from 1924 until 1990, making it the globally largest open pit tin mine at the time (Figure 18). The felsic waste material was accumulated on coarse and fine-grained tailings heaps, which form a prominent landmark (Figure 19). Although no feldspar was recovered, the Uis pegmatite and the tailings bear glass and ceramic-grade feldspar as indicated by the study of Harrison et al. (2002). In this study, the total resource of the Uis mine waste dump was estimated as 75 million tons, of which 46 % may be of economic interest (45 % feldspar, 1 % mica). Clays from the slime dam of the former mine are used by Namclay Bricks and Pavers since 2006 to produce face bricks as well as non-facing bricks and pavers.

Currently, Uis tailings and the Uis tin mine are owned by two different companies. As of 2020, the tin mine is operating a pilot processing plant and aims to ramp up the production in the near future. The project is connected to water and power lines. The closest deep water port is Walvis Bay, 220 km to the southwest and the next railhead lies 130 km to the east in the town of Omaruru.

Figure 18: Outcropping pegmatite at the Uis tin mine (Photo: BGR-GSN-Project 2019, with kind permission of AfriTin Mining Limited Ltd.).

Figure 19: Tailings heap of historic Uis Tin Mine (Photo: BGR-GSN-Project 2019, with kind permission of AfriTin Mining Limited Ltd.).

De Rust

The De Rust pegmatite is the largest of the De Rust pegmatite swarm within the Brandberg West – Goantagab pegmatite belt (Diehl 1992c). Outcrops are 100 – 470 m long, up to 30 m wide and can be followed over a length of roughly 2.4 km. The pegmatite is located 6 km to the east of farm De Rust and about 2.5 km north of the Ugab River, northwest of the Brandberg massif and roughly 70 km from the nearest town of Uis.

According to Diehl (1990), the De Rust pegmatite is a Li-rich rare metal pegmatite that was mined for cassiterite and tantalite but also for minor quantities of spodumene between 1960 and 1990 (Figure 20). The quartzo-feldspathic tailings remained on site (Figure 21). The pegmatite shows well-developed zonation with a border zone (quartz, alkali feldspar, muscovite), outer (quartz, microcline-perthite, muscovite, altered petalite) and inner (quartzo-feldspathic rock with large spodumene crystals with accessory deep blue apatite, lepidolite, eucryptite, zircon and monazite) intermediate zone as well as a core zone (quartz, subordinate microcline, muscovite, sporadic tantalite).

Alkali feldspars are often albitised in the intermediate zone. Disseminated tantalite and cassiterite are associated with these greisen zones.

Currently, exploration activity is carried out at the De Rust deposit (currently known as Soris Project) to revive lithium mining in Namibia.The nearest railhead is located in the town of Karibib and the deep-water port of Walvis Bay is 120 km to the southwest. Windhoek is about 180 km to the southeast.

Figure 20: Remnants of historic open pit mining of De Rust pegmatite northwest of the Brandberg massif (Photo: BGR-GSN-Project 2019).

Figure 21: Tailings of historic mining activity at De Rust pegmatite (Photo: BGR-GSN-Project 2019).

7.2 Minor deposits

Molopo

The Molopo tin mine, or so-called Petalite Pegmatite, is the largest of the Strathmore Pegmatites in the Uis – Cape Cross Pegmatite Belt and is situated 20 km north of Cape Cross. It was mined for niobium-tantalum, cassiterite, lithium and beryllium minerals as well as book-mica in the late 1960s and '90s, but in fact never produced any tin concentrate (Figure 22). Small stock-piles of feldspar and other felsic material are found in the surroundings of the former mine (Figure 23). The pegmatite body is about 120 m long and up to 40 m wide, dipping steeply towards north northeast (Diehl 1992c). A well-developed zoning can be observed (Diehl 1990), but metasomatic alteration induced the formation of secondary minerals (colourless mica, albite, tourmaline, bentonite) overprinting the original mineralogy. The core consists of albite and quartz, surrounded by a quartz-microcline-perthite-albite-muscovite intermediate zone, which makes up the majority of the pegmatite. A three meter wide border zone comprises coarse-grained muscovite-books, quartz, plagioclase and bluish-green apatite. Rare metal mineralization occurs in the intermediate and metasomatic replacement zones.

Figure 22: Open pit of former Molopo Tin Mine (Photo: BGR-GSN-Project 2019).

Figure 23: Feldspar stockpile at former Molopo Tin Mine (Photo: BGR-GSN-Project 2019).

Tantalite Valley

The only pegmatites of the south that were actively mined and produced ceramic and glass-grade feldspar as a by-product occur on farms Umeis and Kinderzitt in the Tantalite Valley area, 20 km south of Warmbad. The Tantalite Valley pegmatites include several individual subhorizonal dikes, that are up to 1000 m long and 0.2 to 40 m wide, plunging towards southeast (Diehl 1992b). Four of those are of economic interest: Homestead, Whitkop, White City (cf.Figure 24) and Lepidolite (also known as Purple Haze) pegmatites. They are all well zoned (quartz core, inner and outer intermediate zones, wall zone) and were predominantly targeted for beryl, columbite-tantalite, as well as lithium and bismuth minerals.

Currently, an extensive exploration program is conducted on the Tantalite Valley pegmatites to ramp up tantalite mining in Namibia, potentially with a lithium by-product.

The next railhead is situated in Karasburg, 80 km to the north. Electricity is currently supplied by generators and water is recovered through various drill holes, but with aspiration to supplement water from the Oranje River 15 km to the south.

Figure 24: White City Pegmatite of the Tantalite Valley Mine (Photo kindly provided by Kazera Global Plc).

7.3 Subordinate deposits

Other smaller pegmatites that comprise high-grade feldspar or have yielded feldspar as a by-product in the past lie on farms Sandamap 64, Kaliombo 119 (Bergers Pegmatite) and Okakoara 43 (Ricksburg Pegmatite) in the Karibib-Usakos area (Schneider 1992), as well as south to southeast of Warmbad (Sandfontein, Sandfontein West, Sperlingsputz, Norechab, Haakisdoorn, Gaobis, Gaidip and Ramansdrift; e.g. Figure 25) (GSN 2016). Most of them have been mined for cassiterite, niobium-tantalum, lithium minerals, beryl, tourmaline or aquamarine.

Figure 25: Remnants of historic small scale mining on farm Sperlingsputz in southern Namibia (Photo: BGR-GSN-Project 2017).

8 Analysed feldspar samples

During the course of the cooperation project between the Economic Geology Division (EGD) of the Geological Survey of Namibia (GSN) and the German Federal Institute for Geosciences and Natural Resources (BGR) several sampling campaigns to southern and central Namibian pegmatites provinces took place. Typical feldspar reference samples were selected from the outcrops. Prior to the field trips literature and other datasets were reviewed regarding information on feldspar occurrences or previous feldspar mining activity to identify specific target areas.

In southern Namibia, predominantly feldspar occurrences within pegmatites were targeted that were not previously mined (cf. Figure 26). Thus, with the exception of Sperlingsputz as well as the White City pegmatite of the Tantalite Valley Mine, all samples were recovered from surface outcrops. Most samples taken from pegmatites in central Namibia derive from either historic pits or sites with current exploration focus. Only few originate from surface outcrops (cf. Figure 27).

Overall, 48 feldspar samples were analysed for major and trace elements at BGR labs. Furthermore, one feldspar sample was tested for its suitability in the glass and ceramic industry in a separate study (FGK 2015). Two analyses originate from a detailed study of the Uis Tin Mine Tailings conducted by the British Geological Survey (Harrison et al. 2002). Thus, a total of 51 feldspar analyses (results see Table I in the Appendix) were interpreted with respect to their applicability in the various potential feldspar-consuming industries.

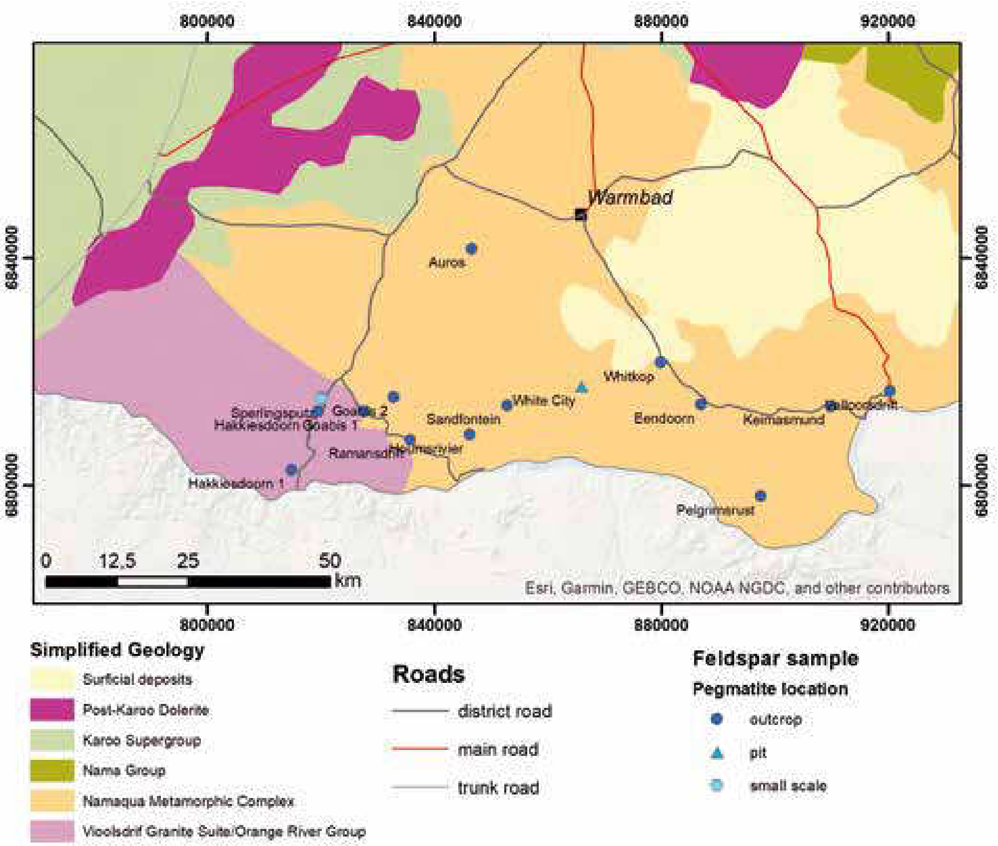

Figure 26: Feldspar sample locations within pegmatites of the Namaqua Metamorphic Complex in southern Namibia. The Oranje River represents the natural border to South Africa. Symbol shape describes the sample site. (Data source of map: Geological Survey of Namibia 2020).

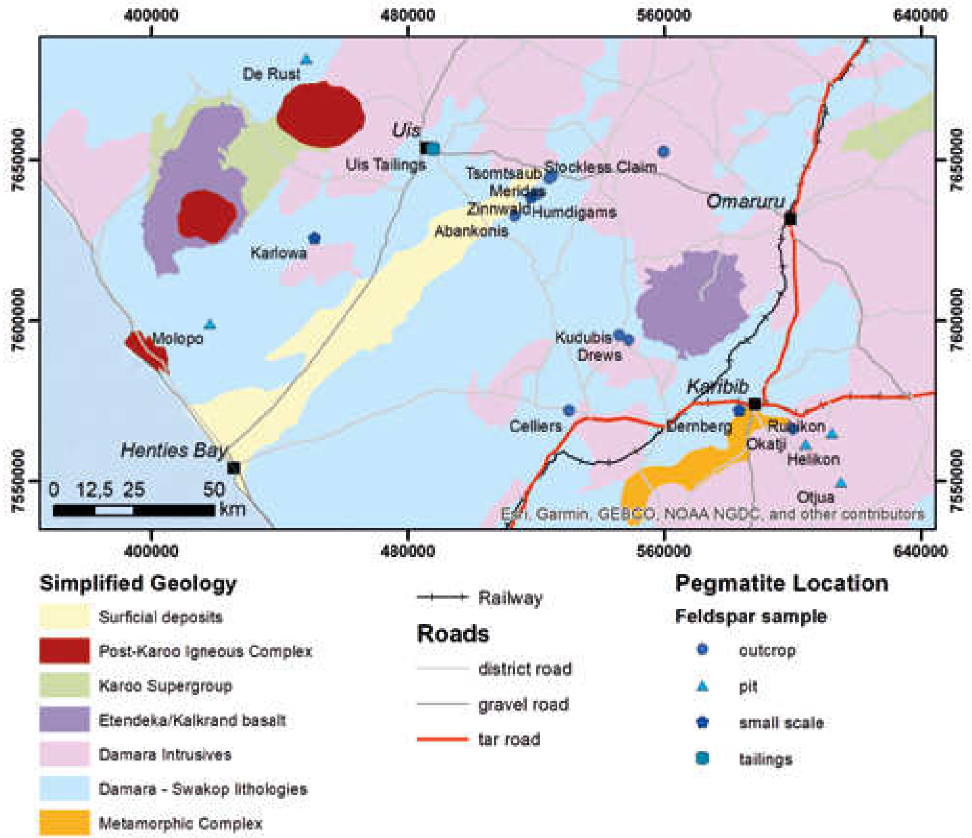

Figure 27: Feldspar sample locations within pegmatites of the Damara Orogen in central Namibia. Symbol shape describes the sample site. (Data source of map: GEOLOGICAL SURVEY OF NAMIBIA 2020).

9 Interpretation

Six of the 51 analysed Namibian feldspar samples are sodium feldspars per definition (Na_2O > 7 %). Eight samples show the typical composition of so-called graphic feldspar (i.e. alkali feldspar intergrown with quartz), with variable amounts of Na_2O and K_2O and very high SiO_2-values. Four samples are impure feldspars or a mixture with other minerals. The remaining 33 analyses represent potash feldspars per definition (K_2O > 10 %), but with considerable amounts of Na_2O.

The evaluation of the economic suitability for various economic applications of the analysed feldspar samples is based on the chemical specifications in Chapter 4. The results are shown in Table 3, classifying in **unsuitable** (several or all chemical requirements are not met), **moderate** (one element exceeds or doesn't reach the threshold value) and **good** (all specifications are met) suitability.

It should be noted that the analysed feldspars were collected as typical grab samples from the respective pegmatite bodies. The chemical composition of the sampled feldspars should be considered as typical, yielding a first indication of their economic potential. Statistical sampling will be needed for further evaluation.

Generally, one third of the tested feldspars cannot be used for any economic application. This is mainly because of too low (K_2O) or too high (Na_2O, Fe_2O_3, MgO) amounts of relevant major elements or due to the presence of unfavourable traces (e.g. Cu, Mn). The other two thirds are suitable for selected applications.

There is no clear geographic trend, meaning that feldspars from southern and central Namibia are equally suitable from a chemical point of view.

Table 3: Evaluation of suitability of Namibian feldspars for different applications based on chemical requirements described in Chapter 4. Suitability is classified into "unsuitable: several or all chemical requirements are not met", "moderate: one exceeds or doesn't reach the threshold value", and "good: all specifications are met". See Appendix for chemical composition of samples.

	Farm	Glaze	Pottery	Coloured Glass	Clear Glass	Ceramics
Southerm Pegmatites	Auros 1	good, but high Mn	good	moderate	unsuitable	good
	Auros 2	good, but high Mn	good	moderate	unsuitable	good
	Auros 3	unsuitable	unsuitable	unsuitable	unsuitable	unsuitable
	Eendoorn 1	good, but high Mn	good	moderate	unsuitable	good
	Eendoorn 2	good, but high Mn	moderate	moderate	unsuitable	moderate
	Goabis 1	good, but high Mn	good	moderate	unsuitable	good
	Goabis2	unsuitable	unsuitable	unsuitable	unsuitable	unsuitable
	Hakkiesdoorn 1	good, but high Mn	good	moderate	unsuitable	moderate
	Hakkiesdoorn 2	unsuitable	unsuitable	unsuitable	unsuitable	unsuitable
	Hakkiesdoorn 3	unsuitable	unsuitable	unsuitable	unsuitable	unsuitable
	Hakkiesdoorn 4	unsuitable	unsuitable	unsuitable	unsuitable	unsuitable
	Houmsrivier 1	unsuitable	unsuitable	unsuitable	unsuitable	unsuitable
	Houmsrivier 2	good, but high Mn	good	moderate	unsuitable	moderate
	Houmsrivier 3	good, but high Mn	good	moderate	unsuitable	moderate
	Keimasmund 1	good, but high Mn	good	moderate	unsuitable	moderate
	Keimasmund 2	good, but high Mn	good	moderate	unsuitable	good
	Pelgrimsrust	good, but high Mn	good	moderate	unsuitable	moderate
	Ramansdrift	good, but high Mn	good	moderate	unsuitable	moderate
	Sandfontein	moderate, high Mn	good	moderate	unsuitable	unsuitable
	Sperlingsputz	good, but high Mn	good	moderate	unsuitable	good
	Velloorsdrift 1	good, but high Mn	good	moderate	unsuitable	moderate
	Velloorsdrift 2	good, but high Mn	moderate	moderate	unsuitable	moderate
	White City	moderate, high Mn	good	moderate	unsuitable	unsuitable
	Whitkop	unsuitable	unsuitable	unsuitable	unsuitable	unsuitable

continuation Table 3

	Farm	Glaze	Pottery	Coloured Glass	Clear Glass	Ceramics
Central Pegmatites	Abankonis	good, but high Mn	good	moderate	unsuitable	moderate
	Celliers, Sandamap	unsuitable	unsuitable	unsuitable	unsuitable	unsuitable
	De Rust 1	unsuitable	unsuitable	unsuitable	unsuitable	unsuitable
	De Rust 2	good	good	moderate	unsuitable	moderate
	Dernberg, Karibib	good, but high Mn	moderate	moderate	unsuitable	moderate
	Drews, David West	unsuitable	unsuitable	moderate	unsuitable	unsuitable
	Helikon 1	unsuitable	unsuitable	unsuitable	unsuitable	unsuitable
	Helikon 2	unsuitable	unsuitable	unsuitable	unsuitable	unsuitable
	Helikon 3	unsuitable	unsuitable	unsuitable	unsuitable	unsuitable
	Helikon 4	unsuitable	unsuitable	unsuitable	unsuitable	unsuitable
	Humdigams	unsuitable	unsuitable	unsuitable	unsuitable	unsuitable
	Karlowa	good, but high Mn	good	moderate	unsuitable	moderate
	Kudubis 1	good	good	moderate	unsuitable	good
	Kudubis 2	unsuitable	good	moderate	unsuitable	moderate
	Meridas	good, but high Mn	good	moderate	unsuitable	moderate
	Molopo 1	good, but high Mn	good	moderate	unsuitable	moderate
	Molopo 2	good, but high Mn	good	moderate	unsuitable	moderate
	Molopo 3	good	moderate	moderate	unsuitable	moderate
	Okatji 2	good, but high Mn	unsuitable	moderate	unsuitable	unsuitable
	Okatji 5	moderate, high Mn	good	moderate	unsuitable	unsuitable
	Otjua	unsuitable	unsuitable	unsuitable	unsuitable	unsuitable
	Rubicon	good, but high Mn	good	moderate	unsuitable	moderate
	Stockless Claim	moderate, high Mn	good	moderate	unsuitable	unsuitable
	Tsomtsaub	moderate, high Mn	moderate	moderate	unsuitable	unsuitable
	Uis Tailings 1	unsuitable	unsuitable	moderate	moderate, high Cu + Mn	unsuitable
	Uis Tailings 2	unsuitable	unsuitable	unsuitable	unsuitable	unsuitable
	Zinnwald	unsuitable	unsuitable	unsuitable	unsuitable	unsuitable

To produce **„clear glass“**, very pure potash feldspar is required. Thus, with one exception, none of the tested Namibian feldspars qualifies for this application, mainly because the contents of Na_2O, CaO as well as elements that induce colouring (e.g. Fe, Mn, Cu etc.) are too high. The coarse grained tailings in Uis bear alkali feldspars with a chemical composition that is close to the desired composition for manufacturing clear container glass. Nevertheless, copper and manganese contents are elevated and require trial processing in potential factories.

Other industrial applications allow feldspar of lesser quality especially with regards to Na_2O content, which yields positive results (cf. samples highlighted in green and yellow in Table 3) for 34 Namibian feldspar samples (collected on 25 separate farms). All 34 feldspars are suitable for the production of **coloured glass** (brown or green). 26 feldspar samples meet the required specifications for the manufacturing of **pottery** and five show a bit less favourable compositions (moderate suitability). For the application in **glaze** production, 26 samples yield good chemical requirements and five moderate. Seven feldspar samples show good results for the manufacturing of **ceramics**, whereas 19 are moderately suitable. Feldspar used in the **paint** industry and as **filler** requires further mineralogical tests. However, a few feldspar samples could potentially meet the requirements.

It should be noted, nonetheless, that traces of manganese are unfavourable for the application in ceramic and glaze production as well as in white fillers and that all tested Namibian feldspars contain minor amounts of MnO (cf. analytical results in Table I in the Appendix). Whether the manganese content disqualifies the Namibian feldspars for application in these industries has to be evaluated during trial processing with potential customers.

Pegmatites of considerable size and those, which are already somewhat developed (presently or previously mined/explored) and contain high-quality feldspars are Sperlingsputz and White City in southern Namibia as well as Molopo, Uis, De Rust and Rubicon in central Namibia. These pegmatites contain either tin, tantalum or lithium minerals for which they are currently explored or were targeted for in the past. All other feldspars that meet requirements for an industrial application are hosted within smaller pegmatites or stem from surface outcrops.

10 Conclusions

Feldspar is a low-value mineral commodity. Particularly depending on the specification (“glass grade”, “ceramic grade”, “crude” etc.) but also the mesh size, a ton of feldspar sells between 20 to 200 US$ (Industrial Mineral Data Base 2019). It is thus crucial to keep the extraction, processing and especially the transport costs as low as possible. As a result, many feldspars are used in local industries and only very high-grade products are exported to international markets. Feldspars of lesser quality will normally sell at a lower price, but local pricing might be influenced by domestic supply and demand balance.

Currently, no major feldspar-consuming industry is present in Namibia. Thus, there is no direct demand for feldspar in Namibia. The demand by a Windhoek-based paint factory is considered negligible in this context. This implies that at present, low to medium-quality feldspars cannot be considered for any application, as it would not be economically viable to export this low-priced commodity. Only chemically pure alkali feldspar (sodium or potash) is valuable enough to justify exploration, mining and export. Technically, this applies to about two thirds of the tested feldspar samples in central and southern Namibia. Nonetheless, it is not economically viable to target alkali feldspars hosted in small volume pegmatites or those that are not associated with active mining or exploration activity.

There is however, a notable indirect demand for feldspar in Namibia, which is inferred through the annually imported ceramic products as well as glassware. Should plans commence to construct a glass or ceramic factory in Namibia, a direct demand could arise for local feldspar production in the coming years.

Until a major feldspar-consuming industry establishes in Namibia, the only potential to export Namibian feldspar lies in pegmatites with extraordinary feldspar quality. Ideally, they were either previously mined, include stockpiles and tailings, or are the target of current exploration or mining activities for other minerals as main product. Feldspar could be extracted as a by-product through handpicking, or concentrating the feldspar content through separation of magnetic minerals and flotation processes, while mining higher priced commodities in the same pegmatite body (e.g. tin in Uis, tantalite in White City, and lithium minerals in Rubicon and De Rust). Further processing like crushing and milling will also be necessary to attain the mesh sizes required by the customer.

The closest export market with the most diverse application potential is in South Africa with various glass, ceramic and paint manufacturers. As most of the relevant industry is situated in Cape Town or the surroundings of Johannesburg, all goods originating from Namibia must be transported for a considerable distance by road or railway. Zambia and Zimbabwe have a small demand for feldspar raw materials for their developing ceramic tile industries. By road (no railway link at present), the distance from Namibian pegmatites to factories in Zambia or Zimbabwe is even further than to South Africa. The European and Asian markets are reached by sea transport via the port of Walvis Bay.

In any case, detailed feasibility studies would be needed for the mentioned individual deposits. Resource economics and especially transportation costs to potential local and international markets need to be evaluated. Potential customers need to be identified to carry out trial processing in their factories.

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Appendix

Table I Chemical analysis of feldspar samples collected in Namibia.

Sample ID	Sample description	SiO_2 [%]	TiO_2 [%]	Al_2O_3 [%]	Fe_2O_3 [%]	MnO [%]	MgO [%]	CaO [%]	Na_2O [%]	K_2O [%]	Cr [mg/kg]	Cu [mg/kg]
Abankonis	feldspar	64,14	<0.001	19,47	0,06	0,005	0,01	0,106	2,43	11,87	<12	<6
Auros 1	feldspar	65,65	<0.001	18,82	0,05	0,005	0,03	0,11	2,6	12,34	<12	11
Auros 2	feldspar	65,67	<0.001	18,92	0,03	0,004	0,02	0,088	2,78	12,07	<12	13
Auros 3	feldspar, quartz, mica	74,79	0,057	15,24	0,59	0,014	0,18	0,661	6,4	0,986	<11	10
Celliers	grey Feldspar, quartz, mica, Li-minerals	67,27	<0.001	20	0,08	0,01	0,04	0,424	9,81	0,619	<11	6
De Rust 1	grey feldspar	69,06	<0.001	16,86	0,04	0,004	0,02	0,628	3,37	7,82	<12	<6
De Rust 2	grey feldspar, amblygonite, petalite	65,13	<0.001	18,82	<0.01	0,002	0,01	0,109	2,43	11,41	<12	<6
Dernberg	pink feldspar	64,21	<0.001	19,22	0,06	0,008	0,02	0,148	1,82	13,05	<12	<6
Drews	white-greyish feldspar	65,6	0,001	19,66	0,09	0,007	0,03	0,088	4,78	8,563	<12	11
Eendoorn 1	feldspar	66,02	<0.001	18,97	0,05	0,005	0,02	0,03	3,21	11,35	<12	8
Eendoorn 2	feldspar	65,27	0,004	18,78	0,07	0,004	0,03	0,103	1,74	13,4	<12	13
Goabis 1	feldspar	66,2	0,002	18,6	0,06	0,007	0,03	0,087	2,67	12,04	<12	12
Goabis 2	graphic feldspar	74,37	0,002	13,98	0,07	0,005	0,02	0,062	1,81	9,397	<12	10
Hakiesdoorn	feldspar, quartz, mica	83,73	0,077	9,56	1,3	0,027	0,36	0,04	0,52	2,809	<11	11
Hakiesdoorn 3	feldspar, quartz, mica	76,11	0,117	14,03	1,89	0,036	0,55	0,119	0,71	4,178	<11	11
Hakkiesdoorn 1	feldspar	65,57	<0.001	18,82	0,06	0,006	0,02	0,08	2,44	12,58	<12	10
Hakkiesdoorn 2	feldspar + mica	74,22	0,041	14,83	0,74	0,013	0,14	0,356	2,02	6,704	<11	10

Table I continued: Chemical analysis of feldspar samples collected in Namibia.

Sample ID	Sample description	SiO_2 [%]	TiO_2 [%]	Al_2O_3 [%]	Fe_2O_3 [%]	MnO [%]	MgO [%]	CaO [%]	Na_2O [%]	K_2O [%]	Cr [mg/kg]	Cu [mg/kg]
Helikon 1	feldspar, quartz, lepidolite	68,71	<0.001	19,05	0,02	0,029	0,05	0,532	9,28	0,679	<11	15
Helikon 2	Na-feldspar	66,61	<0.001	19,63	0,03	0,031	0,14	1,142	9,68	0,226	<11	12
Helikon 3	feldspar + quartz	68,41	<0.001	19,14	0,01	0,02	0,06	0,545	9,88	0,44	<11	17
Helikon 4	feldspar + lepidolite	55,14	<0.001	26,87	0,04	0,121	0,07	0,021	2,39	7,039	<11	21
Houmsrivier 1	graphic feldspar	73,82	0,011	14,52	0,15	0,007	0,02	0,111	2,19	8,88	<12	<6
Houmsrivier 2	feldspar	65,89	<0.001	18,78	0,09	0,008	<0.01	0,058	2,54	12,33	<12	<6
Houmsrivier 3	feldspar	65,74	<0.001	18,86	0,08	0,007	0,01	0,057	2,54	12,38	<12	<6
Humdigams	tailings (feldspar, quartz, mica)	62,5	0,182	19,91	2,13	0,125	0,67	1,531	3,87	3,608	15	14
Karlowa	brown/cream feldspar	63,99	<0.001	19,55	<0.01	0,004	0,01	0,141	2,32	12,1	<12	<6
Keimasmund 1	feldspar	65,32	0,002	18,88	0,04	0,006	0,03	0,17	2,38	12,66	<12	10
Keimasmund 2	feldspar	65,28	<0.001	19,2	0,05	0,003	0,03	0,105	3,09	11,61	<12	13
Kudubis 1	cream feldspar	64,32	<0.001	19,81	0,07	0,002	0,03	0,065	2,97	11,16	<12	<6
Kudubis 2	grey feldspar	64,64	<0.001	19,4	0,04	0,004	0,02	0,065	2,66	11,83	<12	8
Meridas	feldspar + quartz	64,07	<0.001	19,15	0,03	0,002	0,03	0,081	2,22	11,76	<12	<6
Molopo 1	feldspar	64,02	<0.001	19,37	0,03	0,004	0,03	0,151	2,16	12,49	<12	16
Molopo 2	feldspar	64,1	0,005	19,5	0,04	<0,01	0,05	0,08	2,35	12,9	< 0.01 % Cr_2O_3	n.d.
Molopo 3	grey feldspar	64,29	<0.001	19,29	0,01	<0.001	0,01	0,065	1,72	13	<12	<6
Okatji 2	grey feldspar	64,46	<0.001	18,64	0,05	0,006	0,06	0,176	1,33	13,19	<12	14
Okatji 5	reddish feldspar	64,29	<0.001	19,29	0,15	0,018	0,04	0,108	2,71	11,76	<12	10

Table I continued: Chemical analysis of feldspar samples collected in Namibia.

Sample ID	Sample description	SiO_2 [%]	TiO_2 [%]	Al_2O_3 [%]	Fe_2O_3 [%]	MnO [%]	MgO [%]	CaO [%]	Na_2O [%]	K_2O [%]	Cr [mg/kg]	Cu [mg/kg]
Otjua	feldspar + quartz	80,04	0,007	12,29	0,14	0,037	0,03	0,338	6,18	0,37	<11	13
Pelgrimsrust	graphic feldspar	66,92	0,004	17,88	0,07	0,005	0,01	0,108	1,46	13,08	<12	<6
Ramansdrift	feldspar	65,71	0,002	18,82	0,06	0,003	0,03	0,087	2,41	12,57	<12	11
Rubicon	feldspar	64,74	<0.001	18,92	0,03	0,007	0,03	0,066	2,04	12,4	<12	10
Sandfontein	feldspar	65,98	0,002	18,9	0,11	0,011	0,02	0,062	2,8	11,83	<12	<6
Sperlingsputz	feldspar	65,6	<0.001	18,84	0,07	0,006	0,03	0,051	2,83	12,07	<12	11
Stockless Claim	feldspar	66,05	0,009	18,71	0,11	0,012	0,04	0,145	2,89	10,54	<12	<6
Tsomtsaub	feldspar, quartz, mica	65,31	<0.001	19,31	0,09	0,007	0,05	0,157	3,46	10,19	<12	<6
Uis Tailings 1	K-feldspar	62,89	0,03	18,2	0,05	0,14	0	0	0,6	15	0.00 % Cr_2O_3	0.02 % CuO
Uis Tailings 2	Na-feldspar	66,59	0,08	19,16	0,02	0,16	0	0,04	11,61	0,06	0.04 % Cr_2O_3	0.03 % CuO
Velloorsdrift 1	feldspar	65,5	0,003	18,83	0,09	0,006	<0.01	0,083	2,08	12,89	<12	<6
Velloorsdrift 2	feldspar	65,35	0,003	18,84	0,06	0,004	<0.01	0,082	1,86	13,21	<12	<6
White City	feldspar	64,84	<0.001	18,92	0,08	0,011	0,03	0,09	2,35	12,23	<12	15
Whitkop	graphic feldspar	74,07	0,021	13,86	0,47	0,01	0,03	0,124	1,79	9,176	<12	14
Zinnwald	feldspar, quartz, Li-minerals	69,9	0,008	18,35	0,15	0,012	0,04	0,249	7,36	2,416	<11	<6

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