An Investigation into

SUMARY OF THE MINERALOGICAL CHARACTERIZATION OF A SILICA SAND SAMPLE FROM JORDAN, AND MARKETING EVALUATION

prepared for

JORDAN MINISTRY OF ENERGY AND MINERAL RESOURCES

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Executive Summary

This is a summary of data, recommendations and conclusions from report 19073-01 for the Jordan Ministry of Energy and Mineral Resources for mineralogical and marketing evaluation of a silica sand sample.

Summary of Mineralogical and Chemical Results

1. Whole rock analysis by XRF of the sample indicates that SiO_2 is 95.1%, and the main impurity is Al_2O_3 at 2.67%, and lower Fe_2O_3 (0.18%) and TiO_2 (0.12%).
2. The sample consists of quartz (98.5%), kaolinite 1.23% and trace amounts of other minerals including rutile. Note that the amount of quartz is likely overestimated with the mineralogy tools.
3. The P_{80} of quartz is 275 µm; that of kaolinite 30 µm; and that of rutile 141 µm.
4. Liberation analysis indicates that:
    a. Pure quartz particles account for 1.8%, free for 96.2% and liberated for 1.81%. Free particles (<100%->95% quartz) indicate the presence of rims, attachments or intergrowths of quartz with other minerals indicating that they are not absolutely clean.
    b. Pure kaolinite accounts for 57.6%, free for 6.2%, and liberated for 10%. A large part of the kaolinite is associated with quartz (24.5%).
    c. Pure rutile accounts for 26.9%, free for 25.4%, and liberated for 27.9%. The remainder occurs as middlings with quartz (11.8%), complex middling particles (6.2%), and other minerals (1.4%).
5. An analysis of the morphology of the quartz shows that the majority of the quartz (87.6%) tend to be more equant than elongated.
6. Electron microscopy (SEM-EDS) analysis shows that kaolinite is the main mineral impurity in the sample. It occurs as intergrowths, coatings, and inclusions in quartz. Fe-oxide, Fe sulphides, and rutile are also associated with quartz.
7. Quartz grains were analyzed by LA-ICP-MS to determine the trace elements in their crystal structure. Several analyses show that quartz hosts <4 ppm Ti to 600 ppm Ti (± 401 ppm) and other trace elements. Iron (Fe) also shows a wide range from <22 ppm to 9327 ppm (± 8898 ppm). Aluminum also varies widely from less than 5 ppm to 9358 ppm (± 1922 ppm). Ca, S, Ni, Cu, Ba, Zn appear to present in widely variable concentrations. On the other hand, Sr, Rb, Ag, Cd, In, Sb, REE are below detection limits of a few ppm. The higher elemental values are derived from micrometric inclusions in the quartz grains analyzed.

- Malvern analysis yields a d(0.8) of the sample at ca. 390 µm. A wet screen analysis yields a P_{80} of 291 µm.

Conclusions and recommendations

- The mineralogical results cannot predict the final product and purity of the quartz sand without additional test work. The mineralogical analysis indicates what is possible and where potential issues might occur during processing due to the inherent mineralogical features of the sample.

- The present mineralogical data indicate the silica sand is derived from a quartzite cemented with kaolin clay. The liberation analysis, TIMA analysis and Laser Ablation analysis indicates the silica grains are weakly cemented by interstitial clay coatings and particles, with the presence of minor amounts of other interstitial minerals. It is critical to note that very fine-grained inclusions of kaolinite and other minerals might not be removed at this grind size.
- The silica sand should be capable of significant upgrading using low cost attrition scrubbing. Light acid washing may be required to reduce iron levels to values acceptable for applications requiring very low iron assays.
- The P_{80} for the quartz is 275 μm, D_{10} is approximately 130 μm, top size of approximately 650 μm and a D_{50} of approximately 220 μm, indicating the silica sand has a good size distribution for most applications.
- Additional test work is suggested to determine the upgrading potential. SGS has issued a separate proposal to test the following:
    - attrition scrubbing test to remove kaolinite from quartz
    - magnetic separation to separate any Fe-oxides
    - flotation testing to determine kaolinite and other impurities can be separated from the quartz. Flotation might not be ideal for the region but it provides a laboratory avenue to test the removal of the impurities.
    - Acid leaching of the sample to remove as much impurities as we can from the sample.
- Silica sand from Jordan could be readily processed to high quality material using simple, low cost beneficiation techniques such as attrition scrubbing and washing. Testwork will be required to establish process parameters such as solids density, attritioning time, attritioning intensity, washing/screening requirements and final product recovery. Requirements for additional processing such as Wet High Intensity Magnetic Separation (WHIMS) and/or acid washing can be determined based upon the results of the initial process test work and evaluation of the costs of the additional processing versus the benefits in terms of product quality, available market volumes and product prices.
- The un-beneficiated (non processed) quartz could only be used in low value applications such as cement, mortar mixes, etc. and possibly low value ceramics such as quarry tiles and other red body tiles. There could also be a possibility to use the quartz in coloured glass, but only as a portion of the mix.

- Once the quartz is beneficiated, processed silica sand should be readily capable of meeting the quality requirements of all but the most demanding applications (those demanding extremely low iron, titania and alumina levels, i.e. <100 ppm). Potential markets for >99.5% SiO_2 may include (see full report) a variety of applications from insulation glass fibre, reinforcing glass fibre, container glass, to golf sand. The final product has to be tested to properly determine its applications. Beneficiation will probably yield a range of specifications, so assays by batch would be useful to provide a range of products.

- Export markets in Saudi Arabia, UAE, Israel and other regional markets such as India may be attractive due to the high quality of the processed Jordanian silica sand and availability of low cost water transport from Aqaba to regional ports.

- Disclaimer:
    - It is critical to note that these current results reflect the particular samples tested.
    - Note that the findings in this report are based on what is mineralogically possible, under ideal separation conditions. For instance, it assumes that it is possible to separate a kaolinite grain with a minute attachment of another mineral from a particle that contains no inclusions or attachments. Practically, this separation might be more complex. Thus, the findings in this report should not be considered as a prediction of recovery performance. Rather, this provides insight into the limitations with respect to mineralogical characteristics.
    - The mineralogical data cannot accurately predict the upgrading potential of the silica sand without the additional metallurgical testwork.

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