Mineralogy and surface chemistry assessment of heavy minerals concentrate and commodity minerals produced by Titanium Corporation

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The quantities of commodity minerals such as zircon ($ZrSiO_4$), titanium-dioxide (rutile, anatase), and ilmenite ($FeTiO_3$) in froth-treatment tailings from Athabasca oil sands are sufficient to motivate recovery efforts. Titanium Corporation (TIC) has developed a proprietary process to recover those minerals from froth treatment tailings generated during production of bitumen from oil sands. As a bonus, the recently demonstrated pilot-plant-scale recovery of the bitumen content from >5 wt% in those tailings to <0.5 wt% in the heavy minerals concentrates produced adds environmental value to the TIC process, and constitutes a further incentive to the recovery effort. Characterization of TIC's process streams and products is crucial to understanding and improvement of the corresponding mineral processing technologies, as well as building market support for customer applications. A comprehensive characterization using complementary techniques was therefore conducted here for the heavy minerals concentrate (HMC) and various grades of the three commodity minerals (leucoxene, ilmenite, and zircon) produced by TIC. The characterization techniques included: (1) metal concentrations by X-ray fluorescence (XRF) spectrometry; (2) mineral contents by powder X-ray diffraction (XRD); (3) carbon and sulphur contents by standard techniques; (4) surface analysis by X-ray photoelectron spectroscopy (XPS); and (5) chemical composition mapping by scanning electron microscopy (SEM) combined with energy-dispersive X-ray spectroscopy (EDXS). In addition, selected samples were treated by oxygen plasma ashing (OPA) to selectively remove any organic materials occurring in a sample. When combined to measurement of bitumen content by standard Soxhlet-Dean and Stark extraction with toluene as the solvent, an estimate of the proportion between bitumen and total organic matter could be obtained. These results were then used to assess the extent of mineral-organic associations in the HMC. The mineral compositions of HMC, leucoxene, ilmenite and zircon samples was determined by a novel quantitative phase analysis (QPA) methodology parameterized with singular-value decomposition (SVD) based least-squares refinement. Recently developed at the NRC, the SVD-QPA methodology combines experimental results from techniques (1), (2) and (3) above to quantify the mass fractions of each individual phase comprised in the samples, including crystalline, amorphous and organic phases. SVD-QPA results for ~20 HMC samples produced using tailings from various oil sands operators showed little variability for the main mineral groups (i.e. clay minerals, heavy minerals, organic carbon, quartz+silica, Ca-Mg carbonates). The clay minerals content was about 16−17 wt% in the HMCs, while small variations were noted between two HMC series in terms of their contents of iron-bearing minerals (pyrite, siderite, amorphous Fe-hydroxide, ilmenite). A most notable information was that the HMCs contained stable proportions of zircon (7−10 wt%) and titanium-dioxide polymorphs (15−18 wt%). The degree of phase purity obtained by SVD-QPA for the leucoxene product revealed that the total concentration of TiO_2 polymorphs accounted for 78−83 wt% of its total mass; the remainder being quartz (7−10 wt%), clays (4−6 wt%), and Fe-bearing minerals (~2 wt%). The ilmenite product demonstrated a strong degree of ilmenite alteration towards rutile, with a TiO_2 content of 78−84 wt% and an Fe/(Fe+Ti) atomic ratio of 1.3−1.7%. Finally, multivariate factor analysis of XPS and SEM-EDX chemical data allowed identification of the following mineral associations: particle liberation for Zr and Ti heavy minerals; quartz intergrowths with the Ti-bearing mineral phases; quartz inclusion in zircon; and pyrite-quartz physical associations. Surface components of the HMC consistent with pyrite weathering (iron hydroxides, iron sulphates) were also resolved by XPS multivariate factor analysis. The wealth of mineralogical and surface-chemical results presented here will undoubtedly help maximizing recovery yields and further refining the quality of commodity minerals produced TIC.