Rapid, accurate field analysis of phosphate ores with handheld XRF

The need for rapid phosphate ore analysis

Phosphate rock (phosphorite) is the primary source of phosphorus used in fertilizers, making it indispensable to global food production. As high-grade phosphorite deposits become increasingly depleted, mining operations must process lower-grade and more compositionally variable phosphate ores. This trend places greater emphasis on rapid, accurate elemental analysis to support exploration, grade control, process optimization, and compliance with environmental regulations. Handheld X-ray fluorescence (HHXRF) has become a key analytical tool for these applications by providing fast, non-destructive, multi-element analysis directly in the field or at the production site.

Elemental composition of phosphate ores

Phosphate ore deposits vary considerably in mineralogy and chemical composition depending on their geological origin. The principal phosphate mineral is apatite; however, phosphate deposits also contain varying amounts of silica, carbonates, alumina, iron oxides, magnesium, sodium, potassium, sulfur, chlorine, and numerous trace elements. Among these trace elements, cadmium (Cd) and uranium (U) are of particular interest because of their environmental, regulatory, and economic implications. In phosphate ores, cadmium (Cd) and uranium (U) are commonly considered “penalty” elements because they create environmental, regulatory, processing, and product-quality challenges. Their presence reduces the marketability of phosphate ores or fertilizers in regions with strict limits on such elements, while their removal increases processing cost. For these reasons, the elemental analysis of phosphates is essential throughout the mining and fertilizer production chain.

Handheld XRF for rapid phosphate ore analysis

Handheld X-ray fluorescence (HHXRF) analyzers have emerged as valuable tools for on-site elemental analysis of the major and penalty elements in phosphate ores. The analyzers’ portability, ease of use, and ability to deliver analytical results within seconds make them ideal for rapid decision-making in mining exploration as well as mining operations for guiding extraction, stockpile management, quality control and environmental monitoring. While handheld XRF does not replace laboratory-grade analysis for certification purposes, it provides immediate compositional information that can significantly improve operational efficiency.

The Thermo Scientific™ Niton™ XL5 Plus Handheld XRF Analyzer (Figure 1a) combines a compact, lightweight design with advanced analytical performance for field-based elemental analysis. Featuring a 5 W / 50 kV / 500 µA max. proprietary X-ray tube and a large-area silicon drift detector (SDD) with a graphene window, the Niton XL5 Plus analyzer delivers accurate elemental analysis across all stages of mining and exploration. The Mining Mode on the XL5 Plus analyzer can measure 41 elements, from magnesium (Mg) to uranium (U), using four optimized excitation conditions to enhance the signal-to-noise ratios of fluorescence lines across the full energy spectrum. Mining Mode uses a proprietary fundamental parameter (FP) based algorithm that accounts for the high variability of sample composition by correcting for matrix absorption and secondary enhancement effects; this improves analytical accuracy across a wide range of sample compositions. Users can optimize settings of Mining Mode and store that group of preferred settings under Profiles. Profiles enable users to have multiple analytical methods on the same instrument; the most appropriate profile for a given task can be easily selected to perform desired measurements quickly.

Figure 1. (a) Niton XL5 Plus analyzer; (b) Result of elemental analysis display for phosphate ore; (c) Sample analysis using the Thermo Scientific™ mini test stand.

Analytical method

The analysis of phosphate ores can be carried out in two ways: either directly on the rock face ("point-and-shoot" mode) or on prepared powder samples. Operating the handheld XRF analyzer in "point-and-shoot" mode can be suitable to quickly locate high-grade ores, but results in limited accuracy and analytical sensitivity. Proper sample preparation is essential to generate accurate quantitative results and achieve sufficient sensitivity to detect impurities. Sample preparation consists of collecting and homogenizing phosphate material using a grinder. In case the moisture content is high, drying might also be necessary before grinding. The homogenized powder is then introduced into a sample cup, and the analysis carried out using the XL5 Mini Test Stand (Figure 1c). This approach allows longer measurements and generally yields results that are more comparable to those from laboratory methods.

In the study presented here, eight grams of nine finely ground phosphate certified reference materials were packed into sample cups fitted with polypropylene film and measured for 120 seconds on the Niton XL5 Plus handheld analyzer using four beam conditions (30s/Main Range, 30s/Low Range, 30s/High Range and 30s/Light Range) in the Mining Mode.

Analytical performance

The results from the analysis of nine samples obtained using the Niton XL5 Plus analyzer have been plotted against the certified values. The correlation coefficient R^2 is a measure of how closely the data sets correlate with each other, where a perfect correlation would have an R^2 of 1. As can be seen in Figure 2, plots a, b, and c, there is excellent agreement between the measured and certified values for the major elements present (phosphorus (P), calcium (Ca), and silicon (Si)), demonstrating the accuracy of the handheld XRF analytical method for the analysis of phosphates.

In addition, the measurement of penalty elements such as U, present at low concentrations (certified in the sample set down to 20 ppm), was found to be accurate (Figure 2d). Although only a few samples were certified for cadmium (Cd), this element has been detected in most samples, as can be seen on the spectra shown in Figure 3.

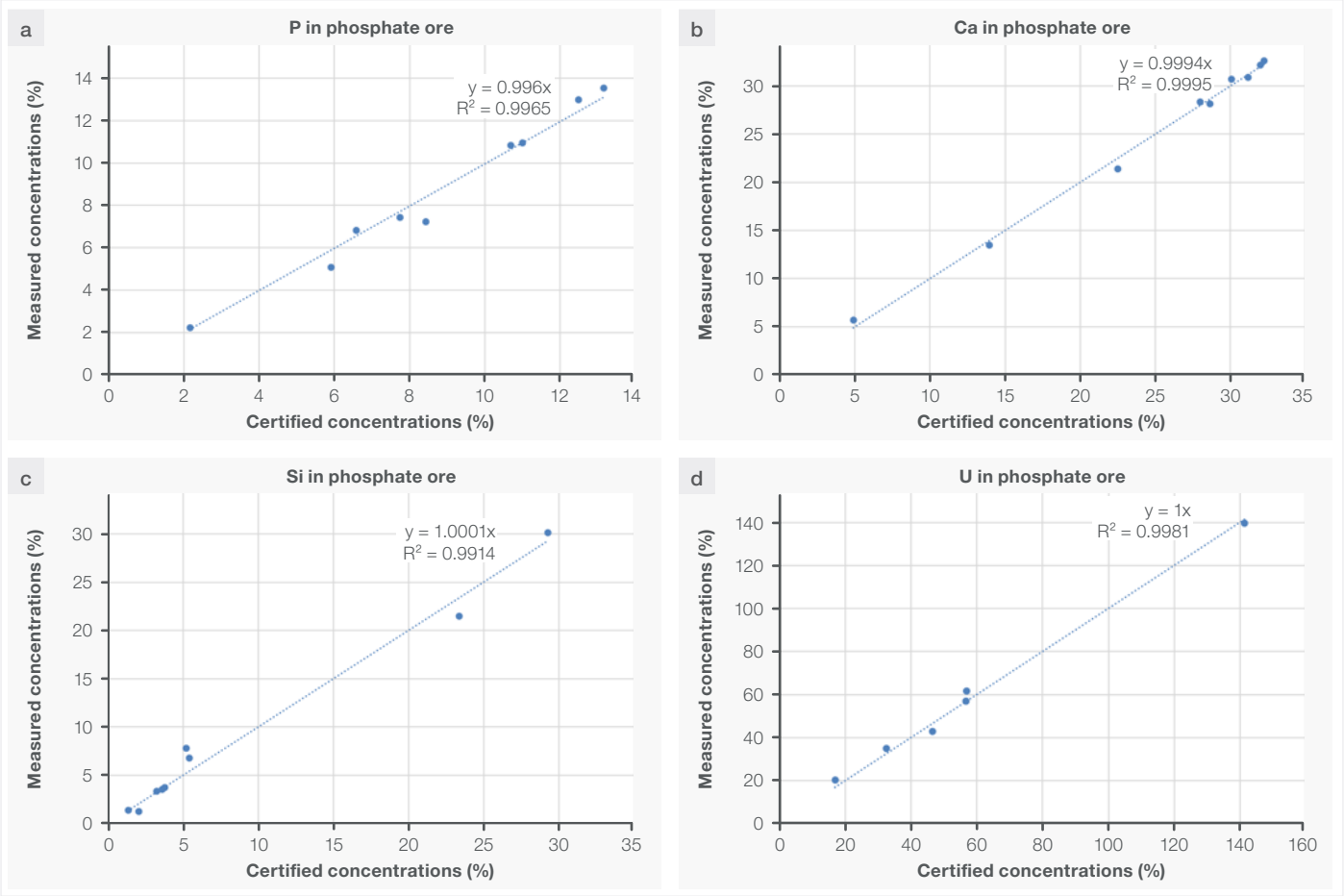

Figure 2. Correlation between certified laboratory values and measurements obtained using the Niton XL5 Plus handheld XRF analyzer for (a) P; (b) Ca; (c) Si; and (d) U.

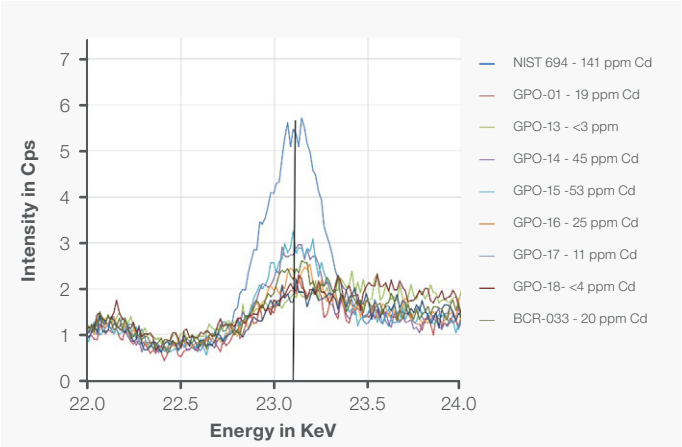

Figure 3. Spectra of phosphate samples in the vicinity of the Cd Ka-line. Concentrations indicated in the legend are measured values: only the concentration in NIST 694 is certified (131 ppm).

Key findings

The Niton XL5 Plus handheld XRF analyzer provides rapid, accurate, multi-element analysis of phosphate ores, enabling informed decision-making throughout exploration, mining, and fertilizer production. Combined with appropriate sample preparation, the analyzer delivers excellent agreement with certified laboratory values for both major constituents and critical penalty elements such as uranium and cadmium.

By providing immediate analytical results at the point of need, the Niton XL5 Plus analyzer helps improve ore characterization, optimize process control, and reduce reliance on time-consuming laboratory analyses.

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