Sample	Au (g/t)	Tot S (%)	S² (%)	As (%)
Mil feed	2.29	1.2	1.07	0.26
Flolation concentrable	17.39	9.56	8.22	2.65
BIOX product	34.60	2.58	0.42	0.20
BIOX CIL talling	3.69	3.36	0.86	0.12
Sample	Fe (%)	Org C (%)	Tot (%)	CO³ (%)
Mil feed	6.32	1.08	11.25	10.50
Flolation concentrable	8.26	3.21	5.05	9.02
BIOX product	3.20	6.67	7.13	3.78
BIOX CIL talling	1.69	4.84	5.75	4.55

Table 1. Results of partial chemical analysis.

The results confirm the sulphidic nature of the ore being treated as sulphidic gold ores should have sulphur content in excess of 1% (Marsden and House, 2006). The relatively low arsenic grade of 0.26% in the mill feed suggests low amounts of arsenopyrite in the ore compared to pyrite as depicted by the relatively high levels of iron. The 0.13% difference in sulphide sulphur and total sulphur grades is an indication of the presence of sulphates from natural oxidation of sulphide minerals. The plant normally keeps a large stockpile buffer of Gold dissolution (%) = (1 - ab) x 100 more than one month to reduce risk of mill downtime during periods of low mining production. Natural oxidation of sulphide minerals has been seen to take place on the stockpile, and this may explain the presence of sulphates.

Two factors critical to the amenability of an ore to BIOX® treatment are the ratios of Au: S^{2-} and S^{2-}: CO_3^{2-}. The industry rule of thumb is a Au:S^{2-} of > 0.7 as this renders the project viable with low downstream operating costs (Aylmore and Jaffer, 2012). The flotation concentrate sample collected showed a ratio of 2.1, which is far above the cut point. Further, a S^{2-}:CO_3^{2-} ratio of 0.9 is recorded. Lower ratios render the BIOX reaction net acid consuming and vice versa. A net sulphuric acid consumption is attended by a mass loss across BIOX. Such a mass loss normally results in a grade increase post BIOX® as depicted by the high grade difference between flotation concentrate of 17.39g/t and BIOX CIL feed of 34.6g/t. The opposite is not desired as lime addition to correct low pH results in the precipitation of gypsum and a mass gain after BIOX. Gypsum precipitation leads to passivation of gold surface with subsequent decline in cyanidation recovery. The ideal situation is to blend ROM ore to achieve a balanced ratio in concentrate where no pH adjustment is required in BIOX.

The BIOX® product sulphide sulphur grade of 0.42% indicates a sulphide oxidation of about 95% on BIOX®. The data further shows a high total sulphur grade of 2.58%. Such observations have been attributed to elemental sulphur, sulphates and formation of some intermediate sulphur compounds such as polysulphide (S_x^{2-}). These sulphur species are undesirable for the subsequent cyanidation process as they act as cyanicides and cause large losses of cyanide by the formation of thiocyanate (SCN-). In fact, Hackl and Jones (1997) reported over 15 kg/t NaCN consumption for every 1 %w/w elemental sulphur. The recorded BIOX CIL tails grade of 3.69 g/t is consistent with plant operating data and falls within range of unpublished survey data collected from six BIOX® operating plants in the world as shown in Figure 2. Operators of these BIOX plants do not see such solid tails grades in the range of 2-16 g/t as alarming since they are treating concentrate grades in the range of 30- 160 g/t (Anon, 2013).
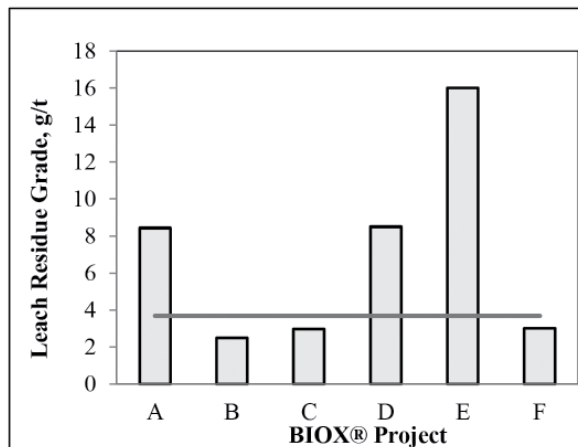
Figure 2. Survey results of residue grades from six BIOX® operating plants in the world.

DIAGNOSTIC LEACHING

The diagnostic leach test attempts to broadly categorise the gold associations as either free or cyanide leachable, gold in carbonates, gold in sulphides (pyrite and arsenopyrite), gold in carbonaceous matter and un-liberated gold in quartz. Diagnostic leaching has gained prominence among operational metallurgist because it is cost-effective, simple and offers a near alternative to conventional mineralogical characterisation techniques such as X-ray diffraction (XRD), electron microprobe analysis (EMPA), energy dispersive spectrometer equipped scanning electron microscopy (EDS-SEM), Quantitative Evaluation of Minerals by Scanning Electron Microscopy (QEMSCAN) and Mineral Liberation Analyzer (MLA) (Lastra, 2007). The diagnostic leaching procedure consists of sequential leaching of the ore by selective oxidising agents followed by cyanidation at each stage. The selection of the oxidizing agents depends on the mineralogy of the ore, objective of the test, and type of ore (Lorenzen and van Deventer, 1993; Torres and Costa, 1995).

This test was conducted on the flotation concentrate sample and the BIOX CIL tailings sample. The idea was to ascertain the gold inclusions before the BIOX pretreatment step and to interrogate the gold associations in the CIL leach residue, and shed light on the causes of high tailings grade. The graph of gold deportment is shown in Figure 3.
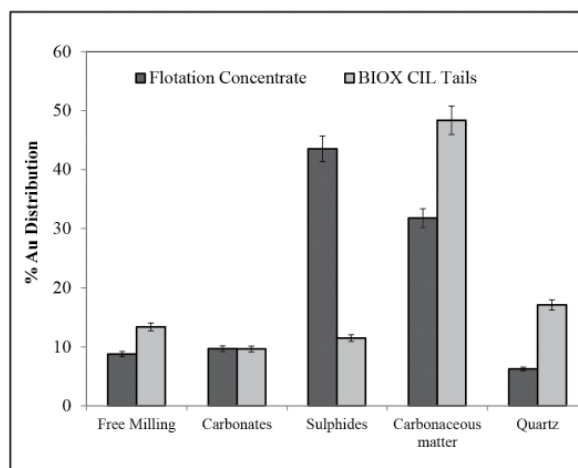

Figure 3. Gold deportment in flotation concentrate and BIOX CIL tailings.