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The use of unmanned aerial systems for the mapping of legacy uranium mines

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ABSTRACT

Historical mining of uranium mineral veins within Cornwall, England, has resulted in a significant amount of legacy radiological contamination spread across numerous long disused mining sites. Factors including the poorly documented and aged condition of these sites as well as the highly localised nature of radioactivity limit the success of traditional survey methods. A newly developed terrain-independent unmanned aerial system [UAS] carrying an integrated gamma radiation mapping unit was used for the radiological characterisation of a single legacy mining site. Using this instrument to produce high-spatial-resolution maps, it was possible to determine the radiologically contaminated land areas and to rapidly identify and quantify the degree of contamination and its isotopic nature. The instrument was demonstrated to be a viable tool for the characterisation of similar sites worldwide.

1. Introduction

Cornwall, south-west England, has a rich and expansive metallic mining heritage. The region has exploited its granite-derived high-grade mineral vein deposits for economic gain since pre-history, with its landscape having been heavily impacted as a result. Significant exploitation of these deposits was performed at the turn of the nineteenth century fuelled by the industrial revolution and the associated demand for minerals. The workings from this era have left a lasting mark on the land, and are recognised as important to the national heritage of the region thus supporting economic activity associated with tourism. One such mine, South Terras, actively produced high grade uranium and radium ores, from 1870 to 1930. The mine is situated near Tolgarrick Mill, 1.6 km south-west of the village of St Stephen, 22.5 km south-west of St. Austell. It is documented that radium arising from the operation was utilised by Marie Curie for her ground-breaking research on radioactivity.

Its purlieu lay in the valley of the River Fal, working a mineral lode associated with the southern portion of the metamorphic aureole surrounding the St. Austell granite, which is thought to run approximately half a mile north of the South Terras workings (Dines, 1956). The normal tin mineral lodes run east–south-east, but the crosscourse lode containing the late stage, low temperature uranium minerals runs ten degrees west of north and carries nickel, cobalt, arsenic, bismuth and silver in addition to uranium (Smale, 1993).

During operation of the site, the primary ore mineral worked in the mine was pitchblende [UO_2–U_3O_8] but a secondary zone of mineral enrichment occurred in the upper levels of the mine consisting of torbernite [$Cu(UO_2)_2(PO_4)_2 \cdot 12H_2O$] and autunite [$Ca(UO_2)_2(PO_4)_2 \cdot 10{-}12H_2O$]. These two minerals provided the majority of uranium production at South Terras. The primary mineralisation phase is thought to have occurred at around 225 Ma and was subsequently followed by remobilisation and partial loss of radiogenic lead 60 Ma (Smale, 1993). Within the mine the ore grade was particularly high, with sections of the primary lode containing up to 30% uranium by weight. Once extracted, processing of raw material was conducted on-site in neighbouring buildings. Between the periods 1873–1881 and 1900–1910, the mines were documented to have produced 736 tons of uranium ore (Dines, 1956).

Owing to the absence of legislation regarding radiological contamination at the time of the workings, little occurred to control the amount of environmental pollution. As a result, with the eventual abandonment of the mine in 1927, a significant degree of radiological contamination existed on the site, which has previously received only limited characterisation, unpublished in the public domain.

The buildings associated with the mining and subsequent processing works exist to the north-west of the site, as outlined in a

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plan of the works produced by Ashwell in 1889 (Fig. 1). These buildings have since degraded following the overgrowth of woodland. The current overgrown state of the site presents a challenge to traditional characterisation methods, such as walk-overs, for mapping the distribution of residual contamination.

Airborne radiation monitoring has previously been conducted over the St Stephen region, with the most recent survey conducted as part of the Tellus South-West project (Beamish, 2014), led by the British Geological Survey (BGS). This survey, conducted in light-weight aircraft with an altitude of 56 to over 200 m at speeds typically between 60 and 70 m s^{-1} using a 200 m survey line separation identified a radiation anomaly at the South Terra site. Typically, standard regional airborne radiometric surveys use bulky and heavy suitcase style detectors, carried by large helicopter or fixed-wing vehicles (Schwarz et al., 1995a,b; Sanderson et al., 1995; Mellander, 1995; Okuyama et al., 2008; Sanada and Torii, 2014; Sanada et al., 2014). However, challenges are presented with these systems when attempting to produce high spatial resolution data owing to the high altitudes at which they must operate; with resolutions averaging upwards of 300 m (Sanderson et al., 1995). Helicopter or fixed-wing based systems are often expensive (both the aircraft and detector) and require well-trained pilots for their operation, therefore making such a technique unfeasible to characterise small sites. Here we present how a small unmanned aerial system (MacFarlane et al., 2014) operating at low altitude [<15 m] can be used to determine the extent of residual radiological contamination over a disused mining site, providing an accurate assessment of the distribution of radio-contamination, down to the metre scale. Such a tool is complementary to existing high altitude, lower resolution aerial surveys and slower ground-based methods. With increased resolution defining the minimum areas of contamination, the costs associated with the subsequent site remediation are significantly reduced. The ability to locate small (metre scale) regions of high activity, which should be avoided is essential to radiation protection, particularly for tourism.

Low-altitude characterisation of contamination has occurred following the accident at the Fukushima Daiichi Nuclear Power Plant in eastern Japan. Sanada and Torii (2014) and Sanada et al.

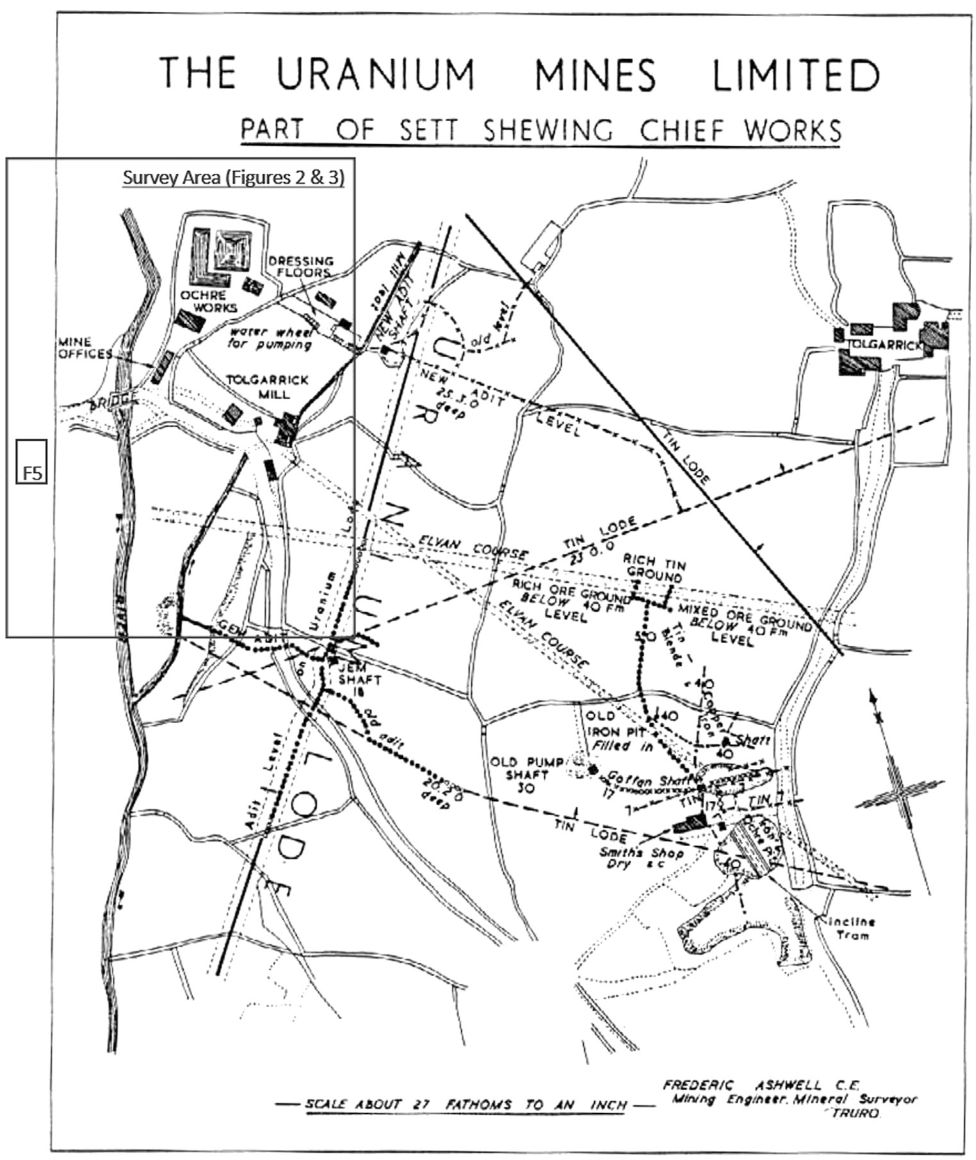

Fig. 1. Plan of the Uranium Mines property, redrawn from the original by F. Ashwell, which accompanied the prospectus issued by Uranium Mines Ltd in 1889 (C.R.O. X 116/42). The surveyed South Terras mining operations (Figs. 2 and 3) are identified in addition to the location of Fig. 5.