UNDERSTANDING GEOLOGY AND STRUCTURE: AN ESSENTIAL PART OF MINERAL RESOURCE ESTIMATION

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SUMMARY

The assumption of continuity of mineralisation between sampling points, as stated in the JORC Code, requires a "confident interpretation of the geological framework". The elements of relevance to a geological framework vary greatly depending on the commodity and style of mineralisation. In general terms, at least two elements must be considered to underpin a geological framework: space and time.

The geometry and location of a mineralised body are controlled by physical and/or chemical elements, which can be unravelled by detailed geological mapping, adequate geochemical (including a quality analysis-quality control program) and structural interpretations, and by 3D geological modelling. These elements may involve, among other, aspects of stratigraphy, chemical or physical properties of the rocks (e.g. texture, grain size) and structural features such as faults, fractures and folds.

Mineralisation events that lead to economic deposits are often relatively short-lived periods of focused fluid transfer and element-exchange, which result in mobilisation and deposition of metals in well-defined areas. Understanding the temporal framework and interaction of structural elements and mineralising events (determining genetic relationships, e.g. pre-, syn- and post-mineralisation) results in the development of more accurate geological models and can lead to predictive capabilities and new discoveries.

We present case studies in regional metamorphic, igneous, sedimentary and surficial geological environments, demonstrating how understanding the mineralisation system not only results in increased confidence in the resource, but also facilitates reduction of exploration risks.

Key words: Structural Geology, JORC, 3D Modelling, Uranium, Iron, Graphite, Gold

INTRODUCTION

The development of mineral exploration projects from greenfields to resource estimation involves a wide variety of exploration activities, initially aimed at identifying opportunities in the form of mineralised targets, and then aimed at reducing exploration risk by developing a better understanding of the target. Once a mineral resource can be reported, the geological understanding of the mineralisation system should be such that there is sufficient confidence to correlate between sample points that form the basis of the resource. This confidence derives from many factors, which are summarised as a "geological framework" (JORC 2012). It implies a knowledge of the style of mineralisation and the geological context, which we refer to as a "Geological Model".

We present a number of examples from surficial, regional metamorphic, sedimentary and igneous geological environments, demonstrating that the development of a good geological model of the mineralisation system drastically improves the quality of mineral resource estimates.

DETRITAL IRON ORE

As part of an exploration program for iron ore mineralisation (Baniaka Project in Gabon, Central Africa), structural mapping and ground verification of linear magnetic anomalies identified steeply dipping BIF units, interspersed with a series of paragneisses and metavolcanic rocks. The BIFs and associated greenstones are deformed into upright tight and shallow doubly-plunging fold structures, and cross-cut by later fracture-sets along which deeper oxidation resulted in demagnetised zones. The deformation was associated with upper regional amphibolite metamorphism, which led to recrystallisation of magnetite and quartz. The tight folding resulted in structural thickening along hinge zones, and structural duplication along limbs, locally enhancing prospectivity for iron mineralisation.

A program of pitting and trenching was completed across the mapped BIF units, and identified a thin cover of yellow to light brown fine clay with minor silt interpreted to represent a windblown blanket of loess, beneath which a residuum is preserved on both the BIF and non-BIF lithologies, dominated by iron oxide, iron oxy-hydroxide, quartz and clay (Figure 1). Follow up auger drilling indicated that the residuum varies from 1 to 16 m thickness, with the thickest accumulations associated with plateau landforms developed on thinner, structurally duplicated BIF units, and less extensive accumulations associated with ridge landforms typically underlain by thick BIF units or along hinge-lines of the regional folds.

The composition of the residuum varies depending on the substrate on which it is developed. On the country rocks the residuum is comprised of nodules, quartz fragments, clays and occasional weathered bedrock fragments. The residuum developed on top of BIF and adjacent slopes comprises an upper unit of unconsolidated pebble to boulder gravels (detrital iron) and a lower layer of duricrust (canga or caprock). Caprock duricrust is variable and is most common on the flatter plateau areas, while canga duricrusts develop along slopes of the ridge landforms. On plateaus, the detrital iron accumulations are interpreted as eluvial lag deposits, often preserving a weak fabric from the substrate that has experienced slope creep. Up-profile and downslope, the detritals are slightly more sorted with higher matrix content of fines material, which grade into a colluvium. The detrital iron deposits are often coarse-grained and clast-supported at the base, becoming matrix-supported towards the top as the proportion of in-mixed loess and clay increases.

Weathering and oxidation, related to increased permeability of steeply-dipping BIF units along metamorphic layering or to zones of increased fracturing (along fold hinges and adjacent to margin-parallel or cross-cutting faults), has resulted in the mobilisation of silica-alumina, and the gradual disaggregation of the recrystallised BIF units. This process of disaggregation is assisted by the recrystallised nature of the BIFs, and the coating of quartz grain boundaries by remobilised iron oxy-hydroxides in supergene (meteoric) fluids, as well as by local alteration of magnetite and amphiboles. Thus, the top part of the BIF substrate to the detrital iron deposits is comprised of incompetent and semi-competent BIF (soft BIF), which disintegrates into powder in which quartz and magnetite grains are liberated. Deeper down the BIFs become more competent, forming partly oxidised hematite-magnetite and then primary fresh magnetite BIF.

As this example demonstrates, the development of the detrital iron geological model not only requires an understanding of regolith development in relation to landforms (the preservation factor), but also a good grasp of the underlying geology, which controls the make-up, quantity and quality of the ore. It was found that areas of structurally complex protore BIF are the most prospective for detrital iron.

FLAKE GRAPHITE

An example of a flake graphite project (Epanko Project, southern Tanzania) highlights the importance of a detailed structural geology understanding to inform resource estimation. Earlier resource estimates had adopted a simple deformational history for mineralisation identified over considerable strike-length. Based on field and core structural observations (e.g. Figure 2) three main deformation events (D_1 - D_3) were identified, that affected the geometry of graphite mineralisation, the distribution of flake size and the distribution of deleterious elements (e.g. sulphide).

The project area contains a package of high-grade metamorphic (upper amphibolite – granulite facies) rocks, which are complexly deformed. The major regional structural control is in the form of a D_1 synform, which plunges 88°→178°. The fold is slightly asymmetric, with the western limb dipping 80°→265°, and the eastern limb dipping 45°→126°. Parasitic F_1 folds are typically tight to isoclinal, with plunge directions varying relative to their position within the regional F_1 synform. Shallower plunges noted towards the north (along limbs) and steep plunges in the south indicate an F_2 overprinting event. Parasitic F_2 folds can be seen in outcrop, and plunge 34°→324° and are associated with a penetrative S_2 schistosity. Whereas F_1 folding controls the main geometry of the graphite-bearing units, F_2 folds appear to control the plunge direction of graphite mineralisation, while graphite flakes are enlarged on S_2 fabrics. The parasitic F_2 folds typically display a cyclicity of 200 – 400 m. The footwall is marked by a tectonic breccia, which is interpreted as a regionally extensive fault zone, and extends southward along the eastern limb of the interpreted synform. Locally, there is also evidence of later overprinting imparting S_3 cleavage in quartzite, which is also evident in remote sensing and geophysical data.

In summary, the geology of the project area is complex due to the high-grade metamorphism and at least three overprinting deformation events. The deformation events have implications for the geometry of graphite mineralisation, distribution of flake size and the distribution of deleterious elements (e.g. sulphide). Primarily, D_1 and D_2 have provided the main controls on geometry, grade and flake size of graphite mineralisation structures.

SANDSTONE-HOSTED URANIUM MINERALISATION

The Takardeit uranium prospect is located in northern Niger (West Africa) where uranium has been mined since the 1970s from the open pits of the Société des Mines de l'Aïr (SOMAIR) and the underground operation of the Compagnie Minière d'Akouta (COMINAK). Uranium mineralisation in these two mines is defined as tabular and roll-front deposit types, hosted in the Carboniferous sandstones of the Tarat and Guezouman Formations.

These sedimentary formations form part of the larger Iullemmeden Basin extending over Niger, Algeria, Benin, Mali and Nigeria, with the Tim Mersoi defined as a sub-basin. The Tim Mersoi Basin is comprised of Devonian to Cretaceous sediments overlying the West African Craton, in which uranium mineralisation was first identified in the early 1950s by the French Bureau de Recherches Géologiques et Minières (BRGM) and later the Atomic Energy Commission (CEA). Uranium is also known in the younger Jurassic to Cretaceous sediments with the large Imouraren deposit hosted in the Tchirezine 2 sandstones and the Takardeit mineralisation hosted in the Tchirezine 1 sandstones of Jurassic Age.

The Tarkardeit prospect was extensively explored by CEA during the 1970s. Mineralisation is associated with yellow carnotite and lenses of darker carbonaceous material within channels of greenish grey, medium- to coarse-grained sandstones overlying mudstone horizons (SRK Consulting, 2009 and CEA, 1973). High-grade mineralisation is reported at surface with up to 17 % U_3O_8 in assays of rock chip samples collected in 2009 (NGM Resources Limited, 2009). During the early 1970s, CEA completed a drilling program at Takardeit comprised of 133 holes over an area of 10 km^2. It reported a first non-compliant resource estimate of 100 to 150 t U at a cut-off grade of 1,000 ppm (CEA, 1973). The mineralisation was interpreted as being restricted to the contact between the Tchirezine I and the underlying Mousseden in a number of high-grade palaeochannels, in areas where the palaeochannel direction changed allowing increased deposition of organic matter. The mineralisation intercepted in drilling was deemed of little economic interest compared to the high-grade surface occurrences and the prospect was abandoned.

On the back of higher uranium prices, the Takardeit prospect was the focus of renewed interest in 2009–2010. Additional exploration and drilling, stepping outside the earlier defined palaeochannels, led to the preparation of an Inferred Resource reported in accordance with the 2004 JORC guidelines. A total of 23 million tonnes at 210ppm (0.0210 %U_3O_8) was estimated for a contained 4,230 tU at a cut-off grade of 120ppm (0.0120 % U_3O_8, NGM Resources Limited, 2010). In contrast to the earlier palaeochannel model, the mineralisation was interpreted to be a tabular mineralised envelope over approximately 6 km^2 (Figure 3).

The example of the Takardeit mineralisation illustrates the importance of understanding the geological setting. CEA favoured a mineralised system restricted to 300–500m wide palaeochannels, whereas recent exploration favoured a tabular interpretation continuous over 1.6 km. This new geological framework allowed the definition additional mineralisation.

GOLD MINERALISATION

The successful development of a project from mineral exploration target through to mineral resource relies heavily on the collection of quality datasets, but most importantly, it relies on the interpretation of these datasets. Innovations in 3D modelling such as implicit modelling have been an important step in improving how ore bodies are interpreted and modelled. Advanced 3D visualisation and modelling toolsets have changed how geologists understand and interpret ore bodies beyond just geometrical understandings, by providing valuable insight into the underlying geological and structural controls on mineralisation. This in turn has improved the development of resource domains by ensuring they honour not only grade distributions but also the geology and structure.

As an example of 3D structural modelling, recent work conducted at Kirkland Lake Gold’s Maud Creek Gold Deposit in the Northern Territory, Australia, has highlighted the importance of developing a robust geological and structural framework to better understand mineralisation controls and distributions for defining resource domains. The Maud Creek Deposit lies approximately 20 km to the east of Katherine in the Northern Territory and is hosted within the Proterozoic Finnis River Group within the Pine Creek Orogen. Mineralisation within the deposit is hosted within the north-south striking Maud Creek Fault, which marks the contact between sedimentary rocks of the Tollis Formation and mafic tuffs of the Dorothy Volcanic Member. Mineralisation is recognised to occur within stockwork and massive quartz veins with additional disseminated gold within the surrounding wallrocks.

As the deposit is understood to be strongly controlled by structure and lithological association with the tuff sequences, it was important for the resource domaining process to accurately define the distributions of the key host lithologies and fault architecture. Geological modelling of the deposit was conducted using the Leapfrog™ 3D modelling system, integrating all available datasets including drilling, historic pit mapping, regional geological mapping and geophysical datasets. Five main geological units were modelled including tuff, metasediments, dolerite, andesite and overlying cover sequences. To better understand the mineralisation distributions and controls, preliminary modelling of the gold grade was conducted using Leapfrog’s implicit modelling system (Cowan et al., 2003, Figure 4). This quickly confirmed the strong fault control on gold mineralisation, with gold mineralisation illustrating a steep easterly dip along the Maud Creek Fault with a steep (70-80°) south-east plunge. This plunge was observed to follow the intersection of the Maud Creek Fault with a cross-cutting fault structure defined from pit mapping, with increased thicknesses of mineralisation occurring along this junction. Away from the main fault, gold was also recognised within a sub vertical zone proximal to the Maud Creek Dolerite, along which a north-south trending shear system was interpreted.

From these preliminary observations, detailed wireframes of the host vein bodies could be developed. Vein geometries were modelled and constrained within key horizons to honour the structural observations. Additional wireframing of the grade halos surrounding the veins was conducted in harmony with the observed geometries and structural controls.

CONCLUSIONS

This paper presents case studies in surficial, regional metamorphic, sedimentary and igneous environments for different commodities and styles of mineralisation. The common thread that underpins all examples is the importance of having a geological model in harmony and compatible with observations at all scales. A good geological model provides ideas on the relative timing of geological events, and the geometry of the mineralisation systems (space and time). The interpretation of high-quality geological data and its integration and use in 3D modelling not only results in a reduction of some of the exploration risks by delivering a predictive geological framework, but also increases confidence in the resource.

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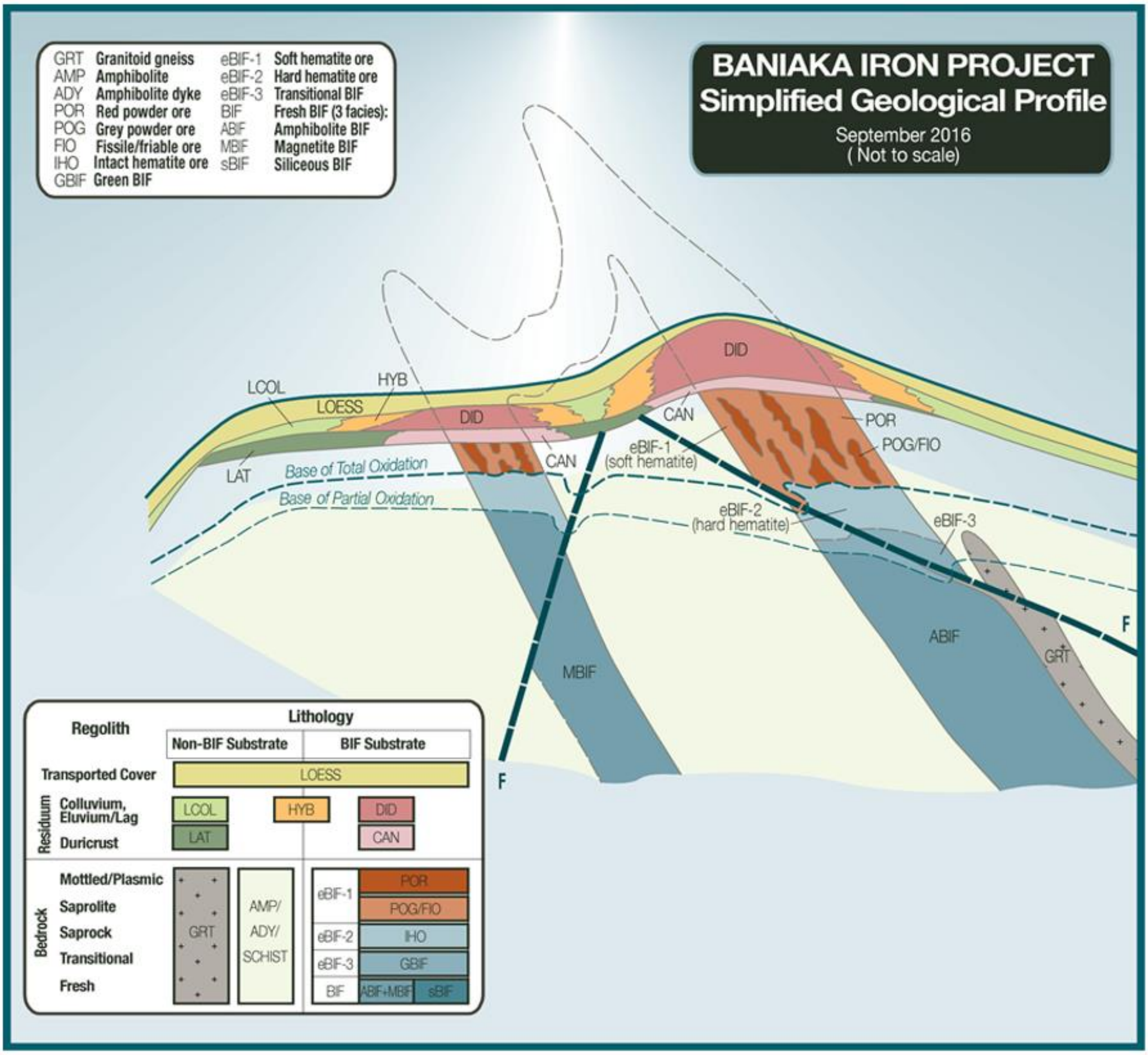

Figure 1: Schematic geological model of detrital iron in the Baniaka Project, Gabon

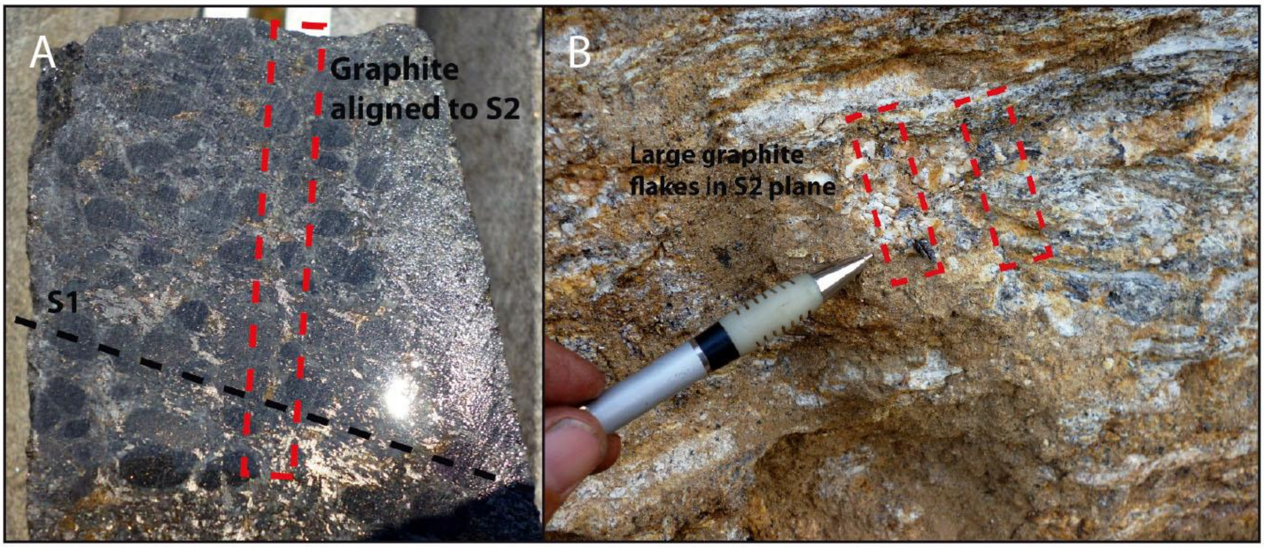

Figure 2: Structural control of graphite mineralisation in the Epanko Project; A – Graphite aligned to the S_1 and S_2 fabrics within drill core; B – Large graphite flakes forming along the S_2 plane

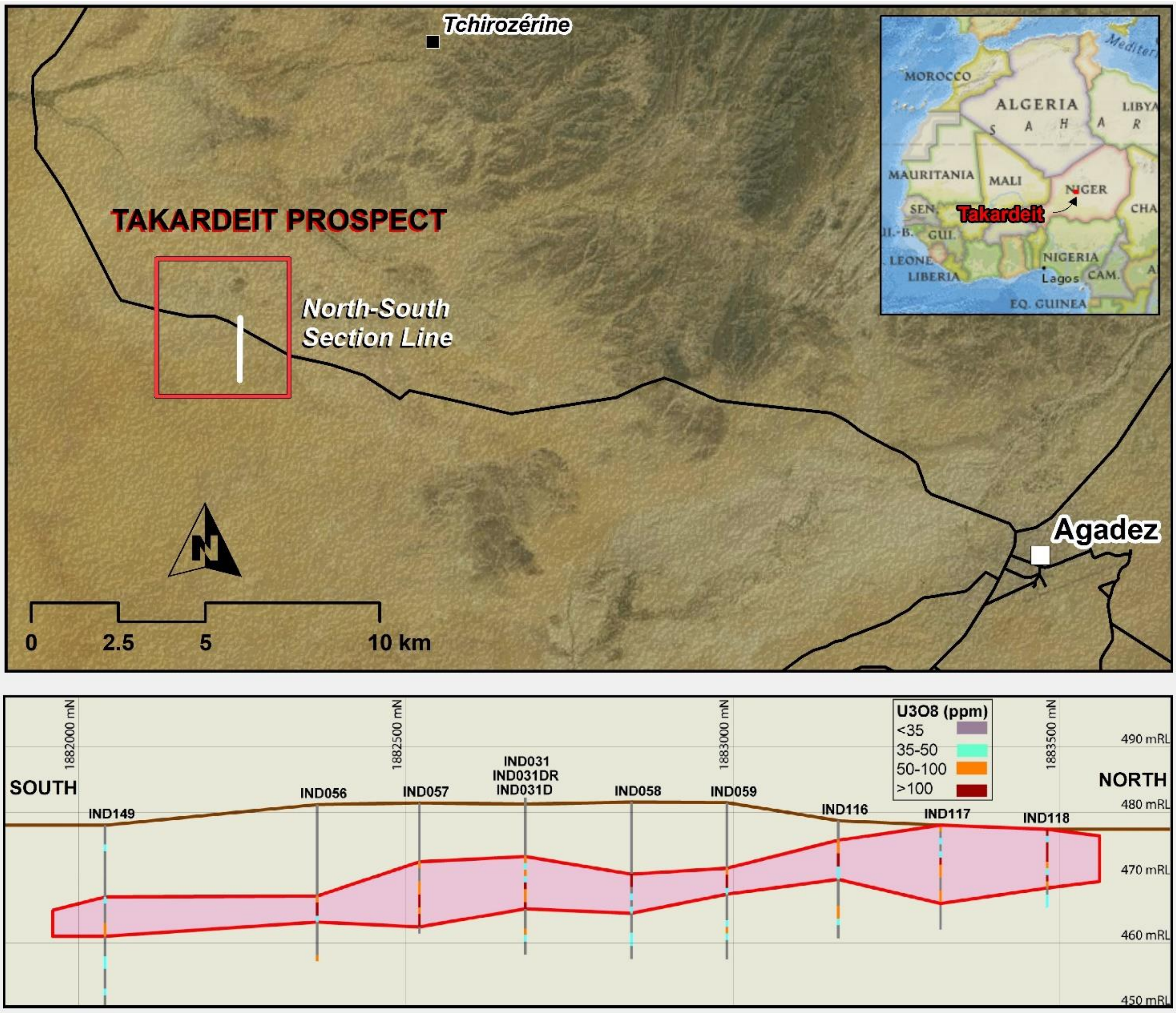

Figure 3: **Location and cross-section through the Takardeit uranium mineralisation, showing gently-dipping tabular nature of the deposit (section from NGM, 2010)**

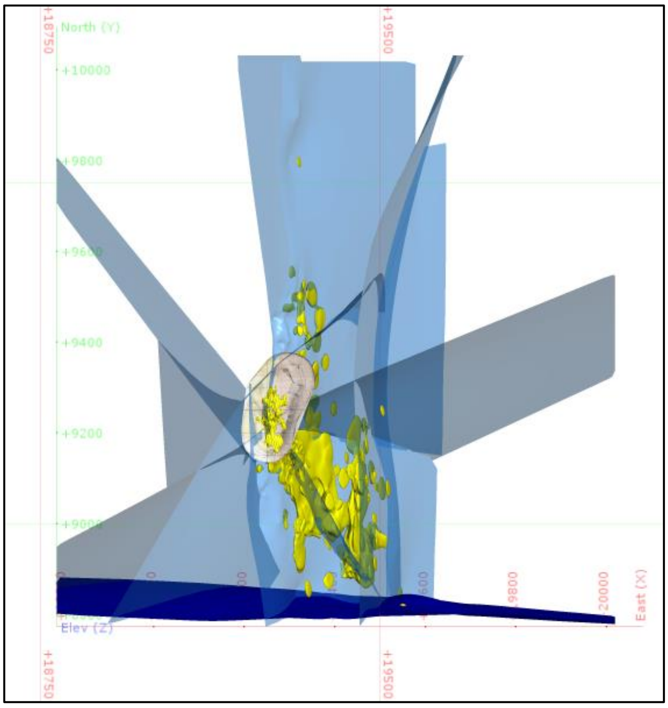

Figure 4: Preliminary modelled gold grade shell (yellow) and fault architecture (blue) illustrating southeast plunge of gold mineralisation along intersecting fault structure