Yaouré Seismic Survey: Defining a Complex 3D Structural Framework with High Resolution Seismic Data

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SUMMARY

Approximately 4Moz of gold have been discovered to date at the Yaouré gold deposit in Côte d'Ivoire, demonstrating the high endowment of the area despite little exploration at depths beyond 350m. With the objective of accelerating its search for mineralisation under and nearby to the known mineralisation, Perseus completed a 16km^2 3D seismic survey and a 24km regional 2D seismic line.

The data have been interpreted to build a detailed 3D structural model at Yaouré and this, together with the interpretation of the 2D seismic data have provided critical new insight into the underlying mineral system by illuminating previously unseen geological features, which occur beyond the limits of traditional geophysical measurements. Preliminary results have revealed: the down-dip extensions of known mineralised structures; additional previously unknown analogues of these structures both at Yaouré and about 10km to the west; and a large intrusive body underneath the known mineralisation. This has provided targets which will be tested by drilling over the coming year.

Wireline logging, elemental and spectral analysis is planned. This information will be fed back into the interpretation using data science and quantitative interpretation workflows to develop further targets and a living solid 3D litho-structural model which can be updated and refined as new information comes to hand.

Key words: seismic, 3D, reflection, gold, minerals, structure, intrusion, Côte d'Ivoire, Africa

INTRODUCTION

The Yaouré Gold Mine is a major gold mine in Côte d'Ivoire with total Measured, Indicated and Inferred resources of approximately 4 Mozs of gold consisting of both oxide and sulphide ore. Gold grades for all categories of resources (Measured, Indicated and Inferred) ranges between 1.1 to 1.4 gpt Au but individual grades within the deposits can reach above 20 gpt Au, especially on the proposed underground portion of the CMA lode. To date drilling has mostly only been to depths of less than 350m.

Up until now geochemical sampling has driven much of the exploration around Yaouré. Given the strong gold endowment, there is considerable potential to discover more resources at greater depths where surface geochemical methods are less effective. Targeting at greater depths via conventional approaches which are heavily reliant on drilling are time consuming and can be expensive. 3D seismic techniques are finding a growing role in this application because of their ability to rapidly image the litho-structural framework over tens of cubic kilometres with a resolution of tens of metres.

Consequently, in 2020 Perseus Mining engaged HiSeis to complete a 3D seismic survey covering 16 km^2 and an additional 24 km 2D line extending to the west of the deposit.

YAOURÉ PROJECT BACKGROUND

The Yaouré Gold deposit is located in central Côte d'Ivoire, 50 km north-west of the country's administrative capital Yamoussoukro. The deposit was identified in 1983 by the French Bureau de Recherches Géologiques et Minières (BRGM) following up on a gold occurrence originally discovered in 1932. Since 1983 there have been various phases of exploration and two phases of mining on separate oxide ore bodies, initially by Compagnie Minière d'Afrique (CMA) (1999-2002), and subsequently by Cluff Gold (2008-2011).

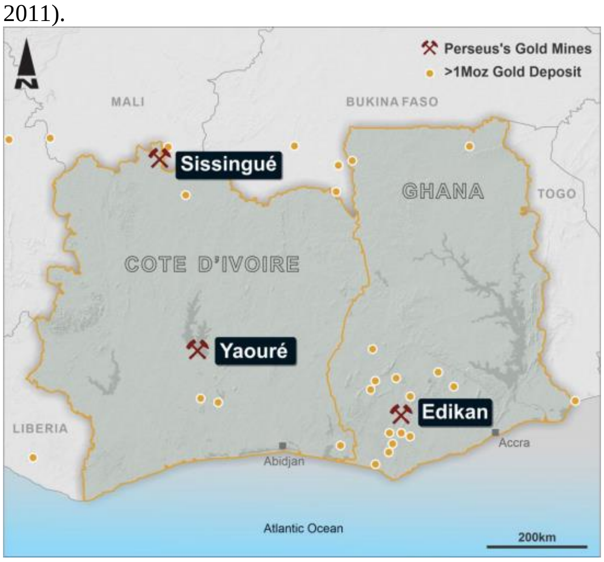

Figure 1. Location of Perseus Mining's Yaouré gold project in West Africa.

In 2012, Cluff Gold changed its name and became Amara Mining. Exploration since then has largely focussed on evaluating the potential of the deeper sulphide zone beneath the two mined oxide zones beneath the Yaouré and CMA pits.

Perseus Mining Limited acquired the project in April 2016 following its merger with Amara Mining PLC and embarked on an aggressive campaign to infill drill the resources in and around the historically mined Yaouré pit area and the CMA thrust zone (Figure 2) to improve geological understanding. In November 2017, Perseus announced a positive Definitive Feasibility Study with a mine life of 8.5 years and an annual average gold production of 215,000 ounces.

Perseus Mining is looking to drill high-value targets from the seismic survey for development of further gold resources in additional open pits and deeper underground resources to extend the mine-life considerably past the 8.5 years.

GEOLOGICAL SETTING

The Yaouré project area lies on the south-eastern edge of a 100km long Birimian greenstone belt informally termed the Yaouré volcano-sedimentary belt. The greenstone belt is NNE trending and composed of a complexly deformed assemblage of PaleoProterozoic volcanic and sedimentary rocks intruded by mafic to felsic sills and dykes. The Yaouré deposit is located along and immediately south of a major NNE-trending structural discontinuity that controls the internal geometry of the gold-bearing volcano-sedimentary and intrusive rocks.

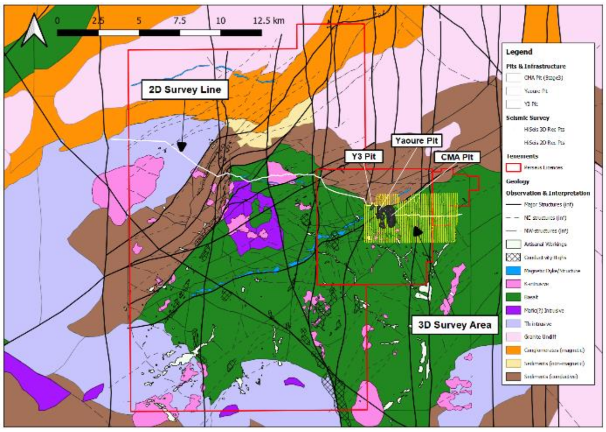

Figure 2. Litho-structural interpretation of the south-eastern part of the Bouaflé Greenstone Belt that hosts the Yaouré gold deposit (Perseus Mining) showing the location of the 2D seismic line in white and the 3D survey area in yellow.

Locally, the gold resources are hosted in basalts and in granodiorite that have been affected by deformation resulting in two types of structures:

- The N-S trending brittle-ductile structures that dip 30-40° towards east: These structures include the well mineralised "CMA" structure;
- The NW- and NE-oriented sub-vertical structures.

The resulting structural architecture suggests a compression in the ESE direction, forming N-S oriented thrust faults and conjugated strike-slip faults (Figure 2).

The CMA structure is the most prominent deformation zone and contains the highest-grade resource that will be mined in both open pit and underground scenarios. It comprises both ductile fabrics and brittle fault cataclasites. The deformation package was injected with multiphase dilatational quartz-carbonate veins. Alteration is pervasive, with sericite, tourmaline, pyrite and consistent pink carbonate, mainly dolomite and ankerite. The CMA mineralisation is open down-dip and part of the seismic survey strategy was to determine the geometry of the CMA structure at depths of over a kilometre to determine the best targets for follow-up drilling.

YAOURÉ ROCK PROPERTY DATA

The seismic reflection method works by transmitting vibrational waves into the ground and recording the reflections of these waves. Seismic waves are reflected from boundaries where there is a change in acoustic impedance. Acoustic impedance (AI) is equal to the product of seismic velocity and density. Seismic velocity correlates with rock competence. Hard, intact rocks have high seismic velocities and softer, more fractured rocks have lower seismic velocities.

Prior to the 2D and 3D surveys, rock property measurements were made on 430 core samples from 6 drillholes to better understand the reflective interfaces in the Yaouré geology. P-wave velocities were measured by an ACS UK1401 ultrasonic tester and density was calculated using standard procedures based on wet and dry weights. All measurements were made at ambient surface pressures and temperatures and the core was not sealed prior to weighing.

Measurements made on core are not as reliable as wireline measurements because microfractures expand to varying degrees when removed from *in-situ* pressures. Any expansion can reduce the measured seismic velocities. Nevertheless, at such a remote site this was seen as a cost effective first step compared to mobilising a wireline logging crew. Measurements from one drillhole are shown in Figure 3.

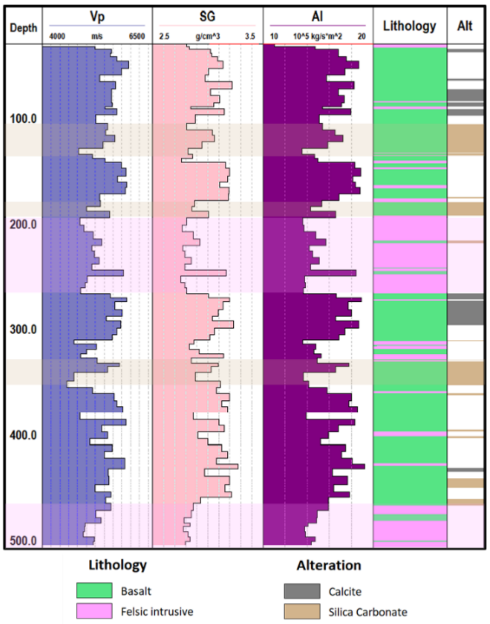

Figure 3. P-wave velocity, density and acoustic impedance as a function of depth correlated against lithology and alteration. Light shading has been used to highlight the correlation between the location of the felsic intrusives and relative lows in acoustic impedance.

These measurements show:

- unaltered basalt is characterised by high AI (~17x10^5kg/s.m^2);
- felsic intrusives are characterised by low AI (~14x10^5kg/s.m^2); and
- silica-carbonate altered basalt (which is associated with mineralised structures such as the intersected CMA south structure) is characterised by lower AI (~15x10^5kg/s.m^2) than unaltered basalt.

We infer that the felsic intrusives and silica-carbonate alteration around structures are likely to be seismic reflectors at Yaouré.

Wireline logging is planned to confirm these results and assist more quantitative interpretation but Covid-19 has delayed the ability to mobilise suitable crews and equipment to site.

SEISMIC ACQUISITION DETAILS

Figure 4 shows an overview of the layout of the seismic survey conducted at Yaouré. The blue lines running north-south show the receiver locations and the red lines running predominantly east-west show the source positions. The topography at Yaouré is quite steep and had a significant bearing on the source locations.

The Yaouré survey was acquired in 3 distinct phases due to overlapping construction of a large tailings storage facility (TSF). The first phase of the survey covered the TSF in the central and southern parts of the survey area (see Figure 4) and construction was shutdown during this phase. This area was acquired as a static patch with all receivers live.

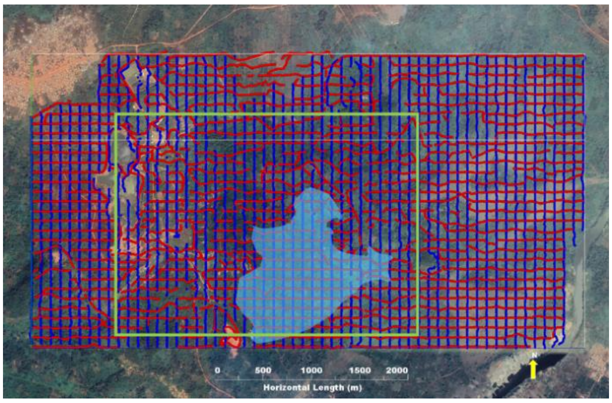

Figure 4. Seismic survey layout. Blue lines show receivers, red lines show sources. The under-construction tailings storage facility (TSF) is shaded in blue. The initial area covered by a static receiver patch is outlined by a green box.

Once the static patch had been acquired, all receivers were picked up off the TSF and construction of the TSF recommenced. Layout progressed to the west and the western half of the survey was acquired with a typical rolling spread.

As the survey progressed, it eventually rolled off the western extent. As the roll off occurred, the crew began rolling in from the eastern side. This was the third phase of the acquisition program. The survey rolled from east to west back to the middle where the TSF was positioned. No sources or receivers were able to be placed on the TSF when the eastern and western areas were acquired but, outside this area, the receivers were overlapped to stitch the 3 areas together. The stitch worked well and an excellent offset and azimuth distribution was achieved for coverage of the entire survey footprint.

Once the 3D survey had been completely shot, the 2D line was acquired. The survey parameters used during acquisition are summarised in Table 1.

Acquisition Parameters	
Vibrator	INOVA AHV-IV 60,000lb
Vibrator array	1 vibrator active
Sweep frequency range	6-120Hz
Sweep type	Linear
Operating force	70%
Geophones	Single Quantum nodes
Filters	Hi Cut 205 Hz
Sample rate	2 ms
Record length	3000 ms
3D	
Total survey area	16km^2
Number of receivers	13199
Active receiver spread	20 lines x 160 stations
Receiver station spacing	12.5 m
Number of source points	12512
Source point spacing	12.5 m
Max fold	300
Max offset	±1000 m
2D	
Line length	24km
Receiver station spacing	5m
Source point spacing	5m

Table 1 Summary of acquisition parameters

INTERPRETATION

3D seismic survey

The 3D seismic data shows reflectors and or breaks coincident with the down-dip trajectories of all east dipping mineralised structures (Figure 6). These features extend to depths of 1km or more. Most of these mineralised structures have only previously been modelled to depths of around 350m so the data confirms considerable down-dip potential at Yaouré. The seismic data enables the 3D shape of these features to be modelled in 3D. At Yaouré it has been noted that the best grades on the CMA structure are seen where the structure flattens presumably due to increased dilation at this point. These positions will provide a focus for future drilling.

Figure 6 shows there are a series of previously unrecognised east dipping structures parallel to the CMA and drilling is planned on these in the coming months.

The 3D seismic data shows a zone of considerable complexity down-dip and below the CMA structure and unravelling this is likely to be a key to accelerating the search for additional high-grade mineralisation. Continued interpretation of the seismic will allow the 3D structural geometries to be established but, at this point, a small number of deep (~1km) drillholes are required to confirm what the key reflectors represent geologically. We expect the calibration provided will support the creation of an enhanced solid 3D litho-structural model which will accelerate future deep targeting in this highly prospective terrain.

A surprising outcome of the survey was the detection of a distinct seismically quiet zone at about 1.2km depth below the known mineralised structures (Figure 6). This zone is very similar to a quiet zone associated with intrusives and intense alteration imaged by seismic below the St Ives gold field in Western Australia (Stolz et al, 2004) and elsewhere (e.g. Turner et al 2016). We infer that the quiet zone at Yaouré is also an intrusion and whilst its presence was not previously known, there was speculation noted in the 2017 NI 43-101 Technical Report for Yaouré (Abbott et al, 2017). A drillhole into a similar zone below St Ives was reported to intersect 1200m consistently over about 0.22gpt (Snow, 2020) and thus the intrusion may have significant implications for the emplacement of gold at Yaouré and consequently on where best to target. The seismic data provides a tool for determining which structures are connected to the intrusion. This would be difficult to conclusively ascertain by drilling alone.

The reflectivity from the mineralised structures at depths shallower than 350m is subdued. We infer that this is at least partly due to the reduced seismic fold (discussed below) at these depths. HiSeis has noted similar reductions in image quality at similar depths at other sites where similar acquisition geometries were used (e.g. Foley et al, 2018). Shallow imaging can be improved by using closer line spacing and tighter source and receiver sampling along lines but there is a trade-off with increased survey cost. HiSeis has also been investigating new processing approaches to improve shallow image quality and hopefully will be able to show the results of these at Yaouré come presentation time.

There are other variations in amplitude along the reflectors down-dip of the modelled mineralised structures (as seen in Figure 5**Error! Reference source not found.**) and these could be important indicators to the more mineralised positions. This can be due to changes in the contrast in properties across the structure, changes in the contrast between the fault/alteration zone and the surrounding host rock or a change in the thickness of the fault/alteration zone. HiSeis was hoping to have some wireline results to help resolve this in time for this extended abstract but have been unable to get the logging done due to the Covid-19 pandemic restrictions.

Given the results of the rock property measurements made on core and that the host rock is predominantly basalt apart from a series of felsic dykes, it is like that the changes in reflectivity are due to:

1. A change in the alteration around the fault (which might be indicative of the passage of a greater volume of mineralising fluids);
2. A change in the width of the damage zone associated with the fault; or
3. Felsic porphyries being variably emplaced along the fault.

If item 1 is a dominant cause, zones of higher reflectivity become important targets.

In addition to the specific outcomes outlined above, the interpretation of the 3D seismic has generated a 3D structural model to 2km depth (Figure 5) beneath the area of the 3D seismic survey. Once additional deep drilling, wireline measurements and additional elemental and spectral data is obtained, the intent is to turn this into a solid 3D litho-structural model which can guide targeting but also be input into additional machine learning and artificial intelligence workflows.

2D seismic

The 2D seismic data highlighted a structural domain 10km west of Yaouré which has a very similar seismic expression to Yaouré (Figure 7). Principally there are a set of east dipping features similar to the mineralised CMA structure. Surface mapping shows that this domain is around a major fault juxtaposing the Yaouré basaltic rocks against bedded sediments. The seismic also shows a distinct quiet zone indicative of an intrusive underneath this similar to Yaouré.

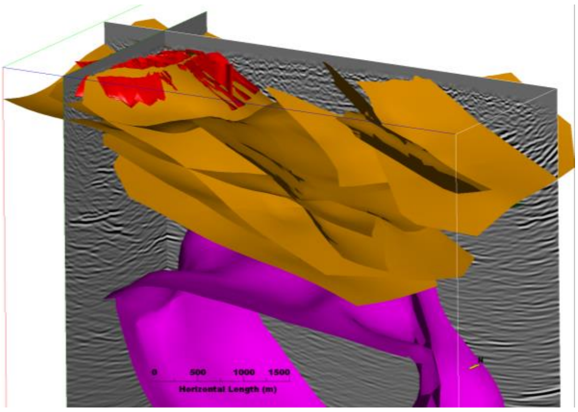

Figure 5. 3D structural model interpreted from the seismic data. The red surfaces show the mineralisation wireframes from drilling. The yellow structures show the east dipping CMA analogues and the pink surface shows the outline of the interpreted intrusive.

The 2D data also shows additional CMA analogues immediately to the west of the 3D survey area. There is a seismically quiet zone underlying this area also.

Seismic fold

Seismic fold is a measure of the number of source receiver combinations which contribute to the image. At shallow depths it is necessary to exclude far offset combinations because the reflections arrive essentially coincident with signals that travel along or close to the surface

CONCLUSIONS

The 2D and 3D seismic surveys completed at Yaouré have enabled the detailed mapping of the local 3D geological architecture to depths of more than 2km. This mapping is facilitating the identification of a number of exploration targets that will be tested by drilling over the coming months and years. These targets include:

- Favourable positions on known mineralised structures down-dip from existing drilling;
- Analogues of the east dipping CMA structure; and
- Zones of increased structural complexity which may have provided increased dilation zones for the deposition of gold mineralisation.

The seismic data also point to the existence of a large intrusive body sitting approximately 1.2km below the known Yaouré mineralisation. It is thought that this and similar intrusions may have played an important role in the formation of mineralisation.

Wireline logging, spectral and elemental analysis is planned as soon as Covid-19 restrictions allow and this information will be fed back into the current model using advanced quantitative interpretation techniques and machine learning algorithms to inform the importance of the connectivity of structures mapped by the seismic to the intrusion and to develop further targets. With this information, a living, solid 3D litho-structural model will be developed which can be updated and refined as new information comes to hand.

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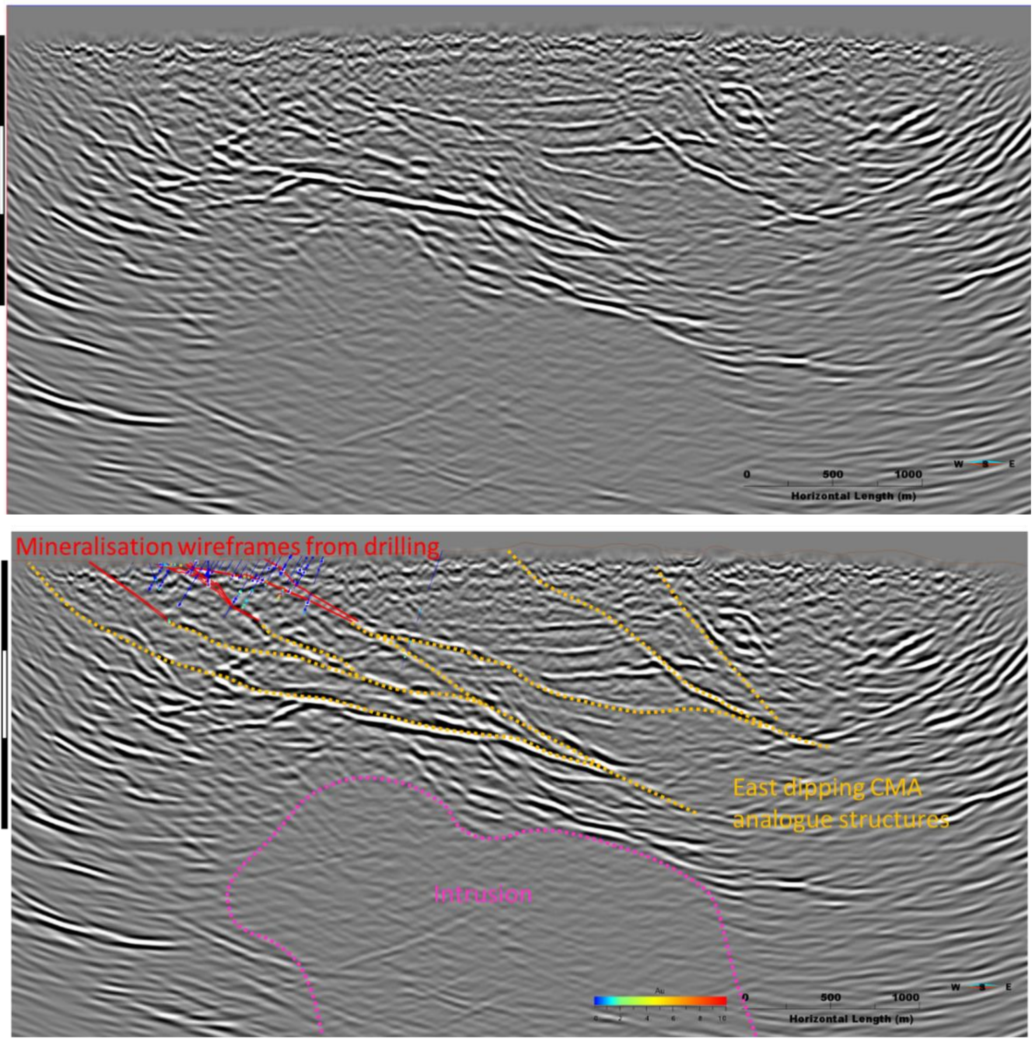
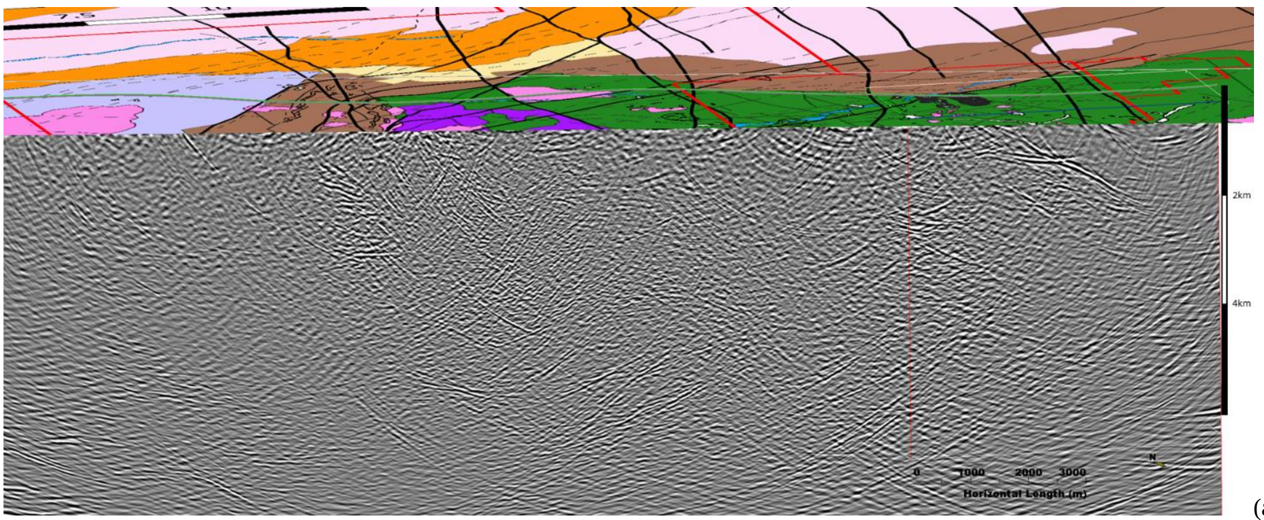


(a)

(b)

Figure 6. E-W vertical slice through the seismic cube with (a) without overlays and (b) with mineralisation wireframes based on drill intercepts (red), interpreted east dipping CMA analogue structures (yellow) and the interpreted underlying intrusive (pink) overlain.



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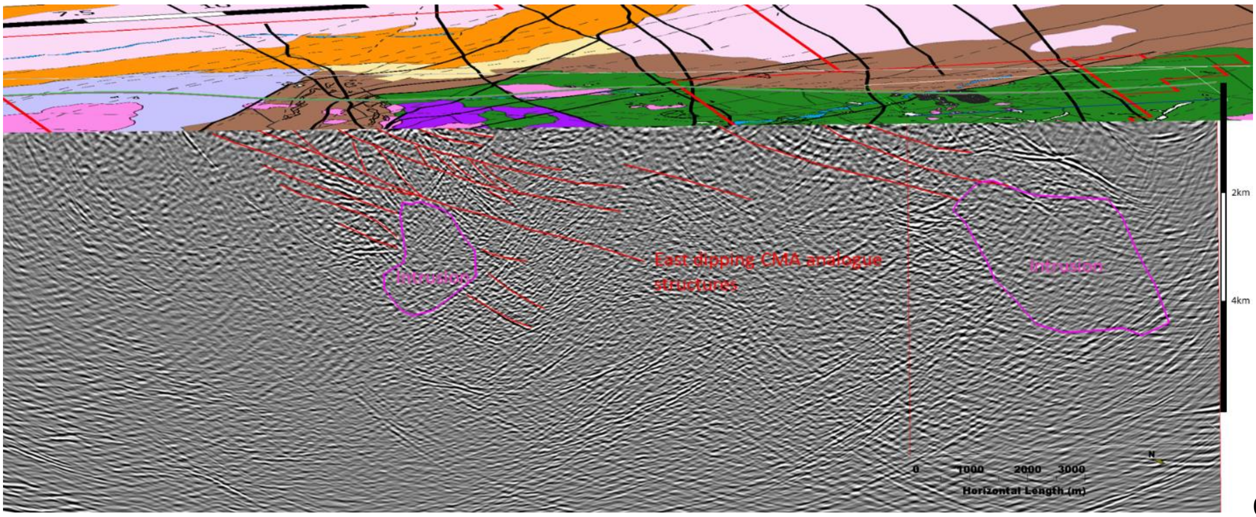

(b)

Figure 7. Data from 2D seismic line (a) without interpretation and (b) highlighting interpreted intrusives (pink) and CMA analogue east dipping thrusts (red).