Design and Implementation of Microseismic Monitoring at Yaramoko Mine

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ABSTRACT

Due to an increasing seismic hazard at the Z55 underground mine at the Yaramoko project in Burkina Faso, a microseismic monitoring system was required to be installed. A system comprising seven sensors was designed to capture the remaining life of mine stoping areas with an event location accuracy of between 20-50m based on past experience. Several issues occurred during installation due to hole blockages resulting in late changes to the system design but with accuracy still in the desired range. Monitoring systems, hazard management plans and trigger action response plans were successfully implemented providing safer operational controls to withstand the risk posed by seismicity. System health has generally been good with occasional outages which are discussed to provide examples of operational experience for other sites considering microseismic systems.

Keywords: microseismic, seismicity, monitoring, hazard management

1 INTRODUCTION

Yaramoko mine site is an underground and open pit gold operation in Burkina Faso owned by Roxgold, a Canadian based gold operator. Mining of the Z55 underground mine at Yaramoko commenced in 2015 and has extended to a depth of approximately ~1100 mbs as of the start of calendar year 2025.

The onset of stress related damage and ground noise at a depth of approximately 750 m below surface at Z55 precipitated the need to purchase a microseismic monitoring system to quantify the associated seismic hazard at the mine. The system was designed by consulting engineers from MineGeoTech who provide geotechnical support to the mine.

In June 2024 the system was successfully commissioned by the Institute of Mine Seismology (IMS) which included two NetSPs, four 14 Hz triaxial geophones and three 14 Hz uniaxial geophones. Along with the seismic system installation, a set of Trigger Action Response Plans (TARPs) and procedures were developed to manage the seismic hazard on site.

This paper will present details of the mining environment, system design, system installation, an assessment of the seismic hazard, and the design and implementation of the site procedures and processes developed to manage the hazard.

2 YARAMOKO MINE

The Yaramoko mine site is located 200 km southwest of the capital Ouagadougou in Burkina Faso, Figure 1. It includes two underground mines, Z55 and Bagassi South and one open pit at the Z109 deposit. The Z55 underground is the largest of the three and is accessed via a single access portal from the surface to the bottom of the mine approximately 1100 mbs.

The mining method at Z55 is longhole stoping with cemented rockfill (CRF) backfilling. Mining areas are divided into four level panels which are mined bottom up with the fourth level in each panel left open as a sill level with rib pillars between stopes.

Roxgold own and operate the Bagassi South deposit while Z55 and Z109 are contractor operated with African Underground Mining Services (AUMS) the primary contractor at Z55.

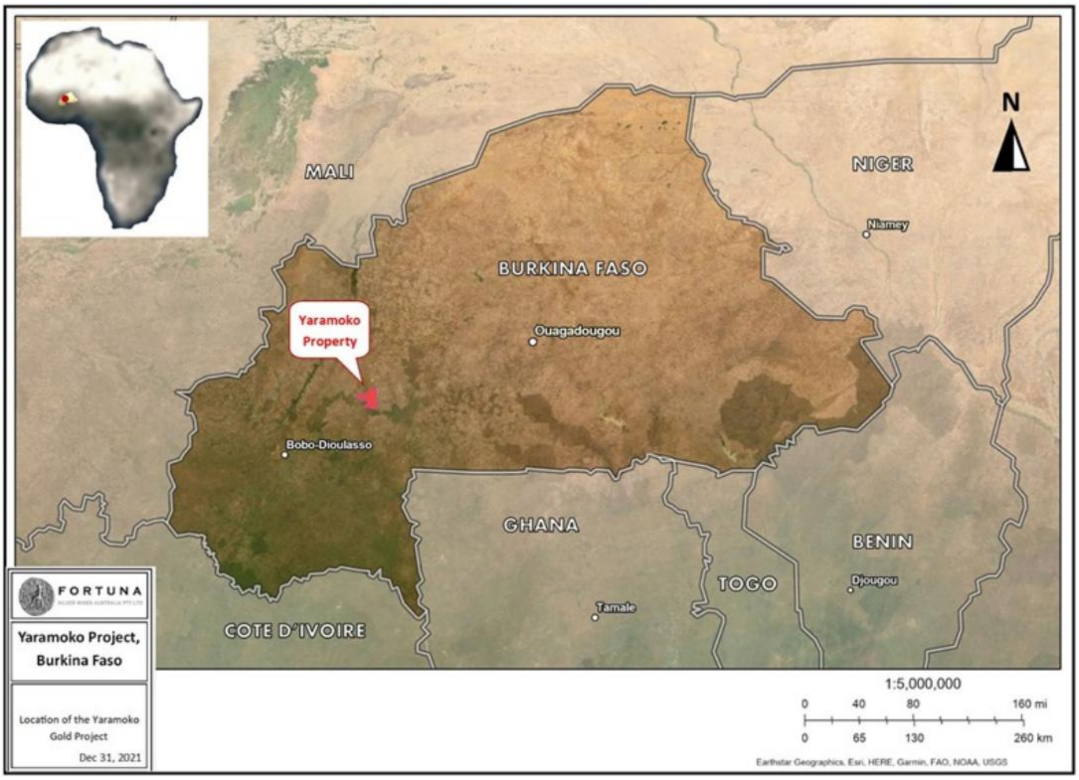


Figure 1 Yaramoko mine site location (Fortuna Mining, 2025)

3 GEOLOGY

The Yaramoko project is situated at the northern end of the Hounde Greenstone belt which is 400 km long by 60 km wide. The Z55 orebody consists of a gold bearing quartz vein that is hosted within a shear that crosscuts a granitoid body with inclusions of altered volcanic rafts. The mineralized portions of the shear are expressed as a quartz vein in the brittle deformed granitoid body and appears to be ductile deformed with mineralized mafic volcanics. The shear is laterally extensive, up to 400 m along strike.

The granitoids and mafic volcanics form both the hangingwall and footwall of the shear zone and are competent lithologies prone to brittle failure with uniaxial compressive strength (UCS) values ranging from 100-180 MPa for the granite and 97-171 MPa for the mafic volcanics and Young's Modulus values of approximately 30 GPa for both.

4 MINE LAYOUT

The Z55 deposit is accessed by a single decline from a surface elevation of approximately 5320 mRL (Figure 2). The portal was developed from a box cut with no open pit operations above the underground mine.

Each level is accessed via a central access drive off the main decline. The sublevel interval was previously 17 m but was updated to 20 m from the 4774 level down to reduce the amount of development required in the mine.

The decline design was a corkscrew design with partially overlapping decline stockpiles on every level. At the onset of rock noise and stress related ground movement, the decline was initially shifted to the west at the 4492 level to avoid some geologist modelled faults with stockpiles on alternating sides of the level access until changing to a figure-eight decline design from the 4410 level down due to the increasing seismic hazard and the small pillar between the stacked levels of the corkscrew design.

Stoping sequence was retreat back to the central access drive which was successfully employed for the majority of the mining at Z55 before needing to switch to a centre-out continuous retreat stoping front, requiring the introduction of footwall bypass drives from the 4470 level down.

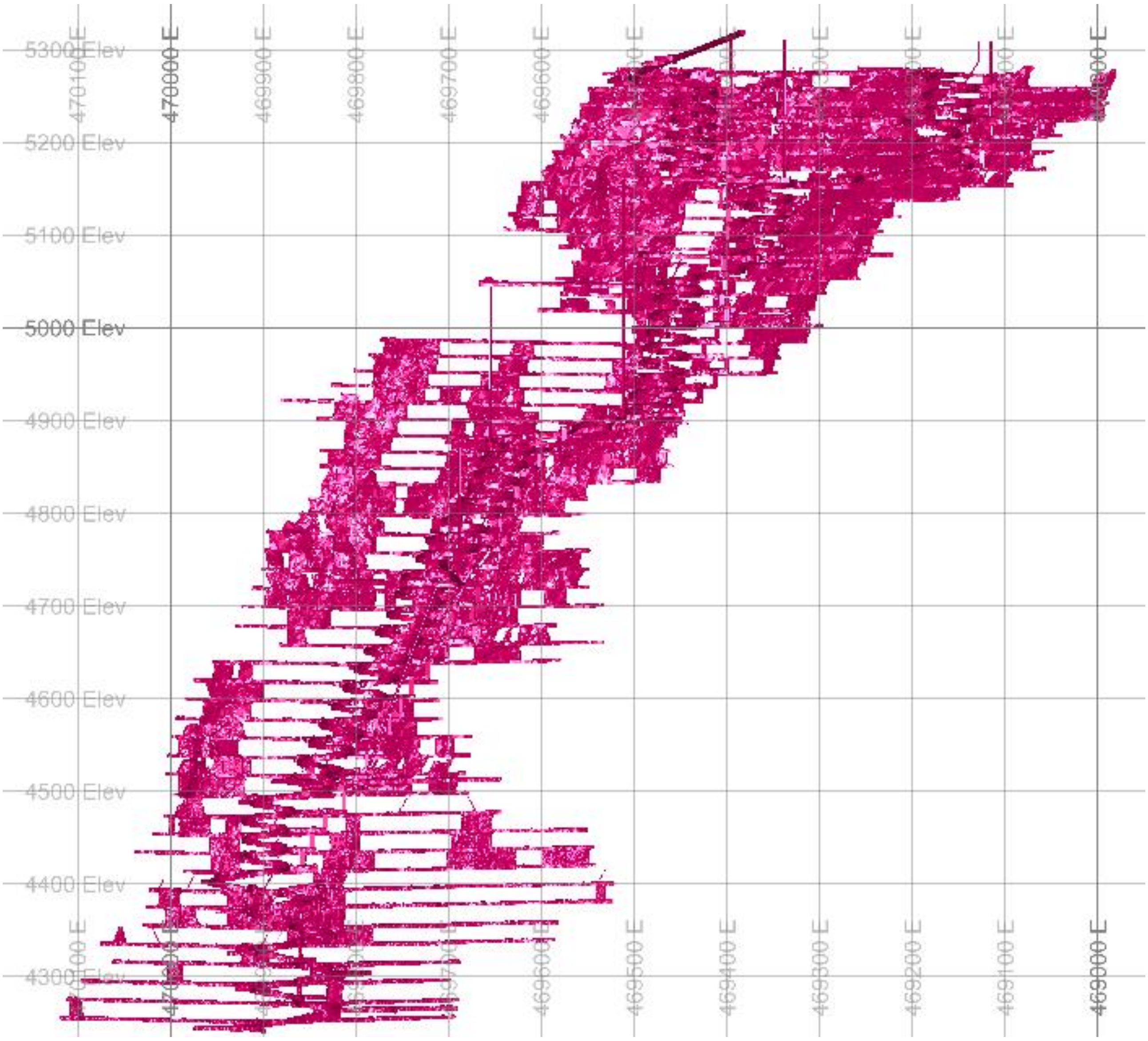


Figure 2 Z55 mine as-builts December 2024

5 STRESS ENVIRONMENT

Acoustic Emission (AE) testing was performed by the Western Australian School of Mines (WASM) in January 2025 to estimate the in-situ stress field at Z55 due to the seismic hazard at the mine. Samples were collected from a depth of 604 mbs and 953 mbs. The results suggested the major principal stress is oriented perpendicular to the main orebody with a σ_1 to σ_3 ratio of approximately 1.8-1.9 (Figure 3).

Minor rock noise and signs of movement of rock blocks due to stress were observed at a depth of approximately 750 mbs, corresponding with a major principal stress to UCS ratio of ~0.26.

However, this stress assessment was not available in the early days of the onset of seismicity to assist in understanding the appropriate mine design changes required to mitigate seismicity activity and the rock mass and ground support scheme data from seismic activity.

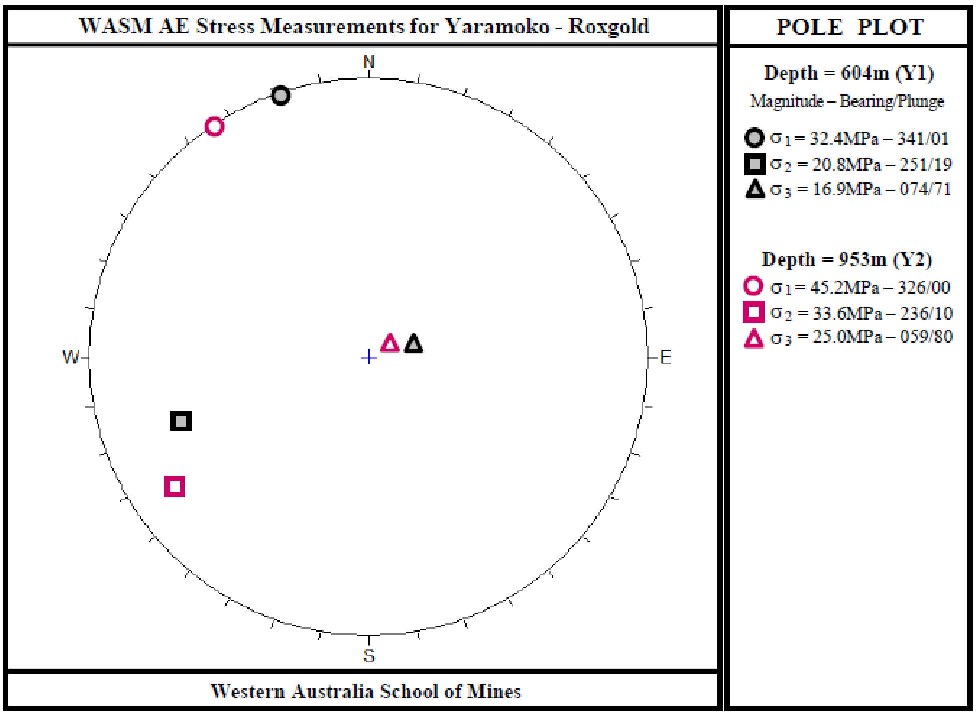


Figure 3 Yaramoko Z55 AE test results (WASM, 2025)

6 ONSET OF SEISMICITY

The onset of seismicity was characterized by occasional rock noise reports and structurally controlled overbreak around the decline development, particularly in proximity to the decline stockpiles, which were stripped to 8 m high, and the level access/decline intersections. This began occurring around the 4574 mRL or approximately 750 mbs.

The overbreak and rock noise initially appeared to be associated with three sub-parallel discrete faults dipping steeply to the west. These structures were not previously known or modelled. This led to a return airway drive being designed and excavated with a four-way intersection right on the contact of one of these fault planes. In March 2022 a significant seismic event occurred which caused the shake down of 5-10 t of material from below the surface support (Figure 4). Four underground workers were nearby at the time so this was deemed a near miss/high potential incident. This event was a suspected fault slip event due to the location of the mapped structure at the 4514 level, approximately 800 mbs.

This event resulted in the shifting of the decline to the east to avoid intersecting the west dipping structures, the introduction of dynamic capacity rock bolts such as Kinloc bolts and plain strand cables, as well as alternating the decline stockpiles either side of the access to avoid the diminished pillar caused by stacking them. This led to a short-term improvement in ground behaviour but following two more significant events felt at the surface that caused damage across three mining levels and the decline, the decision was made to commission a microseismic monitoring system to properly quantify the seismic hazard on site.

The large-scale events also prompted a change in decline design from the 4410 level onwards from corkscrew to figure-eight, to improve the thickness of the pillar between levels, as well as a shift from a retreat back to centre mining sequence to centre out sequence requiring additional footwall drive development.

Figure 4 4514 ventilation access shake down event March 2022

7 SEISMIC SYSTEM DESIGN

The microseismic system at Z55 was commissioned in June 2024 by the IMS following the increasing seismic hazard necessitating monitoring of these events. The system was designed by consultant engineers from MineGeoTech who were providing geotechnical support to the Yaramoko operations. The approach used by MGT to design seismic systems with regards to accuracy and sensitivity of the array with regards to mine operations is explained in Player et al. (2022).

7.1 Proposed layout

The initial system design was proposed to include two data acquisition boxes, each connected to four sensors including two triaxial and two uniaxial 14 Hz geophones. One box would be at the 4610 mRL and the second at the 4430 mRL. The 4430 level was the deepest completed level at the time giving the best location to drill and install the sensors.

The system array was designed to try and optimize the accuracy of the system by designing four of the eight proposed sensors to be installed in the hangingwall of the orebody. Sensors would be installed at the end of diamond drillholes specifically drilled for the seismic installation (Figure 5, left).

The array went through two iterations due to changes in the number of sensors and the plan to re-use previously drilled grade control holes for some of the sensors. This resulted in the design shown on the right of Figure 5 which consisted of seven sensors (four triaxial, three uniaxial) with three sensors on the hangingwall.

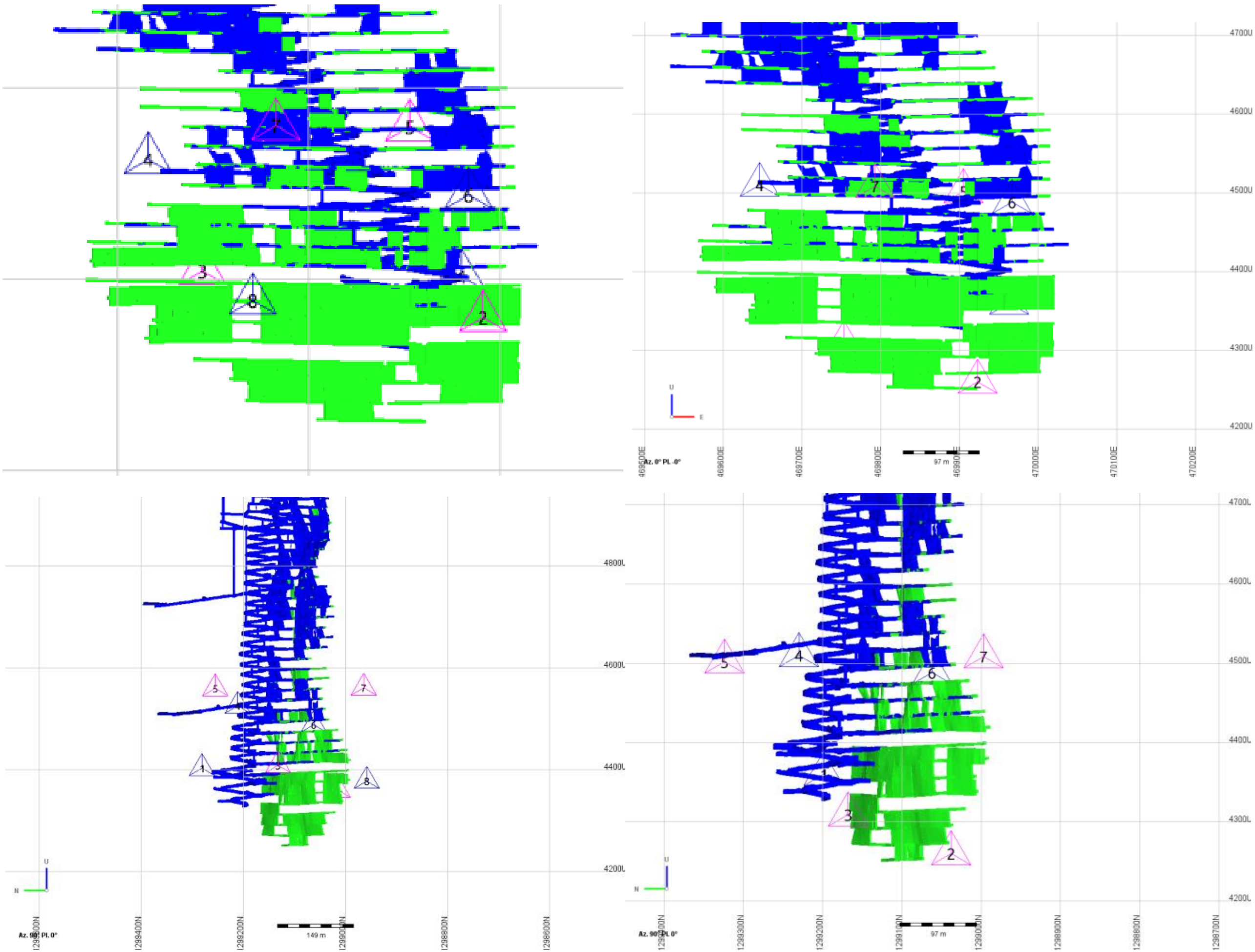


Figure 5 Left - initial proposed seismic sensor array, Right – revised sensor array

7.2 Event location accuracy and sensitivity

The aim of the system design was to achieve an event location accuracy of 20 m for a -0.5 ML event for the majority of the LOM mine design with a supplemental target of 50 m for the remaining areas. These targets were selected based on case studies of previous experience (Player et al., 2022). Using the analysis software Vantage (2024) from IMS, the event location accuracy was calculated and the results of the initial system design shown on the left of Figure 6.

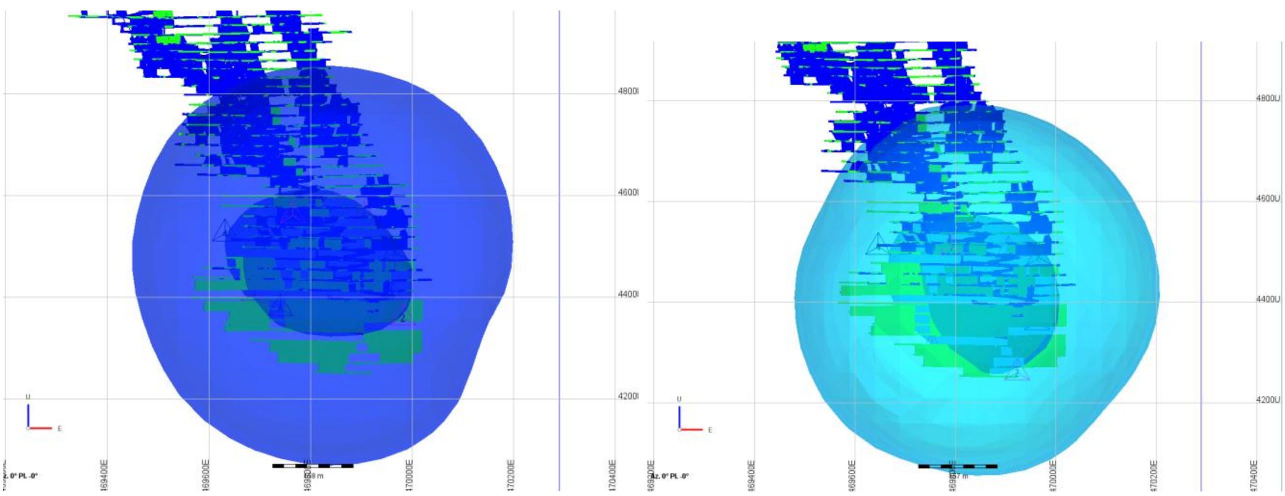


Figure 6 Vantage accuracy analysis of initial design (left) and final design (right) showing 20m and 50m accuracy isosurfaces for a -0.5ML event

The bottom levels of the LOM design were not covered by the 20 m isosurface at the time of the initial design. At that time the orebody was open at depth and it was proposed that an additional box and sensors could be installed at a later stage to improve the accuracy and sensitivity at the bottom of the mine.

By the time the system was redesigned a decision had been made that the mine would not go any deeper, so the design was updated to optimise the accuracy of the system for the remaining LOM shapes by moving the proposed data acquisition boxes deeper to the 4534 and 4330 levels allowing the sensors to provide deeper coverage than initially designed.

The accuracy of the western edge of development was lower than target of 20 m accuracy but it was not possible to cover this area without extensive drilling which would exceed the recommended cable lengths for the sensors of 300-400 m.

8 SEISMIC SYSTEM INSTALLATION

8.1 Installation issues

During the installation of the sensor array in June 2024, four of the holes were installed at the designed hole depths, however, the three holes designed on the hangingwall did not reach the target depth. It was suspected by the engineer from IMS that either the holes had collapsed, or water ingress provided too much resistance when trying to push down the grout hose and sensor (Lubbe, 2024).

The diamond drill holes had been completed approximately two months before the installation of the system due to drill rig availability. The increased stress environment likely led to hole instability over the extended time frame between drilling and installation.

This resulted in one of the hangingwall sensors now being installed on the footwall side of the orebody, however, the other two were successfully installed on the hangingwall side albeit slightly short of the designed end of the hole.

8.2 Installed layout and accuracy

The installed layout of the sensor array is shown in Figure 7 on the left. Sensors 6 and 7 sit on the hangingwall side of the orebody. The installed accuracy analysis is shown on the right of Figure 7 and shows that despite the new locations of some of the sensors the main goals of the 20 m accuracy isorsurface encompassing the key mining areas were achieved.

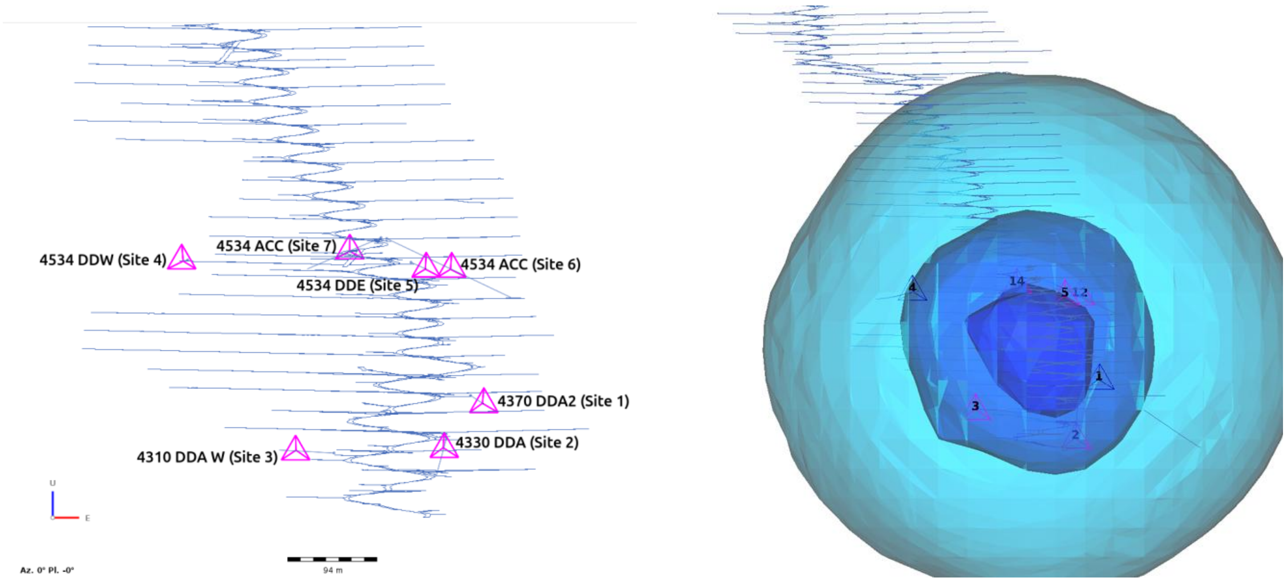
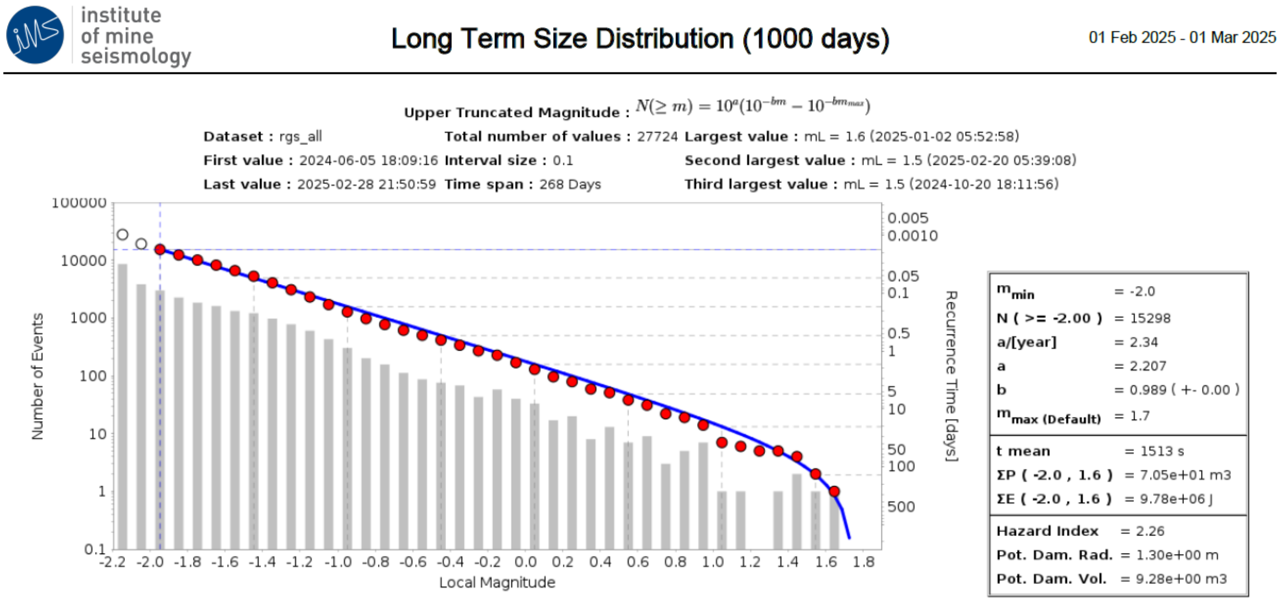


Figure 7 Left - installed sensor array after installation, Right – 10m, 20m and 50m accuracy isosurfaces of updated array

9 SEISMIC SETTING

Since the commissioning of the seismic system in June 2024, over 30,000 microseismic events have been recorded at the time of writing. The frequency magnitude chart for all events larger than -2.0 ML up to the 1st of March 2025 is shown in Figure 8. The largest event has been a 1.6 ML event in January 2025 with an expected M_{max} event size of 1.7 ML based on the truncated Gutenberg-Richter relationship. The b-value is slightly below 1 at 0.989 with an a-value of 2.2 for the 9 month period from June 2024 to March 2025.



Probability Table and Recurrence Times

	mL=0.1	mL=0.3	mL=0.5	mL=0.7	mL=0.9	mL=1.1	mL=1.3	mL=1.5
Mean recurrence days	2.144	3.434	5.554	9.124	15.403	27.332	53.707	138.400
Pr(14 days)	0.999	0.983	0.919	0.784	0.596	0.400	0.229	0.096
Pr(30 days)	1.000	1.000	0.995	0.962	0.857	0.666	0.427	0.195
Pr(90 days)	1.000	1.000	1.000	1.000	0.997	0.963	0.812	0.478
Pr(180 days)	1.000	1.000	1.000	1.000	1.000	0.999	0.965	0.727
Pr(365 days)	1.000	1.000	1.000	1.000	1.000	1.000	0.999	0.928

Event Filters: mL≥-2.3; Accepted Triggers ≥ 2

Figure 8 Frequency- magnitude distribution from June 2024 to Mar 2025 (Gerber, 2025)

Figure 9 shows the Hudson plot of the events >0.0 ML since June 2024 at Z55. This shows a trend of events plotting in the compressive failure region with a small cluster of slip type events at the centre of the chart. This crush mechanism may be a departure from the onset of seismicity in 2022 which was believed to have been associated with slip on structures but due to the lack of seismic system at the time this is only a hypothesis.

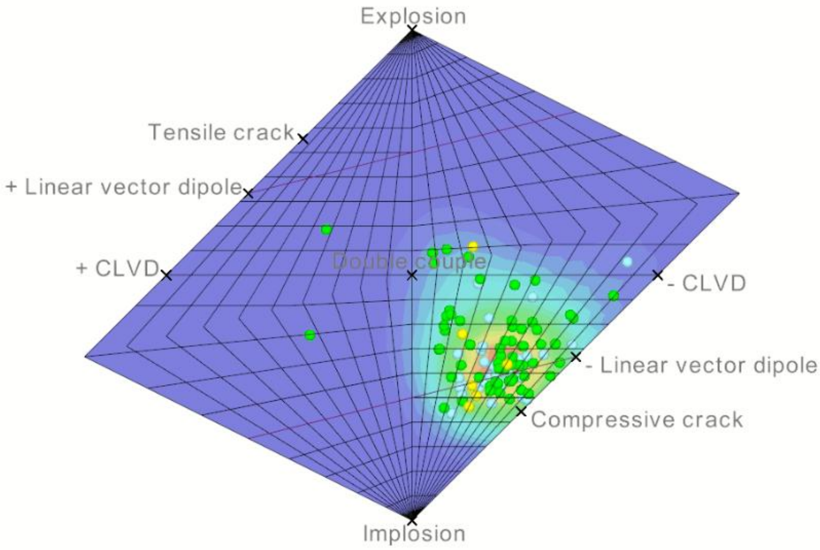


Figure 9 Hudson plot of events >0.0ML since June 2024

10 SEISMIC SYSTEM PERFORMANCE

The performance of the seismic system at Yaramoko has so far generally been consistent but there have been several issues resulting in lost monitoring time and missed events, some of which are discussed in the following sections.

10.1 Loose connections

The underground enclosures are connected to the surface via fibre optic cable run down the main ventilation exhaust shaft. At the underground enclosures, the fibre converter units at the top and bottom of the ventilation shaft and at the surface server room there are numerous wired connections.

During the early operation of the system there were several outages that appeared to have been caused simply by loose connections at various points along the network. Unplugging and replugging the cables was enough to bring the system back online.

These connections have now been rewired to ensure the chances of outages from loose or faulty connections are minimised.

10.2 Power outages

The on-site power is sourced either internationally from Cote d'Ivoire or Ghana or from onsite diesel generators as backup power. Both sources often lead to minor power outages where the power will flick off and back on within seconds.

While uninterruptible power supply (UPS) units were initially installed at the enclosures to provide continuous power during outages, it was found that other sections of the system were vulnerable to power outages including the server connections at surface and the fibre optic converter units both at surface and underground. Following a power outage some connections would need to be reset to get the system working again.

Gradually UPS units were applied to all parts of the network system by February 2025 and the system now appears to be maintaining its capacity across power outages without the need to be reset.

10.3 Server outages

Another source of system outages has been IT issues associated with the Roxgold servers going offline. These happen occasionally and are unrelated to the seismic system itself but have had the effect of resulting in missed data across periods of up to 12 hours. These issues are not likely to be avoidable given the in country infrastructure, but it requires the seismic system array backup systems to be working effectively to navigate which is discussed further in the next section.

10.4 System backup issues

During the outages caused by the issues discussed above, the IMS microseismic system is meant to be capable of continuously collecting seismic data as long as the UPS units at the boxes provide power, usually up to 8-10 hrs. However, it was noticed across several system outages that only the lower enclosure at the 4330 level, which only has three sensors, was continuing to collect backup data. As the minimum filter for IMS data processing was four sensor locations this meant numerous events weren't getting processed once the system re-synced.

IMS investigated the issue and recommended swapping the NetSP units between the enclosures thinking this might be the issue but did not appear to be the cause. IMS then adjusted the inbound LAN and DSL modem filter settings as well as implemented a firmware update for the netADC units which appears to have resolved the issues in February 2025.

11 HAZARD MANAGEMENT

Following the commissioning of the microseismic monitoring system at Yaramoko, the seismic hazard management processes on site needed to be updated and adjusted to better fit the understanding of the seismic hazard. The systems and procedures developed on site are discussed in the following sections.

11.1 GCMP Update

The ground control management plan (GCMP) is the overarching documentation used on site to outline how the seismic hazard is to be managed. It outlines the expectations on how:

- Seismic events get processed externally,
- How site engineers should generate daily and weekly seismic reports,
- How monthly should be produced by IMS,
- What system alarms and procedures are required,
- Seismic data is recorded on site in particular damaging or large events,
- How often inspections should occur,
- How seismic hazards are assessed on site,
- What ground support is required,
- When exclusion zones are required following firings and how they are determined, and
- How hazards are communicated to the workforce.

11.2 TARPs

Trigger action response plans (TARPs) were developed or updated to describe what should happen in the event of a seismic event underground, in the event of system outage and how to reopen a seismic exclusion zone.

11.2.1 Seismic response TARP

Seismic events were categorized into small (<0.0 ML), significant (0.0-0.7 ML) or large (>0.7 ML) based on a back analysis of the damaging events in the first couple of months after the system was installed. These categorisations are re-evaluated periodically as more data is collected.

Depending on the magnitude category of the event will elicit a different response according to the TARP, ranging from inspections by the shift boss to barricading and waiting for inspections from geotechnical personnel. Increased activity clusters of >25 event per hour can also trigger the TARP and require evacuations and inspections.

11.2.2 Seismic system availability TARP

A TARP was developed to specify what should happen in the case of the seismic system being offline. It highlights and identifies the responsibilities between both the owner and contractor for getting the system checked and back online.

11.2.3 Seismic exclusion zone TARP

As part of the seismic hazard management system used on site, all stope blasts are required to be followed by a seismic exclusion zone determine from back analysis of nearby stope blast responses using the Short Term Response tool from mXrap (2025).

The seismic exclusion TARP therefore specifies the conditions upon which a seismic exclusion zone can be lifted early or must be kept closed for longer. If the blast response drops below 10 events per hour it likely can be re-opened. This has been back analysed as the approximate background level of seismicity at the mine.

If a large or significant event occurs during the exclusion zone, it can only be lifted 3 hours after the significant or large event.

If the seismic system is not functioning at the time of the stope blast, then a mandatory 12 seismic exclusion zone is put in place.

11.3 Procedures

A procedure was developed for the site geotechnical engineers on how to perform the Short Term Analysis for determining the seismic exclusion zone lengths, detailing how to use the mXrap software and outlining the steps and goals of this analysis.

12 CONCLUSIONS

Due to an increasing seismic hazard it was necessary to install a microseismic monitoring system at the Z55 underground mine, part of Roxgold's Yaramoko project in Burkina Faso. IMS was selected as the provider of the system and it was successfully commissioned in June 2024 albeit with some minor alterations to the array design due to likely drill hole closures.

Since the installation of the system site has been able to collect detailed microseismic data to inform and back analyse the hazard management systems put in place to determine what actions need to be taken following a seismic event and during a seismic exclusion zone.

Despite the good quality data collected by the system, there were some operational difficulties experienced leading to excess down time of the system but these have been worked through methodically to identify and rectify each issue as they have arisen with significant improvements observed.

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