Global Leadership Training Programme in Africa 2019

Activity Report of Field Research

Development of an Underground Monitoring System for Improving Safety and Efficiency of Using Wi-Fi Ad Hoc Technology in Southern African Countries

Hajime Ikeda[1]

I. Summary

English Summary

South Africa is very famous for its various mineral resources such as gold and platinum. The benefits of these resources are immeasurable, and South Africa has become a remarkable country for economic development. However, there is a big wage difference between South Africa's rich and poor, and there is still a need to improve working conditions. In particular, mining operations are being improved in safety and productivity through technological advancements, but there are still many problems that still need to be addressed.

Furthermore, underground mining is progressively taking place at deeper depths with some of the gold mines approaching 4 km depth. Because the risks increase with depth with, further innovation is required. In order to realize this, the introduction of smart mining was considered. Smart mining is a general term for new resource development technologies that combine mining and ICT. Advances in resource development technology are beneficial for economic and sustainable development, not only in South Africa but also in Southern Africa, where underground resources are abundant. By using smart mining, efficiency and safety can be improved in mining operations.

As an example of smart mining; in this study, we developed an in-situ stress monitoring system for underground mines and decided to conduct a verification test in one of the underground mines in South Africa. The monitoring system was divided into two parts: a sensing part that measures in-situ stress and a communication part that collects data. For the sensing part, a sensor unit was installed in a borehole after stress release, and a strain gauge together with a 9-axis sensor were used to measure how much force was applied from which direction. Thereafter, the data logger with communication function was wired to enable data collection on the mobile terminal by Wi-Fi Direct communication. In addition, a mobile terminal can transfer data to other mobile terminals, hence transfer data to the surface. Data can be collected by combining the Wi-Fi Direct and the movement of miners in the communication part.

[1] **M.Sc., student (2nd year), Earth Resource Engineering and Environmental Sciences, Akita University, Host University: University of the Witwatersrand, Johannesburg, South Africa, 3rd September – 1st November, 2019**

The communication system we are working on/investigating can be used not only for in-situ stress monitoring in underground mines, but also for locating miners and visualizing temperature and humidity. This could potentially become a foothold for automated operations throughout the mine.

During this stay, experiments were conducted at the Great Noligwa mine and at a Mock-mine at the University of the Witwatersrand (Wits University). I also had the opportunity to learn about other techniques such as Diametrical Core Deformation Analysis and overcoring to measure stress in underground mines. As a result of the experiment, techniques worth improving with regards to the data collection methods in the mine were obtained. During this stay, collaborative research with students at Wits University began, and I was able to spend a meaningful two-month research life besides experiments.

Japanese Summary with Japanese research title

Wi-Fi アドホック通信を使用した地下鉱山モニタリングシステムの開発
-南部アフリカ地域の鉱山現場の安全性と生産性の改善-

南アフリカ共和国は金などの鉱物資源で非常に有名である。また、資源による恩恵は計り知れぬものがあり、南アフリカは経済発展の目覚ましい国となった。しかし、南アフリカの貧富の差は大きく、働く環境にも大きな差があるのが現状だ。特に、鉱山での採掘作業は技術の進歩により安全性と生産性は向上されつつあるが、今なお多くの問題があり、改善が求められている。特に、近年の地下採掘は深部化傾向にある。深部に行くにつれて危険性が増していくため、今以上の技術革新が求められている。これを実現するためにスマートマイニングの導入を考えた。スマートマイニングとはマイニングと ICT を組み合わせた新しい資源開発技術の総称である。南アフリカだけでなく、地下資源が豊富な南部アフリカ地域において資源開発技術の進歩は経済的で持続可能な開発に有益だ。スマートマイニングを使用することで効率や安全性などを採掘部分で改善が可能である。スマートマイニングの一例として今研究では、地下鉱山内の原位置応力モニタリングシステムの開発を行い、その実証試験を地下鉱山内で行うこととした。このモニタリングシステムは原位置応力を計測するセンシング部分とデータを回収する通信部分の二つに分けた。センシング部分は応力解放後のボアホールに対してセンサユニットを設置し、どの向きからどれだけの力が加わるかを計測するためにひずみゲージや 9 軸センサを使用した。その後、有線で通信機能付きデータロガーを媒介し、Wi-Fi ダイレクト通信で携帯端末でのデータ回収を可能とする。また、その携帯端末は他の携帯端末へのデータ転送を行うことができ、地上までのデータ転送をする。通信部分には Wi-Fi ダイレクトと鉱山従事者の人の動きを組み合わせることでデータの回収を可能とする。

今回研究している通信システムは地下鉱山の原位置応力モニタリングだけでなく、鉱山従事者の位置把握や温度や湿度の可視化にも使える。最終的に鉱山全体の自動化運転の足掛かりになればいいと考えている。

今回の滞在中にそれぞれの性能を図る実験を Great Noligwa 鉱山と Witswatersrand 大学内の鉱山で行った。また、地下鉱山内の応力を測定する方法として、コア変形法やオーバーコアリングなどの手法に関しても学ぶ機会を得た。実験の結果として、鉱山内のデータ回収方法を改善するに値する結果が得られた。そして、今回の滞在中に Witwatersrand 大の学生と共同研究が始まり、実験以外にも有意義な 2 ヶ月の研究生活を送ることができた。

II. Research Activity

1. Introduction

Resources will continue to be consumed to enrich people's lives. Populations are growing and people's desire for development is growing, but resources are limited. Thinking about the supply and demand of this limited resource will lead to the achievement of the SDGs. There is a need to introduce technologies such as smart mining for improved safety and productivity in South African underground mines. As the world's finite resources are getting depleted, technological innovation has become more indispensable to the mining industry for it to keep up with both rising demand and decreasing mineral abundance. This brings about the development of a new resource development technologytermed 'Smart Mining' by combining mining and ICT. In southern African countries with abundant underground resources, advances in the extraction of mineral resources are beneficial for economic and more importantly sustainable development. With 'Smart Mining', nearly all aspects of a mining operation can be improved, such include efficiency and safety. One of such applications of this concept is in open-pit mines, where a communication system can be created using satellite technology. However, in underground mines where satellite signals cannot penetrate, optical fiber cables have been used for mine automation and stress monitoring. However, such physical connections are prone to -breakage in an underground environment. It is against this backdrop that a new stress monitoring system using Wireless Sensor Networks（WSN）was then incorporated with the aim to subvert these issues. Several studies have used WSNs to create a stress monitoring system using various wireless communication technologies. This study therefore proposes a stress monitoring system that uses Wi-Fi ad hoc wireless communication. Evaluation of results from experiments that test the system's capabilities has shown that it is sufficient for underground mine monitoring applications. Moreover, this study showed that in addition to improving underground monitoring systems, Wi-Fi ad hoc wireless communication systems could also be used for other implementations of "Smart Mining" such as automation.

2. Study Area

The main aim of my stay in Sourth Africa was to identify problems associated with underground mining operations and to evaluate the current effectiveness of the Wi-Fi Ad Hoc stress monitoring system. I conducted the research at the Digimine laboratory in Wits University. Moreover, I obtained communication performance experiment results from a Great Noligwa mine site and Mock mine. My fieldwork included some sub-activities, one of which enabled me to learn how to measure stress using over core.

The digital mine laboratory is an exciting project where the Chamber of Mines building on West Campus was converted into a 'mine', complete with surface (using the flat roof of the building), vertical shaft (using a stairwell in the fourth quadrant of the building) and Mock mine with control room in the basement. The Mock mine has a life-size tunnel, stope, lamp room, and other features. The Mock mine is equipped with the digital systems that enable the research for the mine of the future and is part of the Wits Mining Institute. As of currently, it is a one-of-a-kind laboratory with a significant research agenda to transfer surface digital technologies into the underground environment – the enabler for a mine that can (automatically) observe, evaluate and take actions. The ultimate objective is to use technology to put distance between mine workers and the typical risks they are exposed to on a daily basis. Although there are some mines in South Africa that have similar systems installed, such installations are mostly vendor-driven-and-supported, resulting in a large dependency on international equipment manufacturers (OEMs).

Harmony Gold's Great Noligwa underground gold mine is situated close to the town of Orkney, on the free state side of the Vaal River in South Africa. We tested communication performance at this mine's 70Level which is approximately 2.7 km underground. The tunnels in the mine are approximately 4.5 m high and 3.5 m wide, with an arched ceiling and exposed surrounding wire nets and some rock bolts. As a part of my sub-activities, we conducted measurement using over core at the same levels.

Great Noligwa mine

3. Methodology

The monitoring system was developed by the following research method divided into two research areas: ① in-situ stress sensing and ② ad hoc communication systems. At last, ③ is about long term-monitoring.

① Find the difference in stress applied to the sensor unit by filling the sensor unit in the bore after stress release. At this time, in order to estimate from which direction, the stress is applied, it is necessary to detect the orientation of the sensor unit. For that purpose, a sensor unit with a 9-axis sensor and a strain gauge inside was constructed, and based on the evaluation of its performance, the shape of the sensor unit, the selection of materials, and the amount of sensing data for one day were collected.

② The sensing data and the data after analysis are bidirectionally transmitted to underground data centers and data centers on the ground by ad hoc communication that extends the communication range using the movement of the miners (passing). For this purpose, communication tests were conducted under various conditions including the underground mine, and the received signal strength and communication speed indicating the strength of radio waves were measured. Based on this result, we tried to calculate the amount of data that can be communicated by passing once with the communication distance.

③ Demonstration of Wi-Fi Ad Hoc stress monitoring system and experimentation. We have so far developed an in-situ stress monitoring system (① sensing + ② communication system) of the underground mine. With regards to the communication system of this monitoring system, the results pertaining to the sufficiency of the results are all that is left before its commercialization for smart mining[2]. We are currently conducting research to introduce smart mining such as this monitoring system in southern Africa[3]. For practical use of smart mining, evaluation of sensing performance should be performed together with the evaluation of communication system performance, this means long-term on-site monitoring tests are needed.

The purpose of this stay was an installation for long-term monitoring, communication test experiment in the underground mine environment, and thereafter, a sensing evaluation. By conducting collaborative research with the participating educational units, the concept of smart mining (Digimine) and its merits can be established, fostering mutual development of mining technology.

4. Research Findings

4.1 Sensing/stress measurements

Associated with the depth of the mine site, I targeted to understand the stress field deep underground, namely deeper than several kilometers for improving safety, there were limitations with regards to the depths boreholes could be drilled. The stress measurement methods should be classified from the viewpoint of measurement principle; (1) stress-relief method (Overcoring*[1]), (2) borehole fracturing methods, (3) core-based methods (DCDA*[2]), and (4) method based on drilling-induced fractures. Typical methods for measuring in-situ stress using drilling include the hydraulic fracturing method, in which the magnitude of stress is measured directly by injecting a high-pressure fluid and causing tensile fracturing, and the drilling core is used in the original method. There is a stress release method that measures the amount of strain when the stress received at a position is released and calculates it by interpreting the physical properties of the rock. However, the hydraulic fracturing method was considered to be unfavorable for long-term safety and stability around the tunnel after excavation, primarily because it may cause damage to the bedrock at the measurement site[4]. The stress-relief method is one of the most widely used techniques in the engineering field. In order to develop an in-situ stress / strain differential monitoring system, it is necessary to develop a measurement unit (sensing) in addition to the communication unit described above. In this study, , focus was on the change of rock stress due to the development of an underground mine , hence the development of a sensor unit that can be installed in a drill hole drilled with a support drill bit (60φ).

[*1]Overcoring: it this method of stress measurement consists of measuring the displacements or the deformations at the wall of a bore hole at the time of a total relieve of the rocks obtained by 'over-coring' around the bore hole[5].

[*2] Diametrical Core Deformation Analysis (DCDA): is one of the newest methods for evaluating the in-situ stress of rocks. It is based on the elliptical deformation of boring cores with stress relief. When a rock core sample is carved out by drilling, it becomes free from in-situ stress, and the expansion should occur elastically[6].

4.1.1 Overcoring

Overcoring*[1] was led by a research group of Prof. Ogasawara from Ritsumeikan University during this research period. The rock conditions of the area at which the study was being conducted were a bit challenging, and it failed several times due to cracks after drilling and human error. Moreover, we had a communication barrier with local boring company workers, which affected experimentation methods. However, we are ultimately able to overcome this and overcoring was a succees, experimentation results were consistent with those from other studies.

4.1.2 Displacement stress measurements

In order to install a sensor unit capable of measuring the stress difference at the original position, it is necessary to adhere to the bore hole after the stress is released. We proposed installation of a sensor unit in the same hole as the overcoring for long-term monitoring. However, we could not proceed due to the rock properties and the performance of the adhesive.

4.2 Underground communication system

The use of wired or wireless communication technology has become common practice in underground mines. Wired communication has features such as an increased risk of disconnection and troublesome redeployment of communication lines. On the other hand, WSNs, have a reduced number of access points, and the sensor itself enables P2P (Peer to Peer) connection. The number of connected terminals, the communication speed, communication distance, and the like are different from each other, making it vital to select accordingly the type and amount of target data. Examples include Ultra Wide Band (UWB[*3]), Bluetooth, a Wi-Fi (Infrastructure) and ZigBee[4] communication systems that the stability of radio waves is important when connecting and performing wireless communications. Also, it should be noted that in a wireless LAN, the longer the distance, the lower the signal strength, hence the communication speed decreases. Therefore, it is possible to determine whether or not the radio wave is stable by measuring the received signal strength and the communication speed represented by RSSI. RSSI is an index indicating the strength of a signal received by a wireless communication device. It is mainly used in wireless communication such as wireless LAN and Bluetooth for the purpose of controlling a transmission range. Stable wireless communication was established when the RSSI exceeded -80 (dBm). Also, the theoretical maximum communication speed differs from the actually measured communication speed. And RSSI and communication speed attenuate with distance. Therefore, in a communication test between two points, it is necessary to measure RSSI and communication speed for each distance. Since radio wave attenuation also changes depending on the surrounding environment, it is necessary to classify cases according to the properties of the surroundings and shields, and whether they are straight or curved. Surrounding conditions include, the presence of moisture, the physical properties of rock walls, and the presence of heavy equipment are representative of those that can be a major factor in radio wave attenuation in underground mines. Another important factor is the uniformity of the tunnel.

Wi-Fi ad hoc and Wi-Fi Direct have been adopted for the ad hoc communication. Unlike Wi-Fi infrastructure, Wi-Fi ad hoc and Wi-Fi Direct allow devices to connect directly to each other without the need for a router or auxiliary wiring, thus realizing communication. Wi-Fi Direct is a communication standard that inherits the advantages of Wi-Fi ad hoc, and also improves the complexity and security of the settings, which were problematic. The first feature is that a smartphone connected to Wi-Fi Direct can be used as an access point. As an initial stage before conducting a demonstration test at an actual mine, a communication device compatible with ad hoc communication and a smartphone were configured, and a data transmission / reception test was performed.

[*3]UWB (Ultra Wide Band): The communication distance is as short as 10 (m), but the number of connected terminals is as large as 100. The communication speed is the fastest at 100 (MB) and the power consumption is 30 (mW) [2, 8].

*4ZigBee: The communication distance is 100 (m) and the number of connected terminals is as large as 65,536. The communication speed is by far the slowest at 0.25 (MB), with a power consumption of 20-40 (mW) [2, 9].

The main uses of underground mine communication systems are monitoring, communication, and locating miners and heavy equipment. Monitoring is divided into environmental monitoring and operation monitoring. Environmental monitoring includes the detection of dust and smoke, measurement of toxic gas concentrations, temperature, humidity, and the monitoring of rock stress. On the other hand, work monitoring includes the detection of derailment of heavy equipment; and automation of heavy equipment and ventilation systems. In addition, being able to grasp the status of underground mines from remote locations will lead to improvements in productivity and safety. Currently, underground mining companies are spending money in the attempt to understand the statuses of underground mines. However, none of the networks used in this study were suitable for underground mining with regards to cost effectiveness. For this reason, some underground mining companies are often hesitant to prepare a communication environment[7].

4.2.1 Great Noligwa mine

To test the communication performance of our system, the communication distance, speed, and the RSSI in various scenarios were measured and analyzed for four days. It is important to note that during these experiments, we were fortunate enough to measure and attain the radio wave attenuation due to moisture, this being because the experimental site was immersed in water due to a water pipe rupture. The results pertaining to this are being currently being considered for journal submission.

4.2.2 Mock mine (at Wits University)

Because it was an experiment inside a Mock mine at the university campus where I stayed, I succeeded in conducting tests under a wide variety of situations. The communication experiments have been conducted the same way as carried out at the Great Noligwa Mine site's experiments. By comparing these results, it makes more sense that this proposed technology could be employed in mines for various mine optimization requirements such as toxic gases monitoring systems and fire warning monitoring systems. This collaborative study at the Mock mine was conducted with Wits University students.

5. Discussion

Analysis shows that he causes of sensing failure was due to the nature of rocks, moreover, there was the problem of as whether the adhesive would be effective long term if installed. It is a pity that the long-term monitoring test operation was not possible during this stay, however having been able to find out what could be a future issue early, was a success in our experiment. The potential adhesive was expected to maintain adhesion for about 10 weeks, unfortunately the inflow of groundwater and the rock characteristics made this a challenge.

Based on the results of the communication test, a heat map was created to determine which part of the mine enables easy communication. While doing this, the results also enabled us to identify places where communication was difficult. Even in the field of communications, parameters that can never be changed largely impact the results. For example, the quality of rocks and the presence or absence of moisture.

6. Conclusion

My fieldwork was part of an attempt to develop a monitoring system of a mine site by using a sensor cell and Wi-Fi Direct. The result of communication performance experiments included sufficient results to demonstrate feasibility. However, the installation of the sensing unit failed as I was unable to investigate the long-term performance of the sensing unit, hence the need to change adjustable parameters such as adhesive changes as an improvement. The results obtained during this stay were useful in measuring the feasibility of the proposed monitoring system. A research report in an academic paper using the obtained results will be published after further review.

Acknowledgement

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References

[1] 池田啓, 川村洋平, トンゴルゼドリック, 伊藤豊,ヒョンドゥジャン, スマートマイニングのための Wi-Fi アドホックによる地下坑内通信技術, *日本情報地質学会*, Vol.29, No.1, pp.3-11, 2018.

[2] Ikeda, H., Kawamura, Y., Tungol, Z. P. L., Molidi, M. A., and Jang, H.: Implementation and verification of a “wi-fi ad hoc” communication system in an underground mine environment, *Journal of Mining Science*, Vol. 55-3, No.1, pp. 505-514, 2019.

[3] Ikeda, H., Kawamura, Y., Mokhtar, N. E. B., Yokokura, J., and Frederick, C.: Study on implementation of wi-fi direct utilizing smart mining in monitoring stress states in underground mines in South Africa, *Fourth South Africa-Japan University Forum*, Johannesburg (South Africa), 2019/5.

[4] Soucek, K., Konicek, P., Stas, L., Ptacek, J., and Waclawil, P.: Experimental approach to measure stress and stress changes in rock ahead of longwall mining faces in Czech coal mines, *Coal Operator's Conference*, 2013.

[5] Fouial, K., Alheib, M., Baroudi, H., Trentsaux, C., Improvement in the interpretation of stress measurements by use of the overcoring method: development of a new approach, *Engineering Geology*,Vol. 49, Issues 3–4, pp. 239-252, 1998.

[6] Funato, A., Ito, T., and Shono, T.: Laboratory Verification of the Diametrical Core Deformation Analysis (DCDA) Developed For In-situ Stress Measurements, *American Rock Mechanics Association*, 2012.

[7] Akyildiz, I. F., and Stuntebeck, E.P.: Wireless underground sensor networks. *Ad Hoc Networks*, Vol. 4, pp. 669-686, 2006.

[8] Moridi, M. A., Kawamura, Y., Sharifzadeh, M., Chanda, E. K., and Jang, H.: An investigation of underground monitoring and communication system. *Tunnelling and Underground Space Technology*, Vol. 43, pp. 362-369, 2014

[9] Moridi, M. A., Sharifzadeh, M., Kawamura, Y., and Jang, H.: Development of wireless sensor networks for underground communication and monitoring systems (the cases of underground mine environments). *Tunnelling and Underground Space Technology*, Vol. 73, pp. 127-138, 2018.

III. Reflection on the GLTP in Africa

I have been conducting research on new resource development technologies that combine mining engineering and ICT (Information and Communication Technology), where, the goal is to be involved in the practical application of smart mining. To that end, I visited South Africa, a state-of-the-art resource country, and decided to go on a dispatch because I wanted to conduct research at underground mining sites in one of the world's best research environments. My research focus is on monitoring systems in underground mining environment, hence the need to understand the situation and problem in the underground. It was a great opportunity for me to join this GLTP in Africa and stay for a 2 months duration in South Africa. During this attachment by GLTP, I stayed at Wits University. I needed to prepare and organize my research by myself. The Mining Technology Laboratory at Akita University and Wits University's Mining Institute Digital Mining Laboratory have not yet built a working relationship, however, Prof. Cawood and a laboratory member helped me a lot in settling down and working in South Africa. Hence, we built a good working relationship through this stay. Staying in South Africa for 2 months was a great opportunity for me to learn and understand many things about both my research and South African culture.

At Great Noligwa Mine, I helped with over-coring work and conducted communication experiments on a communication system brought from Japan at 70 levels below the ground. Before entering the mine, I gave a presentation to the mining company and explained the contents of the experiment. Furthermore, discussions with professors from universities in various fields provided a meaningful opportunity to guide future research. The mine was a few hours' drives from Wits University, so I stayed at an in close to the city for about a week. In order to enter the mine, I received security checks and safety precautions. Wearing the prepared equipment which is communication experiments, the elevator to the basement throbbed. I changed the elevator several times and reached 70 level. Mines were mining nearby and were able to talk during breaks. The drilling work for over-coring failed several times due to the cracked rock due to the soft rock. Eventually, overcoring was successful and the stress could be measured. During this work, I helped winding up cords and unloading equipment. In addition, the communication experiment was conducted smoothly because the basic experiment had been performed so far. During the operation, it was fortunate to be able to conduct a communication test in a flooded state because the location where the experiment was conducted had a water pipe rupture accident. The results obtained in this experiment were satisfactory.

In Wits University, I conducted research at the Digimine Laboratory. There were many international students as well as South African students with master's or higher degrees, and I was able to communicate easily. The concept of the lab is almost the same as my lab I belong to in Akita university, and I am researching Mining using ICT. For this reason, it was good that the contents of the research were similar and we could share each other's research contents. In particular, there were also students majoring communication systems in underground mines, therefore, I took this chance to start collaborative research during my stay. There was an experimental mine in the university's campus, where experiments could be conducted, additionally I was taken to another World Heritage monitoring site. In the progress report held every week, I felt that the research progress was fast because everyone had always reported the progress. In the fall of 2019, Prof. Cawood, a supervisor of Wits University, visited Japan. In the winter of 2020, students who are continuing collaborative research will join Japan. Thanks to GLTP for giving me this opportunity.

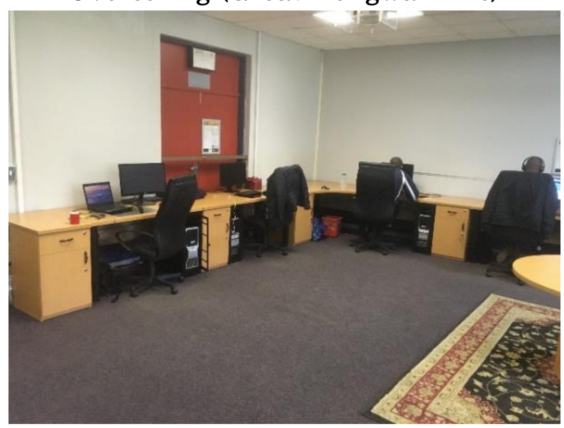
Daily life was very fulfilling. However, Johannesburg is not as safe as Japan, thus, I kept safety first and acted with less danger. However, if you pay attention to the time, the zone and location, you could live a life similar to Japan. In particular, clerks and students in the university were affable. Also, the food was delicious and I was looking forward to try something new. Above all, the steak was cheap and the staple food made from corn flour called Papp was also delicious. The dormitory also had a kitchen, so I cooked what I bought at the supermarket in the morning and night, but mostly did lunch out. Because the prices were low, I was able to live without any inconvenience at the cost of living provided.

In the future, I would like to develop a system for improving mining safety and productivity. However, there are few working mines in Japan, and the opportunity to go to overseas mines is valuable. In order to talk with people working in the mine and researchers working on the mine, I had to stay in the field for a long time. I realized what kind of system was needed during this stay and how other researchers were working on it. I feel that this was an important experience for future research in this field. My experiences through this GLTP can contribute not only to my Master's research, but also to my future career. The period of Master's or Ph.D. studies is limited, so two months are very critical for their students and/or research. I therefore recommend other students to join GLTP and study in Africa.

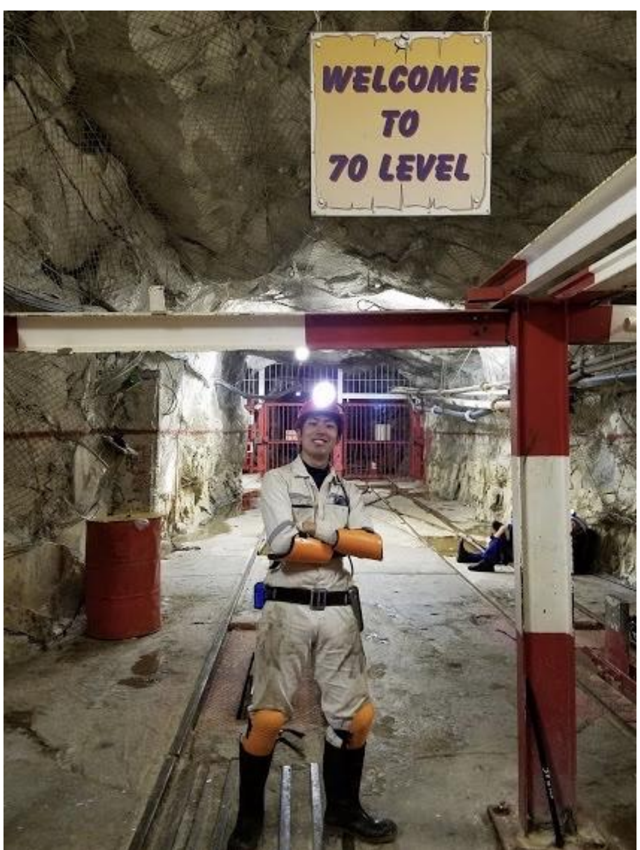
Appendix

Harmony's entrance (Great Noligwa Mine)

Overcoring (Great Noligwa Mine)



Student room (Witswatersrand University)



Weekly meeting (Witswatersrand University)