Internal Ex-Post Evaluation for Technical Cooperation Project (SATREPS[1])

Conducted by South Africa Office: July, 2021

Country Name	The Project for Studies of Seismic Hazard Mitigation in Deep Level South African Mine
Republic of South Africa	

I. Project Outline

Background	The Republic of South Africa has abundant mineral resources and many mines including gold, platinum and coal. The mining sector absorbed 0.5 million of the labor force. Among them, 0.3 million workers were engaged in work in underground mines with risk of mine disasters. The average number of victims per annum decreased from 1.00-1.20 persons per 1,000 workers (the total number of victims: 677-855 persons per year) in the 1980's to 0.56-0.75 persons (the total number of victims: 246-290 persons per year) in the 1990's due to administrative guidance and safety improvement efforts by mining companies. However, about 40% of the victims were killed by fall-of-ground accidents, many of which were caused by "mine tremor" or "rock burst", a quake resulting from the abrupt failure of the rock mass induced by mining activities. The mine tremor not only triggersfall-of-ground accidents in the mining stopes and underground developments but also damages including building collapse on the earth's surface Therefore, it was very important to assess the risks posed by mine tremors and to predict strong motion more precisely as well as to adjust mining plans or design appropriate mining activities based on risk assessments in order to further decrease the victims of mine disasters.		
Project Objectives	Through elucidation of rock properties at seismic sources, enhancement of understanding of preparation and forerunners of earthquakes in gold mines, improvement of reliability of seismic hazard assessment and strong ground motion prediction in gold mines improvement of accuracy of estimation of locations of seismic events and damage assessment of seismic disasters, the project aimed at enhancement of understanding of preparation for and occurrence of earthquakes and improvement of risk management mechanism of mining-induced earthquakes, thereby contributing to application of the seismic hazard assessment and control schemes developed by the project in the Republic of South Africa and worldwide. 1. Expected Overall Goal: Apply the seismic hazard assessment and control schemes developed in this project in deep South Africa mines and worldwide. 2. Project Purpose: Understanding of the preparation for and occurrence of earthquakes is enhanced, and the risk management mechanism of mining-induced earthquakes is improved.		
Project Activities	1. Project Site: Cooke 4 and Driefontein mines in the Far West Rand mining district, Moab Khotsong mine in the Klerksdorp mining district 2. Main Activities: 1) Observation and collection of rock samples at seismic sources and surroundings as well as investigation of rock properties in the laboratory, 2) Monitoring of micro-fracturing and rock deformation as well as analysis of the monitoring data to clarify the forerunning phenomena and its characteristics, 3) Evaluation of spatiotemporal changes in stress and rock mass stability and upgrade of the scheme of seismic hazard assessment, 4) Clarification of characteristics of site amplification of strong motion and scaling relationship in dynamic rupture process based on the monitoring data, 5) Development and validation of a parametric model for prediction of strong ground motion. 3. Inputs (to carry out above activities): Japanese Side 1) Experts: 50 persons 2) Trainees received: 3 persons 3) Equipment: Equipment for monitoring of microfracturing, rock deformation, seismic ground motion, and seismic monitoring system 4) Local operation costs South African Side 1) Staff allocated: 54_persons 2) Facilities and land: Office space, office furniture, communication facilities for the Japanese project coordinators in the Council for Geoscience (CGS) and the Council for Scientific and Industrial Research (CSIR) 3) Local operation costs		
Project Period	August 2010 – August 2015	Project Cost	Ex-ante: 387 million yen, Actual: 346 million yen
Implementing Agencies	Department of Science and Innovation (DSI), Council for Geoscience (CGS), Council for Scientific and Industrial Research (CSIR), The University of the Witwatersrand (Wits)		
Cooperation Agency in Japan	Ritsumeikan University, Tohoku University, The University of Tokyo, Kyoto University, Nagoya University, Kochi University, National Institute of Industrial Science and Technology (AIST)		

II. Result of the Evaluation

< Special Perspectives Considered in the Ex-Post Evaluation >

[Verification of Expected Overall Goal]

Although no verifiable indicator was set for the Expected Overall Goal in the project design, the achievement level of the Expected Overall Goal was

[1] SATREPS: Science and Technology Research Partnership for Sustainable Development

verified by the status of application of the seismic hazard assessment and control schemes developed by the SATREPS project.

1 Relevance

<Consistency with the Development Policy of South Africa at the Time of Ex-Ante Evaluation >

The Project was consistent with South Africa's policies aimed at reducing mine casualties to zero as their final goal and improving the safety level at underground gold mines to international safety standards by 2013 under "The 1996 Mining Health and Safety Act" (1996) and the agreement between the government and mining companies as well as workers.

<Consistency with the Development Needs of South Africa at the Time of Ex-Ante Evaluation>

The Project was consistent with South Africa's development needs for risk assessment of mine tremors and more precise prediction of strong motion as well as adjustment of mining plans or design of appropriate support based on the risk assessments in order to further decrease the victims of mine disaster.

<Consistency with Japan's ODA Policy at the Time of Ex-Ante Evaluation>

The Project was consistent with Japan's ODA Policy for South Africa prioritizing the areas of Science and Technology Promotion and Climate Change covering support for earthquake observation in mining areas through the technical cooperation scheme for science and technology under the 10th South Africa and Japan Partnership Forum in April, 2010[2]. Also, support for human resource development for technologies of disaster observation, prediction and warning was prioritized under the Sendai Cooperation Initiative for Disaster Risk Reduction in January 2005.

<Evaluation Result>

In light of the above, the relevance of the project is high.

2 Effectiveness/Impact

<Status of Achievement of the Project Purpose at the time of Project Completion>

The Project Purpose was achieved at the time of project completion. The research results were internationally and broadly presented at international and professional meetings 65 times in the United States, Canada, Austria, Switzerland, Sweden, Australia, Chile and China (Indicator 1). A recommendation on the improvement of mine safety in South Africa was under preparation and had not been submitted by the time of project completion (Indicator 2). Rock deformation and stress measurement were applied by the mining companies and mine consulting firms at the three target mines (Indicator 3). Three South African Bachelor of Science (BS) holders obtained Master of Science (MSc) degrees with project related researches at Pretoria University and University of the Witwatersrand. Five Japanese BS holders also obtained MSc degrees (Indicator 4).

<Continuation Status of Project Effects at the time of Ex-post Evaluation>

The project effects have continued since project completion. The key research outputs by the SATREPS project have been utilized by various stakeholders and the three target mines have continued to use the transferred technologies. Mining companies have gained knowledge with regard to seismic and geotechnical monitoring and analysis, stress measurement, and numerical modelling. A mine seismology and geotechnical service provider (Groundworks Consulting) has utilized stress measurement technology and data collection introduced by the SATREPS project. University of the Witwatersrand staff members and postgraduate students provided field support, installed instruments and collected data. They also participated in data analysis and interpretation and attended workshops and seminars. Several staff members and students attended conferences and undertook research in Japanese laboratories; meanwhile Japanese staff members and postgraduate students visited South African gold mines, and undertook research work in the Rock Engineering Laboratory and the Seismic Reflection Research Centre at the University of the Witwatersrand. Rock engineering practitioners employed by the Mine Health & Safety Inspectorate attended workshops and seminars where the most important outcomes were presented, e.g. at the Mine Safe Conference.

The CGS continues to maintain and operate the equipment installed under the SATREPS project for daily analysis and recording of seismicity within the mining region. This information is incorporated into the seismological reports and is used for research within the CGS. Also, the network of strong ground motion sensors installed on surface in the Far West Rand mining region continues to be operated by the CGS, along with the Antelope Seismic Processing System. However, the sensitive in-mine instruments have not been used since the experiments conducted by the SATREPS project and were never intended to be. The sensors were installed in 2010/11 in parts of the Cooke #4, Hlanganani and Moab Khotsong mines where mining was planned in the vicinity of structures that were believed to be potentially seismically active. Mining in the vicinity of the experimental sites has been completed. The sensors were retrieved where possible, but those that had been grouted in boreholes were abandoned. Data logging equipment was retrieved.

<Status of Achievement for Expected Overall Goal at the time of Ex-post Evaluation>

The Expected Overall Goal has been partially achieved. Efforts to transfer knowledge and technology, for example through the Ministry of Mineral Resources and Energy's Rockfall and Rockburst Task Team, on which Prof. Durrheim serves; and the 9-person Sibanye-Stillwater 'expert panel', on which both Prof Ogasawara and Prof. Durrheim serve, continue to this day. A draft report entitled "Investigation into seismic management at the deep gold mines of Sibanye-Stillwater" was submitted to the client on August 7th, 2020. The findings of the SATREPS project complement and extend research works that has been conducted in deep South African mines for over 50 years. While the SATREPS project certainly extended knowledge in the field of mine seismology, and is probably the most ambitious mine seismology research project ever attempted in terms of scope and effort, it has not succeeded in 'solving' the rockburst problem, for example by developing a technology to prevent seismic events or to precisely predict their size, time and place at the time of ex-post evaluation.

On the other hand, the key research outputs have been continuously utilized. The novel stress measurements have been transferred to personnel at Anglogold Ashanti, Groundwork Consulting and University of the Witwatersrand. The algorithm to automatically pick P- and S-wave arrival times has been successfully tested and implemented at CGS. Although CGS would like to continue to work on the software developed by Dr. Horiuchi, they have lost the human capacity within the organization to be able to continue it. In addition, new research projects using the research outputs of the SATREPS project have been started. The project entitled "Drilling into the source zones of M2.0-M5.5 earthquakes in deep South African mines", or "DSeis" (October 2015-June 2018) is a prominent case. The Magnitude 5.5 Orkney earthquake on August 5th, 2014 was well recorded by the mine, the Council for Geoscience and the sensors of the SATREPS

[2] Ministry of Foreign Affairs, "ODA Country Data book" 2010

project installed both in the mine and on surface. The proposal was submitted to the International Continental Scientific Drilling Program (ICDP) to investigate earthquake physics and deep life. The multi-national team comprises seismologists, rock engineers and geo-microbiologists from Japan, South Africa, Australia, Germany, Israel, Switzerland and the USA.

<Other Impacts at the time of Ex-Post Evaluation>

There are some positive impacts of the Project confirmed at the time of the ex-post evaluation. The members of academic staff and post graduate students who were involved in the SATREPS project have been continuing to improve their research capacity of data collection, writing papers and attending conferences. Prof. Durrheim, the project manager of this SATREPS project is currently supervising or co-supervising 3 MSc and 4 Ph.D. candidates that are conducting research directly related to the SATREPS project as mentioned above. In addition, the previous CGS staff members involved in the SATREPS project benefitted from the research, especially in the automatic prediction of P- and S- waves of earthquakes. Furthermore, Prof. Durrheim has been appointed by the Minister of Mineral Resources and Energy to serve on a Rockfall and Rockburst Task Team. In this role, he has drawn on the knowledge that he gained during the SATREPS project.

In terms of scientific literacy of government organizations, seismologists and rock engineers at CGS and the CSIR provided field support, installed instruments and collected data. They also participated in data analysis and interpretation and attended workshops and seminars. CGS is responsible for country-wide seismic monitoring, and took responsibility for the strong motion network established in the Far West Rand gold field, the Antelope software and Horiuchi method for automatic location of seismic events. These systems continue to operate.

No negative impact by the SATREPS project was confirmed at the time of ex-post evaluation.

<Evaluation Result>

Therefore, both the effectiveness and impact of the project is high.

Achievement of Project Purpose

Aim	Indicators	Results
(Project Purpose) Understanding of the preparation and occurrence of earthquakes is enhanced, and the risk management mechanism of mining-induced earthquakes is improved.	Indicator 1: Results of the Project is reported at least 5 international, professional meetings.	Achievement Status: Achieved (Continued) (Project Completion) ● Sixty-five papers describing the research results were presented at international and professional meetings in the United States, Canada, Russia, Austria, Switzerland, Sweden, Australia, Chile and China. (Ex-Post Evaluation) ● Verified as the achievement level of the Overall Goal.
	Indicator 2: Formal recommendation on leading Code of Practice is submitted to MOSH* team, rock mechanics practitioner, organized labour, and the Mine Health and Safety Inspectorate. *Mining Industry Occupational Safety and Health	Achievement Status: Not achieved (Partially achieved) (Project Completion) ● A recommendation on the improvement of mine safety in South Africa was prepared but not submitted to MOSH team or other stakeholders. (Ex-Post Evaluation) ● Prof. Durrheim, presented a recommendation concerning the practical and implementable achievements of the SATREPS project at the "Mining Industry Rockburst Workshop" in October 2017 and the MINESAFE2017 "Striving for Zero Harm Driving Excellence through Compliance" Conference in August 2017. However, the recommendation on the improvement of mine safety has not been submitted yet.
	Indicator 3: At least two transferred technologies are adopted in South African mines	Achievement Status: Achieved (Continued) (Project Completion) ● Rock deformation and stress measurement technologies were applied by the mining companies and mine consulting firms at the three target mines, Cooke 4, Moab Khotsong, and Driefontein mines. (Ex-Post Evaluation) ● The three target mines have continued to utilize the transferred technologies.
	Indicator 4: At least four young researchers obtain advanced degree on project related research	Achievement Status: Achieved (Continued) (Project Completion) ● Three South African BS holders obtained MSc degrees with project related research at Pretoria University and University of the Witwatersrand. Five Japanese BS holders also obtained MSc degrees with project related research. (Ex-Post Evaluation) ● Verified as "Sustainable".
(Overall Goal) Apply the seismic hazard assessment and control schemes developed in this project in deep South Africa mines and worldwide.	N.A.	Achievement Status: Partially achieved Efforts to transfer knowledge and technology, for example, through the Mineral Resources and Energy's Rockfall and Rockburst Task Team, on which Prof. Durrheim serves; and the 9-person Sibanye-Stillwater 'expert panel', on which both Prof Ogasawara and Prof. Durrheim serves, continue to this day.. ● The novel stress measurement techniques (CCBO, DCDA and DRA) have been transferred to personnel at AngloGold Ashanti, Groundwork

		Consulting and University of the Witwatersrand. However, this is an ongoing challenge as practitioners change jobs, and mines change hands or close. ● The algorithm to automatically pick P- and S-wave arrival times (and hence locate seismic events) has been successfully tested and implemented at the CGS. Although they would like to continue to work on the software developed by Dr. Horiuchi, they have lost the human capacity within the organization to be able to continue with it. ● The research outcomes have most certainly been used, most notably by the ICDP-DSeis project as mentioned above.

Source：Terminal Evaluation Report, JST Terminal Report, Questionnaires survey with Prof. Durrheim and the CGS staff members

3 Efficiency

Both the project cost and the project period were within the plan (ratio against the plan:89%, 100%, respectively). The project outputs were produced as planned.

Therefore, the efficiency of the project is high.

4 Sustainability

<Policy Aspects>

In accordance with the Mine Health and Safety Act, No. 29 of 1996, as amended, the Mine Health and Safety Council (MHSC) is established as a national public entity (Schedule 3A). The main task of the Council is to advise the Minister of Mineral Resources on occupational health and safety legislation and research outcomes focused on improving and promoting occupational health and safety in South African mines. The Council also oversees the activities of its committees; promotes a culture of health and safety in the mining industry; arranges a summit every two years to review the state of occupational health and safety at mines; and liaises with the Mining Qualifications Authority and any other statutory bodies about mining health and safety. The MHSC's Guideline for the Compilation of a Code of Practice to Combat Rockfall and Rockburst Accidents in Tabular-Metalliferous Mines has been controlled by the Mine Health and Safety Act. The Mine Health and Safety Act, amended in 1996, also established the Mine Health & Safety Inspectorate aiming to execute the constitutional mandate of the Department of Mineral Resources to protect and safeguard the health and safety of mine employees and communities affected by mining operation. Mining companies are required to compile a 'Code of Practice' (CoP) in accord with the above guideline that takes local mining conditions into account. These CoPs are updated regularly to take any new knowledge or technology into account.

<Institutional/Organizational Aspects>

CGS is responsible for countrywide seismic monitoring and is tasked to operate and maintain the network to monitor seismic strong ground motion in the mining districts (the surface installed seismograph stations), and to use the Antelope and Horiuchi processing packages. CGS took responsibility for the strong motion network established in the Far West Rand gold field, the Antelope software and Horiuchi method for automatic location of events. Although the CGS would like to continue to work on the software developed by Dr. Horiuchi, CGS staff members who were working on the software have resigned from the CGS and there are no replacement of those staff members due to budget constraints. The sensitive sensors installed underground in boreholes were never intended to be a permanent installation. They were focused arrays deployed to monitor local seismicity induced by mining (i.e. within tens of meters). Mining in these parts of the mine was completed during the experiment.

In terms of utilization and implementation of research outcomes, the MHSC Committees most directly involved in the dissemination and implementation of any new knowledge are: Mining Regulation Advisory Committee (MRAC), which advises the Council on proposed regulatory changes, guidelines for codes of practice; and on national standards to be approved by the South African Bureau of Standards; Mining Occupational Safety Advisory Committee (MOSAC), a newly constituted committee tasked to advise the Council on safety policies, standards, systems and procedures related to occupational safety risks, safety regulations, safety research and safety data; Safety in Mines Research Advisory Committee (SIMRAC), which reviews OHS risks and establishes the need for OHS research projects; establishes criteria for determining the funding of health and safety research; evaluates research proposals; and oversees the research programme and the technology transfer of research outcomes.

<Technical Aspects>

The researchers who were involved in the SATREPS project have been using skills and knowledge gained during the SATREPS project with regard to the acquisition and analysis of seismic data, stress measurement techniques (CCBO, DRA and DCDA), integration of seismicity and numerical modelling, laboratory measurements of fault rupture on a range of new projects, including the ICDP-DSeis project that involves many Japanese experts and postgraduate students. Also, the SATREPS project contributed to the capacity of CGS to provide a weekly report on mining related seismicity which have been instructed by the Minister of Mineral Resources.

There are several vehicles that have enabled researchers to continue work in the field of mine seismology and mine safety, such as ICDP-DSeis project, projects sponsored by the Safety in Mines Research Advisory Committee (SIMRAC), which reports to the Mine Health and Safety Council, and projects sponsored by the South African Mineral Extraction Research, Development and Innovation (SAMERDI)[3] program.

For the research capacity development of the young researchers, the Project Manager Prof. Durrheim together with colleagues and postgraduate students at the University of the Witwatersrand, have been actively involved in projects related to the "Advanced Orebody Knowledge", using techniques such as seismic and radio wave tomography and machine learning, and "Non-explosive rockbreaking", using techniques such as thermal spalling and cutting with diamond wires and saws. Prof. Durrheim also of the University of the Witwatersrand is currently supervising or co-supervising 3 MSc and 4 PhD candidates that are conducting research directly related to the SATREPS project as mentioned above.

The only research facilities/equipment installed by SATREPS is the Far West Rand seismic strong ground motion network and the associated Antelope and Horiuchi software packages for efficient processing of large amounts of seismic data. These are maintained and

[3] The SAMERDI strategy defines a pathway to 2030, in terms of the modernization of mining.

used at a high uptime by the CGS.

<Financial Aspects>

The budget of MHSC has been allocated from public revenue and is accountable to Parliament. CGS has utilized funds from its parent department to work on research projects utilizing the data from the stations and to continue operation and maintenance of the seismic strong motion stations installed in the Far West Rand mining district and the associated software packages. There are a number of government institutions responsible for ensuring that research outcomes related to mine safety and geohazard mitigation are implemented.

Although the researchers have a continual struggle to secure funds for research, grants have been obtained from a number of sources to continue research in the field of mining-induced seismicity. For example, the International Continental Scientific Drilling Program (ICDP) awarded the DSeis consortium 1 million USD to drill holes into the source zone of the M5.5 Orkney earthquake. The grant was used to leverage in-kind support from mining companies in South Africa, as well as research grants from funding agencies in Japan, Germany, Switzerland and the USA. The quantum of these grants probably amounts to another 1 million USD. Prof. Durrheim holds the South African Research Chair (SARChI) in Exploration, Earthquake & Mining Seismology, and has allocated part of his grant to support postgraduate students and running costs associated with projects in this field. Projects are conducted in both the School of Geoscience and the School of Mining Engineering, with the support of Professor Bryan Watson. The annual amount is of the order of 0.5 million South African Rand (ZAR). Prof. Manzi, Director of the Reflection Seismics Research Centre of Witwatersrand University has allocated part of his grant to support postgraduate students and running costs associated with projects in this field. The annual amount is of the order of 0.5 million ZAR. The SAMERDI program has supported research aimed at making deep mining for gold and platinum more efficient and safer. Prof. Durrheim, Prof. Manzi and and Dr. Nwaila are currently involved in a range of projects with a combined budget exceeding 1 million ZAR in the year 2020/21. Sibanye-Stillwater, a mining company, allocated 1 million ZAR of the 2020/21 grant to the DigiMine project, hosted by the School of Mining Engineering and directed by Professor Cawood, for research related mine seismology and rockbursting. Prof. Durrheim is responsible for these grants.

<Evaluation Result>

In the light above, there has been no problem from any aspects. Therefore, the sustainability of the effects through the Project is high.

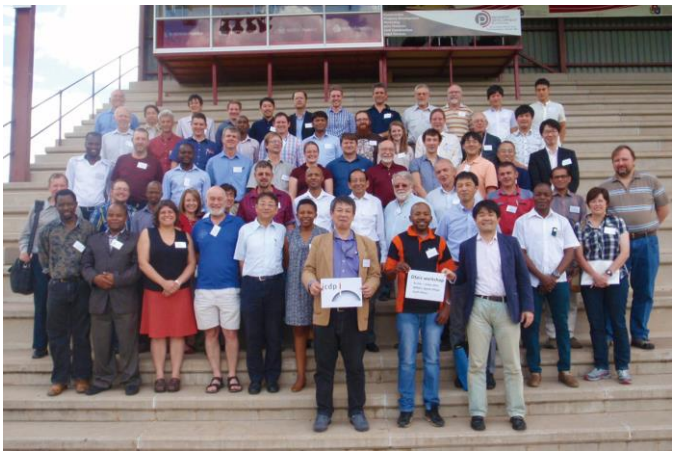
5 Summary of the Evaluation

The project has achieved the Project Purpose of enhancing understanding of the preparation and occurrence of earthquakes and improving the risk management mechanism of mining-induced earthquakes, and has been partially achieved its overall goal of applying seismic hazard assessment and control schemes in deep South Africa mines. Considering all of the above points, this project is evaluated to be highly satisfactory.

III. Recommendations & Lessons Learnt

Lessons Learnt for JICA:

- Both countries' project members suggested that it might be a good idea if JST/JICA could secure a meeting/workshop budget for a counterpart country after project completion. This could help the project members to keep aligned and boost their motivation to achieve the project's overall goal that could lead to have an opportunity for commercialization/social implementation. Presenting project's further research outcomes to private companies could lead to commercialization. At the same time, it could be a good opportunity for the project members to remind them that ex-post evaluation will be conducted three to five years after project completion.



The core members of the SATREPS project at the DSeis pre-drilling workshop in Potchefstroom during October 31st – November 3rd, 2015 sponsored by ICDP and Ritsumeikan University.
(https://www.sciencemag.org/news/2017/05/deep-south-african-gold-mine-scientists-drill-heart-earthquake)

写真3 高知大学／JAMSTECの高知コアセンターで試料を整理する様子。

Researchers organizing samples at the Kochi Core Center of Kochi University and JAMSTEC