南アフリカ共和国
（科学技術）
鉱山地震被害低減観測プロジェクト
中間レビュー調査報告書

平成 26 年 4 月
（2014 年）

独立行政法人国際協力機構
地球環境部

環境
JR
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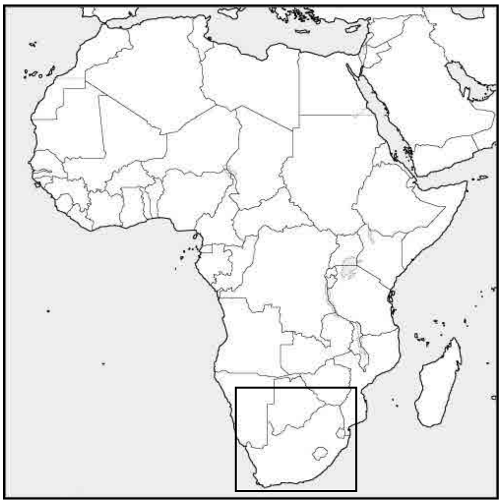
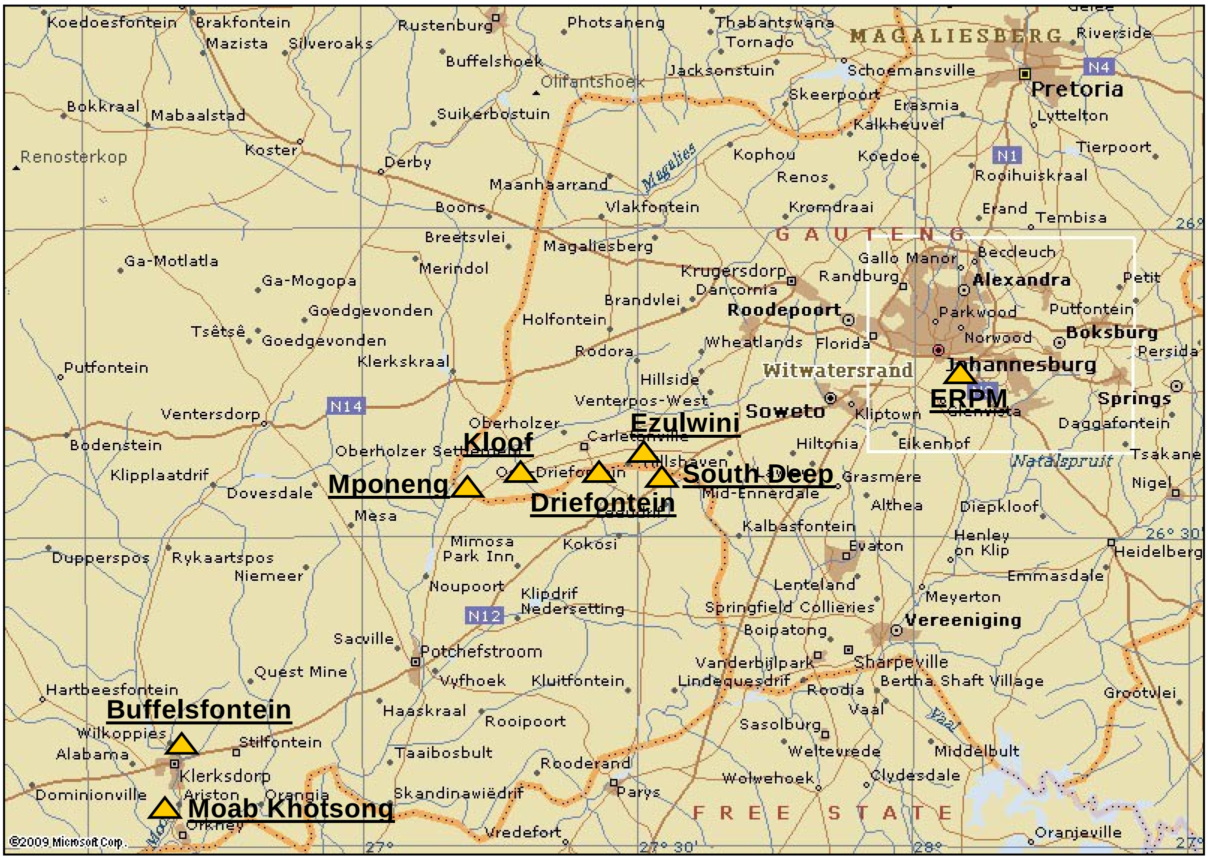
調査対象地域位置図





出典

左上図：http://www.sekaichizu.jp/atlas/africa/p500_africa.html

右上図：http://www.lib.utexas.edu/maps/cia08/south_africa_sm_2008.gif

中央図：http://encarta.msn.com/map_701517687/Witwatersrand.html

現地調査写真

	
地下 3km の坑内（Moab Kotsong 鉱山）	モルタルにより岩盤深くに埋設された 観測機器（Cooke4 鉱山）
	
坑内に設置された AE データレコーダーの メンテナンス（Cooke4 鉱山）	前夜の地震で通行不能となった坑道 （Cooke4 鉱山）
	
プロジェクトによって設置された 地表地震観測機器	合同調整委員会 （Joint Coordinating Committee：JCC）

略　語　表

略語	正式名称	日本語
AIST	National Institute of Advanced Industrial Science and Technology	独立行政法人産業技術総合研究所
CCBO	Compact Conical-ended Borehole Overcoring technique	円錐孔底ひずみ法（応力測定方法）
CGS	Council for Geoscience	地球科学評議会
CMI	Center for Mining Innovation (CSIR)	鉱山イノベーションセンター（CSIR）
CSIR	Council for Scientific and Industrial Research	科学産業研究評議会
C/P	Counterpart	カウンターパート
OECD-DAC	Organisation for Economic Co-operation and Development - Development Assistance Committee	経済協力開発機構 - 開発援助委員会
DMR	Department of Mineral Resources	鉱物資源省
DST	Department of Science and Technology	科学技術省
IMS	Institute of Mine Seismology (former ISS: Integrated Seismic Systems International Ltd.)	（会社名）
JAGUARS Project	Japanese – German Underground Acoustic Emission Research in South Africa Project	南アフリカにおける日独地下微小破壊観測プロジェクト
JCC	Joint Coordinating Committee	合同調整委員会
JICA	Japan International Cooperation Agency	独立行政法人国際協力機構
JST	Japan Science and Technology Agency	独立行政法人科学技術振興機構
KOSH	Klerksdorp-Orkney-Stilfontein-Hartebeestfontein	（地名）
MOSH	Mining Industry Occupational Safety and Health (Chamber of Mines)	鉱業労働安全保健チーム（鉱山会議所）
MHSC	Mine Health and Safety Council	鉱山保健安全評議会
MHSI	Mine Health and Safety Inspectorate	鉱山保健安全監督局
MoU	Memorandum of Understanding	覚書
MQA	Mining Qualifications Authority	鉱山資格局
OHMS	Open House Management Solutions Ltd.	（会社名）
PDM	Project Design Matrix	プロジェクト・デザイン・マトリックス
SANSN	South African National Seismograph Network	南アフリカ国立地震観測網
SATREPS	Science and Technology Research Partnership for Sustainable Development	地球規模課題対応国際科学技術協力
SeeSA	Semi-controlled Experiment in South African gold mines	南アフリカ金鉱山における半制御実験プロジェクト
WMRI	Wits Mining Research Institute (Witwatersrand University)	ウィッツ鉱業研究所

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中間レビュー結果要約表

1. 案件の概要	
国名：南アフリカ共和国 **分野**：防災	**案件名**：（科学技術）鉱山での地震被害低減のための観測研究プロジェクト
所轄部署：地球環境部水資源・防災グループ	**協力形態**：地球規模課題対応国際科学技術協力（SATREPS）
協力期間：2010 年 8 月～2015 年 8 月	**協力金額**：3.8 億円（JICA 予算ベース）
日本側協力機関：立命館大学、東京大学、独立行政法人産業技術総合研究所（AIST）、東北大学	**先方実施機関**：科学技術省（DST）、科学産業研究評議会（CSIR）、地球科学評議会（CGS）、ウィットウォータースランド大学

1-1 協力の背景と概要

鉱物資源に恵まれている南アフリカ共和国（以下、「南アフリカ」と記す）には、金、プラチナ、石炭などの鉱山が多数あり、鉱業全体で約 50 万人が就業している。そのうち、約 60%にあたる労働者が鉱石の採掘など坑内での労働に従事しており、鉱山災害の危険に晒されている。鉱山災害は従来から南アフリカにおいて大きな社会問題となっているが、政府の指導及び鉱山会社の安全性向上への努力により、1980 年代後半には労働者 1,000 人あたりの年間犠牲者（死者）数が 1.00～1.20 人（犠牲者総数では 677～855 人/年）であったが、1990 年代を通じて犠牲者数は漸減し、2000 年代前半には同 0.56～0.75 人（犠牲者総数 246～290 人/年）にまで減少した。しかし、この数年は犠牲者数の減少傾向が停滞している。

これら鉱山災害犠牲者のうち約 4 割は、採掘活動によって岩盤が破壊され断層が生じることで発生する鉱山地震に起因する落盤事故によるものと言われている。また、鉱山地震は、採掘域や坑道などの落盤事故だけでなく地上にも建築物倒壊などの被害を及ぼすことがある。

鉱山地震のリスクは深度が深くなるほど高くなるため、採掘深度 3,000m を超える南アフリカの大深度鉱山は特にリスクが高い。大深度では、岩盤に巨大な圧力がかかっており、そこに採掘のために空隙を作ると岩石が圧力に耐えられず破壊し、断層を生じる可能性が高くなるためである。このような鉱山地震発生のメカニズムが存在する中で安全に採掘するためには、鉱山地震のリスクをより正確に評価し、評価結果に基づく採掘計画の修正や採掘活動の制限などによって鉱山地震被害を減少させることが重要である。

南アフリカの大深度金鉱山では、過去 19 年間にわたって日本の研究者によって鉱山地震の観測研究が行われ、その結果、地震の発生位置や大きさが事前にある程度予測可能になり、また震源となる断層の近くで観測することができることが判ってきた。こうした背景のもと、鉱山内に観測機器を設置し、鉱山地震の発生メカニズムを分析し、被害予測に役立てることを目的とした本プロジェクトが科学技術協力案件として採択された。ここで得られる科学的知見は、自然地震の発生メカニズムの理解促進に役立ち、地震の予知・予測研究に役立つことも期待されている。

1-2 協力内容

(1) プロジェクト目標

地震の準備と発生についての理解が深まり、金鉱山地震の災害リスク管理体制が改善される。

(2) 成果

1：震源の岩石の性質が明らかになる。
2：鉱山地震の準備と前駆変化への理解が深まる。
3：鉱山地震の発生を予測する精度が向上する。
4：鉱山地震による採掘坑内での地震被害を予測する精度が向上する。
5：地震の震源決定及び被害予測の精度が向上する。

(3) 投入（中間レビュー時点）

（日本側） 専門家派遣：研究者（短期派遣）8 名（計 34 回、749 日間）、業務調整（長期派遣）1 名
本邦研修：2012 年に 1 名（短期研修）
供与機材：観測機材（微小破壊観測用センサー、高感度歪計、広帯域地震計、能動震源と受振用加速度計、動的応力変化計、傾斜計、データレコーダー、国立地震観測網ステーションなど）
現地活動費：587 万ランド（2010 年 8 月から 2013 年 1 月までの合計で、内訳はローカルコンサルタント委託費、物品購入費、旅費・交通費など）

（南アフリカ側）
カウンターパート：科学産業研究評議会（Council for Scientific and Industrial Research : CSIR）、地球科学評議会（Council for Geoscience : CGS）、ウィットウォータースランド大学から 30 名。
現地活動費：240 万ランド（2011～2012 年の CSIR、CGS のプロジェクト活動のための出費合計）
事務所スペース・備品の提供

(4) プロジェクトサイト

Cooke 4 鉱山（Gold One 社）、Moab Khotsong 鉱山（Anglogold Ashanti 社）、KDC West 鉱山（Sibanye Gold 社）

2. レビュー調査団の概要		
調査団構成	1. 宮本秀夫（団長／総括）JICA 地球環境部 水資源・防災グループ 参事役 2. 土井ゆり子（協力企画）JICA 地球環境部 水資源・防災グループ防災二課 3. 奥田浩之（評価分析）合同会社 適材適所 4. 佐藤雅之（オブザーバー）JST 地球規模課題国際協力室 上席主任調査員 5. Mr. Llanley Simpson（総括）DST 採鉱・選鉱工程　課長 6. Ms. Lisa du Toit（評価）DST 開発パートナーシップ　課長 7. Ms. Eudy Mabuza（評価）DST 開発パートナーシップ　課長補佐	
	2013 年 2 月 24 日～2013 年 3 月 14 日	**調査種類：**中間レビュー

3. 進捗の確認

3-1 成果レベルの実績

1) 成果 1

・対象 3 鉱山で、予定の探査ドリリングが 2012 年 9 月までに全て終了し（合計約 70 本、総延長約 2.8km）、岩石コア試料と孔内観察により、観測のターゲットとなる想定地震断層の位置が特定された。
・Cooke4 鉱山（及び Mponeng 鉱山）で採取した掘削コア試料の一部は、物性解析のため 2012 年 5

月に日本に輸出された。

2) 成果 2

・Cooke4 鉱山では、想定震源を取り囲む領域に約 30 台の微小破壊観測用センサーを三次元的に埋設し、2010 年 12 月から 2 年以上観測が続いている。また Moab Khotsong 鉱山でも同様の微小破壊観測用センサーの設置が進んでおり、2013 年 4 月より観測が開始予定である。

・採掘に伴う岩盤変形観察のための高感度歪計、傾斜計、広帯域地震計の設置が進み、Cooke4 鉱山では完了、Moab Khotsong 鉱山でも約 80％の設置が完了している。

3) 成果 3

・Cooke4 鉱山では、能動震源と受振用加速度計の埋設が完了し、モニタリングが続いている。また、高密度の微小破壊観測用センサーを用いた震源決定により、掘削面前方岩盤内のダメージゾーンを明確に検出できている。

・日本で実用化されている応力測定方法（円錐孔底ひずみ法）をより小さい口径（直径 60mm）で 2013 年 1～2 月に Mponeng 鉱山、Tau Tona 鉱山で実施し、従来の方法よりもはるかに短時間で応力測定を完了することに成功した。

4) 成果 4

・震源断層極近傍で破壊前線の通過に伴う動的応力変化と断層変位を計測するための動的応力変化計を開発した。Cooke4 鉱山、KDCWest 鉱山で掘削孔と断層の交差部を特定し、2010 年 12 月及び 2012 年 1 月に、それぞれの断層直近に動的応力変化計を埋設し、観測が続いている。

5) 成果 5

・CGS により金鉱山地域の国立地震観測網の設置が進行中であることから、これと同じ仕様の地表地震観測所（強震計）を、Cooke4 鉱山、KDC West 鉱山が位置する Far West Rand 地域に 2012 年 7 月までに 10 点すべての設置を完了した。

・CGS の Silverton データ・センターに、2012 年 7 月までにソフトウェア「Antelope」を始めとする地震解析システムを導入した。

3-2 プロジェクト目標に向けた進捗

金採掘の進行によりこの 2～3 年に M2 級の地震が予想される断層を特定し、Cooke4 鉱山ではその至近距離への観測網の展開が 2010 年 12 月には完了し、ほぼ 2 年以上のデータ収録が続いている。Moab Khotsong 鉱山でも機材の設置は約 80％完了し、KDC West 鉱山での観測網設置もまもなく完了する予定である。また、鉱山地域の地表では南アフリカ国立地震観測網の増強を完了した。

地震の準備・発生の理解促進に関し、Cooke4 鉱山では、鉱山独自の地震観測よりも遥かに高感度・高精度の微小破壊観測用センサー網により、地震発生リスクが高いと思われる面状構造を描き出すことに成功し、その準静的拡大も捉えることができている。

金鉱山地震の災害リスク管理体制の改善については、応力測定方法（円錐孔底ひずみ法）は一連の応力測定を 2.5 時間以内に完了できたことから、従来の応力測定と比べて極めて安価で鉱山内で実用可能な初めての応力測定手法となることが期待されている。

4. 5 項目評価の概要

4-1 妥当性

プロジェクトの妥当性は高い。

1) 震源として予想される断層に接近し、その至近距離に観測網を設置して地震の準備・発生の様子

を詳しく観察できるのは、地下約1～3kmの大深度を持つ南アフリカ金鉱山においてのみである。鉱山地震の発生構造に関する研究成果は自然地震の解明にも資することが期待されており、共同研究実施の意義は大きい。

2) 地震の準備・発生に関する理解を深めるだけでなく、プロジェクトは、高感度観測網を設置して得られる情報によって金鉱山地震の既存の災害リスク管理体制の改善も目指しており、南アフリカ社会のニーズに応えている。
3) 南アフリカの政府担当機関である鉱物資源省（Department of Mineral Resources：DMR）や鉱山保健安全評議会（Mine Health and Safety Council：MHSC）は、更に深度の大きい鉱脈において安全で経済的な採掘を進めるために、地震の発生予測や被害の制御・軽減が重要であるとし、プロジェクト成果に対して高い関心を寄せていることから、南アフリカ政府の方針とも整合している。
4) プロジェクトは、実施機関である CSIR 鉱山イノベーションセンター（Center for Mining Innovation：CMI）及び CGS の研究方針・ニーズと整合している。
5) 科学技術協力は、日本と南アフリカの 2 国間協力における重点項目の一つであり、2013 年 3 月 1 日に開催された第 12 回「日・南ア・パートナーシップ・フォーラム」においても、貿易投資、開発支援、政策対話、科学技術の 4 部会が開催され、実務レベルの議論が行われている。

4-2 有効性

プロジェクトの有効性は中程度である。

1) プロジェクト活動は成果 1～5 の各レベルで着実に進展しており、現時点では、プロジェクト期間内でのプロジェクト目標の達成を阻害する特段の要因は認められない。鉱山の採掘計画が変更されないこと、鉱山ストライキが起こらないこと、想定される大きさ（M2 レベル）の地震が発生すること、等の幾つかの外部条件はあるものの、期間内でのプロジェクト目標の達成が見込まれる。
2) プロジェクトは独立行政法人国際協力機構（Japan International Cooperation Agency：JICA）、独立行政法人科学技術振興機構（Japan Science and Technology Agency：JST）からの予算に加えてその他の研究予算も同時に活用してプロジェクト活動を進めており、目標達成に向けた有効性を高めている。
3) プロジェクト目標に含まれる研究成果の社会実装については、中間レビューを契機にその具体的な道筋・アプローチについての議論が始まったばかりである。今回、中間レビューの中で様々な可能性が提案されたので、今後その実現について議論を深めていくことが必要である。
4) 2010 年 2 月に署名された覚書（Memorandum of Understanding：MoU）に添付されたマスタープランには指標が設定されていないため、プロジェクトはプロジェクト終了時の達成指標を明確に設定することで、更に高い有効性が期待できる。

4-3 効率性

プロジェクトの効率性は高い。

1) マスタープランは明瞭であり、プロジェクト実施機関の間での目標・成果・活動に対する理解度は高い。鉱山ストライキなどにより第 2 回合同調整委員会（Joint Coordinating Committee：JCC）で承認された活動計画から幾つかの遅れは見られるものの、プロジェクトの進捗は順調である。
2) 日本側の投入（専門家派遣、供与機材、本邦研修）は効果的に使われており、南アフリカ側からも高い評価の声がきかれた。機材調達については、2012 年末までに当初予定の全ての調達が完

了している。

3) 南アフリカ側の投入についても、日本側と同様効果的に行われている。南アフリカ側のカウンターパートの変更は最小限であり、日本・南アフリカの研究者間の協力関係は安定している。CSIR、CGS はともに独自予算からプロジェクトの活動費の一部を支出している。
4) 効率性の高さは、鉱山会社のプロジェクト活動への理解・協力や便宜供与（機材の設置場所の提供、通気パイプの設置、竪坑エレベーターの稼働など）にも拠っている。鉱山会社からは協力研究者として技術者がプロジェクトに参加している。
5) プロジェクトはこれまで 2 回の JCC を開催しており（第 1 回 2011 年 4 月 19 日、第 2 回 2012 年 5 月 9 日）、また日本側研究者、南アフリカ側研究者の間のコミュニケーションは非常に良好である。

4-4 インパクト

プロジェクトのインパクトは、上位目標に向けた進展の観点からは中間レビュー時点ではまだ低い。しかしその他については幾つかの重要なインパクトが見られる。

1) プロジェクト成果の鉱山での採用・活用といった上位目標に向けた進展は、今後プロジェクト後半において今後徐々に発現してくることが見込まれる。
2) 現時点のインパクトとしては、本プロジェクトに関わる研究者に対して、IMS〔Institute of Mine Seismology（民間会社)〕主催国際セミナーなど国際会議での講演・発表依頼が増えていることが挙げられる。
3) プロジェクトで導入された微小破壊観測用センサー、応力測定方法（円錐孔底ひずみ法）は、既に鉱山会社、鉱山技術サービス会社が独自での利用を検討している。
4) プロジェクトが支援した CGS のデータ解析センターは、Far West Rand 地域だけでなく、KOSH（Klerksdorp-Orkney-Stilfontein-Hartebeestfontein）地域、Central Rand 地域の地表地震観測網にも利用されている。

4-5 自立発展性

プロジェクトの自立発展性の見込みは比較的高い。

1) プロジェクトの内容は CSIR/CMI 及び CGS の業務と合致していることから、体制的な観点からは継続・発展に適したものとなっている。ただし南アフリカの金鉱業は、全体としては顕著な衰退傾向にあり、政府や民間企業の鉱業に関連する研究活動への投資もここ 20 年で大きく減少している状況にある。
2) プロジェクトで供与し岩石の中に設置された観測機材は、モルタルで埋設されているため、当初の観測目的が終わっても回収・再利用されることはない。しかし一部の観測機材は、閉山後の地震観測のため CGS が引き続きデータ収集に利用することを検討している。CGS の地表地震観測所については、全て CGS の予算によるメンテナンス、データ収集が行われている。
3) CSIR は、予算の削減はあるものの現在の人員レベルの維持を見込んでいる。一方 CGS は、近年は正規雇用の人員増が続いている。CSIR、CGS によれば、プロジェクトは若手研究者育成の良い機会ともなっている。
4) CSIR の予算は、その半分以上を政府機関、民間セクターとの研究契約締結に拠っており、予算的な観点からは持続性は不確かである。これまで鉱山安全管理の研究支援を行ってきた MHSC は、近年は基礎研究への資金支援は行っていない。

5) 鉱山会社、鉱山技術サービス会社が、プロジェクトで導入された観測手法の有効性を認めて、一部を自社システムに取り入れ始めている。今後プロジェクト成果が実用的な観測モデルにつながった場合、利用される可能性は高いと考えられる。

4-6 プロジェクトの効果発現を促進・阻害した主な要因

1) 促進要因：1) 鉱山会社の経営陣や岩盤工学の現場従事者からの、プロジェクト活動の実施に対する理解と多大な支援、2) プロジェクトが雇用したコンサルタント〔(鉱山技術サービス会社である）OHMS（Open House Management Solutions Ltd.）、Seismogen のスタッフ〕の機材設置等に関する働き、3) 南アフリカ側研究者、日本側研究者、鉱山会社の間の長い協力関係、の 3 点が主な促進要因として認められた。
2) 阻害要因 : 1) 鉱山ストライキ発生とそれに伴う入坑停止、2) 鉱山内でのケーブルや機材の盗難、3) 貴金属を含む岩石標本を日本に送るための手続きと認可の遅れ、がこれまでの主な阻害要因として指摘された。

5. 評価結果の要約

5-1 結論

プロジェクトは、南アフリカ社会の開発ニーズや政府の方針と整合し、さらに科学技術協力は日本・南アフリカの 2 国間協力における重点項目の 1 つでもあることから、その妥当性は高い。プロジェクトの基本デザインは適切であるが、今後のプロジェクト目標の達成に向けては、研究成果の社会実装に向けた道筋や、明確な達成指標の設定が求められる。プロジェクトの効率性は高く、これまで活動計画どおりほぼ順調に進行し、機材の調達・設置も概ね完了した。プロジェクトのインパクトは、上位目標に向けた進展という意味では、中間レビュー時点ではまだ低い。持続性については、制度、技術、人材など全体としては比較的高いと判断される。

5-2 提言

1) プロジェクト・デザイン・マトリックス（Project Design Matrix：PDM）

現行マスタープランには指標が設定されていなかったが、中間レビューでの議論の結果、指標、外部条件を含む PDM 案が作成されたことから、JCC で PDM 案を最終化し、承認すること。

2) 研究成果の社会実装

研究成果の社会実装については、今回の中間レビューの中で様々な可能性が示唆された。プロジェクトはこれら可能性の実現に向けて関係者との議論を深めていくこと。

- 微小破壊観測用センサー等の観測網が鉱山地震の発生予測観測に有用であることが証明された場合、鉱山会社が利用できるような実用的な観測網仕様の提案。
- 学術論文としての承認を踏まえて、鉱山会社が各自定めている「安全管理規則」改訂に際しての提言を、鉱山商工会議所（Chamber of Mines）鉱業労働保健安全チーム（Mining Industry Occupational Safety and Health : MOSH）、岩盤工学の現場従事者、労働組合、DMR、鉱山保健安全監督局（Mine Health and Safety Inspectorate：MHSI）等に提出。
- 応力測定方法（円錐孔底ひずみ法）の測定に基づく、応力計算機モデルの改良。
- 鉱山のための教育・訓練支援を行う鉱山資格局（Mining Qualifications Authority：MQA）の教科課程の中に、プロジェクト成果の知識・知見を反映。
- 南アフリカ鉱山で導入されている安全管理システムを開発・提供する民間会社 IMS によるプロジェクト成果の採用を通しての、鉱山会社の災害リスク管理体制の改善。

3) 政府機関との情報共有

中間レビューでは政府関係機関はプロジェクトの成果に高い関心を持っていることも確認されたため、ワークショップ、セミナー、JCC などの機会を通して、DMR、MHSC、MQA などの関係機関との情報共有を進めていくこと。

4) 研究予算の獲得支援

鉱山安全管理研究に対する資金支援が大幅に削減されてきていることから、政府関係機関は、新たな予算や研究基金に対する研究機関のアクセスを支援していくこと。

Mid-term Review Summary Sheet

1 Outline of the Project	
Country: Republic of South Africa **Thematic Area：** Natural Disaster Prevention **Division in Charge：** Water Resources and Disaster Management Group, Global Environment Department	**Project Title：** the Project for Observational Studies in South African Mines to Mitigate Seismic Risks in the Republic of South Africa **Cooperation Scheme：** SATREPS (Science and Technology Research Partnership for Sustainable Development)
Project Period： August 2010～August 2015	**Total Cost：** 380 Million JPY (JICA budget)
Supporting Organization in Japan： Ritsumeikan University, Tokyo University, AIST(National Institute of Advanced Industrial Science and Technology), Tohoku University.	**Counterpart Agency：** DST(Department of Science and Technology), CSIR(Council for Scientific and Industrial Research), CGS(Council for Geoscience), Witwatersrand University.

1.1 Background of the Project

The Republic of South Africa is rich in mineral resources with many mines of gold, platinum and coal. The mining industry contributes to the employment of 500,000 workforces, about 60% of which are underground workers engaged in the mining of minerals in stopes and faced with the risk of mine disaster. Mine disaster has been a big social issue in the country, but administrative guidance and self-reliant efforts of mining companies towards enhanced mine safety have realized the decrease of casualties: from 1.00 - 1.20 per 1,000 persons in late 1980s (the number of victims were 677 - 855 person/year) to 0.56 – 0.75 per 1000 persons in early 2000s (the number of victims were 246 – 290 person/year). In recent years, however, the trend of casualty decrease has been stagnating.

About 40% of the casualty and death of miners is presumably attributed to fall-of-ground accidents not always but often caused by “mine tremor” - a quake resulting from abrupt failure of bedrock by excess stress induced by mining activities. The mine tremor not only triggers fall-of-ground accidents in the mining stopes underground but also sometimes damages buildings on the surface.

The deeper the depth of shafts is, the greater the risk of mine tremor becomes. Gold mines in South Africa face high risks because many of them in South Africa are deeper than 3,000 m or mine remnants in high stress. At abutments of mining, rock mass is often unable to endure the excess stress and abruptly fails, thus inducing earthquakes. As such, in order to further decrease the victims of mine disaster, it is very important to assess the risk of mine tremor more precisely, and adjust mining plans or confine mining activities based on the risk assessment.

In South Africa, in-mine seismic monitoring and stress modeling, which have been commercially available internationally (the former was developed in South Africa), and practical seismic hazard assessment is operational. However, the assessment has stagnated because of limited understanding of earthquakes. To enhance the hazard assessment, observational studies of mine tremor have been conducted by Japanese researchers over the past 19 years in deep gold mines, which included monitoring significantly more sensitive and stable or higher in capacity than civil engineering or geotechnical monitoring and much closer distance to hypocenters than in-mine seismic monitoring. The fine details that can never be elucidated in other than South African gold mines have suggested that the enhancement of hazard assessment is feasible to some extent. With this background, *the Project for Observational Studies in South African Mines to Mitigate Seismic Risk* started in August 2010 under the JICA/JST cooperation scheme of SATREPS. Being allowed much denser monitoring networks in three experimental sites than those in the previous researches, the Project aims at much better understanding of the preparation and generation of earthquakes that have been wanted over years.

In February 2013, at the halfway of the cooperation period, the Project is required to undergo the Mid-term review in accordance with the Article V of the MoU (Memorandum of Understanding) signed in February 2010.

1.2 Project Overview

1) Project Purpose

Understanding of the preparation and occurrence of earthquakes is enhanced, and the risk management mechanism of mining-induced earthquakes is improved.

2) Outputs

1. Rock properties at seismic sources are elucidated.
2. Understanding of the preparation and forerunners of earthquakes in gold mines is enhanced.
3. Reliability of seismic hazard assessment in gold mines is improved.
4. Reliability of strong ground motion predictions in gold mines is improved.
5. Estimation of the locations of seismic events and damage assessment of seismic disasters become more accurate.

3) Inputs

(Japanese Side)

・Eight researchers (short-term), totaling 749 days, and one project coordinator (long-term) dispatched.
・Short-term training for one researcher in Japan in 2012.
・Observation equipment (e.g. Acoustic Emission Sensor, Strainmeter, Broad-band Seismometer, Transmitter and Receiver, Dynamic Rupture Sensor, Tiltmeter, Data Recorder, Surface CGS National Station).
・Local operation costs of 5.87 Million ZAR (total amount from August 2010 to January 2013 including local contract, procurement of equipment, travel cost and allowance).

(South African Side)

・Assignment of 30 counterpart personnel from CSIR, CGS and Witwatersrand University.
・Local operation costs of 2.40 Million ZAR (total amount of CSIR and CGS from 2010 through 2011).
・Office space and equipment.

4) Project Area

Cooke4 mine (ex.Ezulwini) of Gold One, Moab Khotsong mine of Anglogold Ashanti, KDC West mine (ex.Driefontein) of Sibanye Gold (ex.Gold Fields)

<table>
<tr><th colspan="3">2 Review Team</th></tr>
<tr><td>Member of the Review Team</td><td colspan="2">1. Mr. Hideo Miyamoto (Leader) Senior Advisor to the Director General, Global Environment Department, JICA
2. Ms. Yuriko Doi (Survey Planning) Disaster Management Division II, Global Environment Department, JICA
3. Mr. Hiroyuki Okuda (Evaluation & Analysis) Tekizaitekisho, LLC
4. Mr. Masayuki Sato (Observer) Principal Researcher, Research Partnership for Sustainable Development Division, JST
5. Mr. Llanley Simpson (Leader) Director, Mining and Mineral Processing, DST
6. Ms. Lisa du Toit (Project Evaluation) Director, Development Partnerships, DST
7. Ms. Eudy Mabuza (Project Evaluation) Deputy Director, Development Partnerships, DST</td></tr>
<tr><td>Review Period</td><td>24 February 2013～14 March 2013</td><td>Type of Evaluation：Mid-term Review</td></tr>
<tr><th colspan="3">3 Project Performance</th></tr>
</table>

3.1 Achievements of Outputs

(Output 1)

・ All planned drilling was completed by September 2012: totaling more than 70 holes and more than 2.8km in length, in the three mines. For each target mine, an anticipated seismic source (hypocenter fault) was accurately located based on the geological features intersected by those holes.

・ Core specimen from the seismic source of Cooke 4 (and of Mponeng mine) was shipped to Japan by May 2012 for specialized tests such as measurement of elastic properties, fracture parameters/characteristics and stress constrained by cores.

(Output 2)

・ Surrounding the hypocenter fault at Cooke 4, the installation of about 30 acoustic emission sensors and a AE recorder were completed by December 2010, and data has since been accumulated to monitor the activities of micro fracturing and identify potential seismic sources. At Moab Khotsong, a similar acoustic emission monitoring network is being established and the monitoring is scheduled to start in April 2013.

・ On the hypocenter faults, the installation of sensitive strainmeters, tiltmeters, and broad-band seismometer have been almost completed to monitor the accumulation and release of stress and to compare the data with existing stress modeling.

(Output 3)

・ In a line intersecting the hypocenter fault at Cooke 4, one transmitter and three receivers (accelerometers) were installed to monitor change in elastic wave transmitting through the fault.

・ It was confirmed that the AE network of the Project clearly delineated multiple planner distributions of AE that evolved with time. They can be weak planes of potentially impending earthquakes. Identifying weak plane is the first step to enhance seismic hazard assessment, which has been successfully achieved.

・ Modified CCBO (compact conical-ended borehole overcoring) technique in BX size (60mm in diameter) was tested successfully in January and February 2013 at Mponeng and at Tau Tona mine, completing the cycle of procedures necessary for an overcoring within much shorter time than current, conventional methods.

(Output 4)

・ On the hypocenter faults at Cooke 4, three dynamic rupture sensors assembled by an expert with high-capacity acceleration sensors and strain gauges were installed in December 2010 and date has since been monitored to fully record dynamic stress change at seismic rupture front. Another four dynamic rupture sensors were installed at KDC West in January 2012 and has since been recording the data.

(Output 5)

・ Ten surface CGS national stations was set up in Far West Rand area, where Cooke 4 and KDC West are situated, by July 2012 to constitute SANSN (South African National Seismograph Network)

・ A new seismogram analysis computer system and new routines for processing data using Antelope software for the surface CGS national stations were also establshed by July 2012.

3.2 Progress towards the Project Purpose

The Project has focused on the installation of moniting equipment in the first two years at the three target mines. At Cooke 4, planned sensors were installed by December 2010 and underground data has been accumulated for about two years. At Moab Khotsong, about 80% of underground installaion is completed. At KDC West, the installation of equipment is also planned to be finished soon. CGS surface national stations and new seismogram analysis computer system are operational since July 2012.

One of preriminary findings which lead to enhanced understanding of the earthquakes is that the AE monitoing system of the Project finely delinieated the weak planes of concerns and could contstrain stress and strengh on one of the planes. The most important steps to enhance seismic hazard assessment is to identify a weak plane of concern more accurately and constrain stress and strengh on the plane, followed by the caliburation of stress modeling for mine-wide application.

Regarding improved risk management mechanism, CCBO technique in BX size is proved to be much faster and easier than the conventional overcoring techniques. The biggest advantage of CCBO is that it can be done quickly, and hence it can be much cheaper and be an afforable method of stress measurement for the first time at mines.

4 Review Based on the 5 Criteria

4.1 Relevance

The relevance of the Project is high.

1) The project is unique in that the South African mines, unlike any other environment in the world, provide access to near hypocenter and allow observation of possible preparation and forerunners of earthquakes. The Project aims at revealing the precursory phenomena by establishing an intensive monitoring network in the vicinity of impending seismic source (identified faults near mining activities).
2) The project purpose is not only to enhance the understanding of preparation and occurrence of earthquake, but also to improve risk management mechanism of mining-induced earthquake. If such observation of sensitive monitoring proves to be practically viable, then the project findings can directly

contribute to mines' risk management systems.

3) Government authorities emphasize the importance of safe and cost-efficient mining, to which the Project can contribute when its research findings are applied and utilized in mines.
4) The project is aligned with the needs and expectation of counterpart organizations: CSIR/CMI (Center for Mining Innovation), CGS and Witwatersrand University.
5) Science and Technology is one of prioritized areas in the bilateral cooperation between Japan and South Africa. Science and Technology session was held, where SATREPS was noted with appreciation, on 28 February 2013, a day before the 12th South Africa - Japan Partnership Forum.

4.2 Effectiveness

The effectiveness of the Project is medium.

1) Overall, the Project is making a steady progress towards achieving the Project Purpose. At the Mid-term review, there are no immediate obstacles observed that can keep the Project from achieving its goal. There are, however, several important assumptions involved towards the goal such as 1) mining plans at the monitoring sites remain unchanged, 2) severe strike that stops research activity does not take place at target mines, and 3) magnitude of seismic events is large enough within the range of sensor array – M2 events are the targets of the Project.
2) The project is effective in that it has mobilized other funding sources and synthesized them towards the achievement of project purpose.
3) Towards the second half of cooperation period, the Project is now required to be more strategic about how research findings can be utilized for improvement of mine's risk management mechanism. This is a part of the Project Purpose. During the Mid-term review, discussions about ideas/approaches for the implementation of research findings to risk management systems have just started.
4) The Project can become more effective by establishing verifiable indicators, which is not included in the Master Plan attached to the MoU signed in 2010.

4.3 Efficiency

The efficiency of the Project to date is high.

1) Master Plan of the Project is clear and well understood among those who are implementing the Project. Project activities are being advanced generally in accordance with the Plan of Operation. There were some delays of planned activities due to the strikes at the three target mines in 2012, during which no entry to the project monitoring sites was allowed.
2) Inputs to the Project from the Japanese side are effective and highly appreciated by the South African side. The MoU decides the measures to be taken by JICA: dispatch of experts, provision of machinery/equipment, and training in Japan. Japanese researchers have shown a great level of commitment to the Project. All the procurement of necessary equipment was completed by the end of 2012.
3) Inputs of South African side - assignment of counterpart personnel, office space and facilities, and running expenses for the project implementation - are no less effective than Japanese inputs. Turnover of the counterpart personnel is low and the cooperating relationship between the Japanese and South African researchers is very stable. CGS and CSIR, as implementing agencies, have managed their

budget in order to undertake project activities.

4) Efficiency of project implementation is high also because of the cooperation from mining industry. The mining companies of the monitoring site have provided the Project with great support, convenience and facilities.
5) The communication between Japanese researchers and South African researchers are excellent. The Project is being implemented based on the consultation and discussion between the two sides. The Project has so far held two JCC (Joint Coordination Committee) meeting, on 19 April 2011 and 9 May 2012.

4.4 Impact

The impact of the Project is still low at the time of Mid-term Review with respect to the Overall Goal, but some other significant impacts have already been achieved.

1) Progress towards achieving the Overall Goal has not been observed as yet at the time of Mid-term Review, but this is mainly expected in the next two years of the cooperation period.
2) One of notable impacts is that the Project scientists have been invited to speak at several international meetings such as annual IMS(Institute of Mine Seismology) seminar since 2009.
3) Some technologies introduced by the Project (i.e. acoustic emission network and CCBO technique) have already been considered for application by a mining company and a rock engineering service provider.
4) Surface network installed by the Project in Carletonville area is operational and the new Data Processing Center is servicing two additional networks in mining areas (KOSH and Central Rand area).

4.5 Sustainability

The prospect of sustainability of the Project is relatively high.

1) It is indicated that the South African mining industry is in decline and that there has been a drastic reduction in the investment in mining-related research in South Africa, both by government and industry, over the years. Under such situation, the Project is aligned with the mission and responsibility of both CSIR/CMI and CGS, and present institutional arrangement is suitable for the continuation and development of project activities.
2) Most sensors and cables for underground can't be recovered because they are permanently grouted in the rocks. CGS is considering taking over a part of the underground equipment to collect data for a research on the difference between mining-induced earthquake and flood-induced earthquake after the mine is closed. CGS is covering all costs associated with maintenance and data communication for the 10 seismic station installed by the Project.
3) As for human resources, CSIR expects to maintain capacity at the current level. At CGS, the number of permanent staff is growing and CGS is expecting more expertise in mining seismology in line with the Geoscience Amendment Act (2010). CSIR and CGS indicates that the project is providing an excellent environment for training young scientist and post-graduate students, which contribute to the capacity development.
4) The prospect of sustainability from financial viewpoint is still uncertain because the continuation of project work at CSIR largely depends on obtaining new research contracts from governmental departments, private sector and research funding agencies in South Africa (e.g. MHSC) and abroad.

MHSC (Mine Health and Safety Council) presently focuses on the application of scientific knowledge, thus having stopped research funding.

4.6 Factors that have promoted or hindered the implementation of project

1) Several promoting factors observed are: the Project has received great support from mine management and rock mechanics practitioners; local consultants from OHMS (Open House Management Solutions Ltd.) and Seismogen, contracted by JICA, have had good performance; and a long history of collaboration of researchers with mining companies and service providers has helped the Project tremendously.
2) Some hindering factors indicated are: Industrial action (strike) at the mines; theft of cables and equipment within the mine; and delays in obtaining permit to transport and hold rock specimens to Japan.

5 Results of the Mid-term Review

5.1 Conclusion

The relevance of the Project remains high as the Project is aligned with the needs of South African society, and Science and Technology is one of prioritized areas in the bilateral cooperation between Japan and South Africa. The Project is making a steady progress at each Output, but the effectiveness of the Project is assessed medium as the Project can be more effective by setting up indicators and by specifying how research findings can be applied to improve mines' risk management mechanism. The efficiency of the project is high because inputs such as experts, equipment, counterpart assignment and local operational costs are all effectively used for project activities. The impact of the Project is still low at the time of Mid-term Review with respect to the Overall Goal. Overall prospect of sustainability of the Project is assessed relatively high though limited financial capacity of, mainly, CSIR/CMI is observed.

5.2 Recommendations

1) Project Design Matrix (PDM)

As a result of Mid-term review discussions, a draft PDM is designed, including indicators and important assumptions. Mid-term Review mission suggested ICC to finalize the draft PDM and approve it. The Project needs to put efforts to achieve these indicators during the remaining cooperation period.

2) Outreach for the application of research results

Some ideas/approaches for the application of research results were discussed during the Mid-term Review as follows. The Project needs to continue to clarify the potential of each idea with stakeholders.

- The Project can design functional specifications of the monitoring systems and procedures for mines to be able adopt for themselves.
- The Project can submit formal recommendations on "leading Code of Practice" to MOSH (a team within Chamber of Mines), rock mechanics practitioners at deep mines, organized labor, and MHSI (Mine Health and Safety Inspectorate, DMR).
- With conducting more CCBO survey, the Project can help improve the stress computer modeling.
- Knowledge developed by the Project can be included in training conducted by MQA (Mining Qualifications Authority). International/regional initiative such as AfricaArray can also be an arena for knowledge transfer.
- Uptake of the improved hazard management system by such a private organization as IMS can in effect

help transfer technologies to mines and geotechnical consulting companies.

3) To share information with related governmental organization

The Project has already a good communication network amongst research institutes. This should be expanded to other related organizations. Understandings of the potential of the Project outputs that can support their activities should be promoted through occasions like workshops, seminars and JCC.

4) Support for acquiring research budget

Responsible organizations in the government can support research institutions to get access to new budgets or research funds to continue research activities.

第１章　中間レビュー調査の概要

１－１　背景

鉱物資源に恵まれている南アフリカ共和国（以下、「南アフリカ」と記す）には、金、プラチナ、石炭などの鉱山が多数あり、鉱業全体で約 50 万人が就業している。そのうち、約 60%にあたる労働者が鉱石の採掘など坑内での労働に従事しており、鉱山災害の危険に晒されている。鉱山災害は、従来から南アフリカにおいて大きな社会問題となっているが、政府の指導及び鉱山会社の安全性向上への努力により、1980 年代後半には労働者 1,000 人あたりの年間犠牲者（死者）数が 1.00～1.20 人（犠牲者総数では 677～855 人/年）であったが、1990 年代を通じて犠牲者数は漸減し、2000 年代前半には同 0.56～0.75 人（犠牲者総数 246～290 人/年）にまで減少した。しかしながら、ここ数年は犠牲者数の減少傾向が停滞している。

これら鉱山災害犠牲者のうち約 4 割は、採掘活動によって岩盤が破壊され断層が生じることで発生する鉱山地震に起因する落盤事故によるものと言われている。また、鉱山地震は、採掘域や坑道などの落盤事故だけでなく地上にも建築物倒壊などの被害を及ぼすことがある。

鉱山地震のリスクは深度が深くなるほど高くなるため、採掘深度 3,000m を超える南アフリカの大深度金鉱山は特にリスクが高い。その原因は、地下 3,000m を超える大深度では、岩盤に巨大な圧力がかかっており、そこに採掘のための空隙を作ると岩石が圧力に耐えられず破壊し、断層を生じる可能性が高くなるためである。このような鉱山地震発生のメカニズムが存在する中で安全に採掘するためには、鉱山地震のリスクをより正確に評価し、評価結果に基づく採掘計画の修正や採掘活動の制限などによって鉱山地震被害を減少させることが極めて重要である。

他方、南アフリカの大深度金鉱山では、過去 19 年間にわたって日本の研究者によって鉱山地震の観測研究が行われ、その結果、地震の発生位置や大きさが事前にある程度予測可能になり、また震源となる断層の近くで観測することができることが分かってきた。かかる背景のもと、科学技術協力として採択されたものである。本プロジェクトでは鉱山内に観測機器を設置、鉱山地震の発生メカニズムを分析し、被害予測に役立てることを目的としている。また、ここで得られる科学的知見は、自然地震の発生メカニズムの理解促進に役立ち、地震の予知・予測研究に役立つことが期待されている。

2010 年 2 月に結ばれたプロジェクト実施に関する覚書の第 5 条に基づき、5 年間のプロジェクトの折り返し地点である 2013 年 2 月には、合同中間レビュー調査が実施されることとなった。

１－２　調査の目的

中間レビュー調査の目的は次の通り。

1) 日本側及び南アフリカ側の団員から構成される合同調査団による合同レビューを実施する。

2) マスタープランに基づき、プロジェクトの投入、活動・成果の進捗、実施プロセスを確認し、プロジェクト目標の達成見込みを検証する。

3) 評価5項目（妥当性、有効性、効率性、インパクト、持続性）の観点からレビューを行うとともに、プロジェクト実施の促進要因・阻害要因を分析する。

4) 調査結果に基づき、関係機関とも協議しながらプロジェクトの課題及び今後の対応方針に関する提言を抽出する。

5) 中間レビュー調査を踏まえた協議結果について、日本・南アフリカ実施機関の間の合意事項としてミニッツにとりまとめる。

１－３　プロジェクトの概要

2010年2月26日に署名された覚書（Memorandum of Understanding：MoU）中のマスタープランによるプロジェクトの概要は次のとおり。また、最新の活動計画は、2012年5月9日に開催された第2回合同調整委員会（Joint Coordinating Committee：JCC）で承認されたものである。

(1)　プロジェクト目標

地震の準備と発生についての理解が深まり、金鉱山地震の災害リスク管理体制が改善される。

(2)　成果

1. 震源の岩石の性質が明らかになる。
2. 鉱山地震の準備と前駆変化への理解が深まる。
3. 鉱山地震の発生を予測する精度が向上する。
4. 鉱山地震による採掘坑内での地震被害を予測する精度が向上する。
5. 地震の震源決定及び被害予測の精度が向上する。

１－４　調査団の構成

（日本側）

氏名	担当分野	所属
宮本　秀夫	団長／総括	JICA 地球環境部参事役
土井　ゆり子	協力企画	JICA 地球環境部防災二課
奥田　浩之	評価分析	合同会社適材適所
佐藤　雅之	オブザーバー	JST 上席主任調査役

（南アフリカ側）

氏名	担当分野	所属
Mr. Llanley Simpson	総括	DST 採鉱・選鉱工程　課長
Ms. Lisa du Toit	プロジェクト評価	DST 開発パートナーシップ　課長
Ms. Eudy Mabuza	プロジェクト評価	DST 開発パートナーシップ　課長補佐

１－５　調査日程

調査日程は以下のとおり。

Date		団長	土井	奥田	佐藤/JST
2/23	Sat			Dep Japan	
2/24	Sun			Arr. Pretoria 19:30 Meeting with Ms. Kanto from JICA SA Office	
2/25	Mon			09:30 - 15:30 Meeting with Prof. Ogasawara & Mr. Takashima @ Project Office (CGS Room 306)	
2/26	Tue			06:30 Move to JNB 08:50 - 10:00 Meeting at MHSC 10:30 - 12:30 CSIR CMI interview (Project Manager Prof. Durrheim, Dr. Milev and their team) 14:30 - 16:00 Wits Univ interview (Dr. Durrheim and his team)	
2/27	Wed			08:00 - 09:00 Interview with Mr.Thabo (DMR) @ MHSC 11:30 - 12:00 Visiting Goldfields 13:15 – 15:00 Hearing at Anglogold Ashanti Rock Engineering Department Move to Stilfontein 17:30 Briefing with Mr. Raymond and Mr. Gilbert for MK mine	
2/28	Thu			05:30 - 14:00 Moab Kotsong pick-up by Mr. Raymond from guest house 14:00 - 16:00 OHMS interview Move to Fochville	
3/1	Fri			05:15 - 12:00 Cooke 4 visit 12:30 – 13:15 Seismogen Hearing 14:00 – 15:00 Goldfield hearing	
3/2	Sat			Report Preparation	
3/3	Sun			Report Preparation	
3/4	Mon			Move from Carletonville to JNB 14:00 - 15:30 Ground Work hearing	
3/5	Tue		Dep. Japan	Move from JNB to Pretoria 10:00 - 12:30 CGS Courtesy call & Interview (Dr. Cichowicz and his team) 14:00 - 15:30 Meeting at Project Office	Dep. Japan
3/6	Wed		Arr. Pretoria	09:00 - 11:00 Draft Report Preparation @ JICA SA Office 12:00 - 13:00 DST for explanation of draft report (Ms. Lisa & Ms. Eudy)	Arr. Pretoria
3/7	Thu		(11:00) JICA SA Office (14:00 - 15:00) Coutesy call to Embassy of Japan		
3/8	Fri		Site visit to CGS	Report writing	Site visit to CGS
3/9	Sat	Dep. Japan	Writing up the Report		
3/10	Sun	Arrive.	Move from Pretoria to Fochville		
311	Mon	08:30 - 09:00 Goldfields Seismic Monitoring Centre 09:30 - 17:30 Seminar			
3/12	Tue	08:30 - 10:00 Pre-JCC meeting, 12:30 Meeting with JICA, 15:00 - Meeting with DST			
3/13	Wed	10:00 - 12:30 JCC at DST			Dep. Pretoria
3/14	Thu	(09:30 - 10:30) Reporting JICA SA Office (10:30) Dep. Pretoria, Arr. JNB Airport (13:50) Departure JNB EK762			
3/15	Fri	Arr Tokyo			

１－６　調査の手法

中間レビュー調査は、経済開発協力機構（Organisation for Economic Co-operation：OECD）が発行した「開発援助の評価のための諸原則（1991）」を踏まえて作成された「新 JICA プロジェクト評価ガイドライン第 1 版（2010 年 6 月）」に基づいて実施される。プロジェクトに対するレビュー調査の基準となるのは、プロジェクト目標、成果、活動が記載された当該プロジェクトのマスタープランである。

まず、プロジェクトに関する報告書や関連資料を参照しながら、JICA ガイドラインに提示された評価判断のための情報を整理するフレームワークとして、活動状況・進捗表と評価グリッドを用意した。そして、活動状況・進捗表については日本側研究者に記入を依頼するとともに、評価グリッドについては必要情報・データの収集のため南アフリカ側研究者向けの質問票を作成し、事前に配布した。現地調査中は、南アフリカ側研究者から質問票を回収してインタビューを実施し、その他関係者からもヒアリング調査を行うとともに、関連文献・資料を収集し、プロジェクトの観測サイトとなっている鉱山を訪問した。

報告書、活動状況・進捗表、インタビュー、質問票、サイト訪問などを通して収集した情報・データの整理と分析に基づいて、プロジェクトの進捗を確認するとともに 5 項目に基づくレビューを実施し、今後の活動に関する提言を抽出した。

5 項目（妥当性、有効性、効率性、インパクト、持続性）については、次の通りである。

妥当性	プロジェクト目標が、南アフリカの開発政策や社会ニーズ、日本の援助方針に対して、どの程度関連性があるかを評価する視点。
有効性	プロジェクトが目的を達成するために効果的に組み立てられ、その結果として、活動の進捗によるプロジェクト目標の達成見込みを分析する視点。
効率性	成果の産出に向けた投入の内容・量・質・タイミング等を整理して、これらが活動を通していかに効率的に成果に転換されたかを評価する視点。
インパクト	上位目標の達成に向けた進展のほか、プロジェクトの実施によって生じたプロジェクトの枠組み外における正・負の影響を調べる視点。
持続性	達成される成果や便益がプロジェクト終了後も維持されるかどうかについて、制度、技術、人材、財政の各観点から現時点での見通し。

第２章　プロジェクトの進捗

２－１　投入実績

（日本側）

1)　専門家派遣

2010 年 2 月 26 日の MoU 署名に続き、2010 年 8 月の業務調整員の派遣によりプロジェクトが開始された。プロジェクト開始から 2013 年 3 月までの間に、8 名の日本人研究者が、短期派遣で計 34 回、合計 749 日間派遣されている。2012 年 11 月には、業務調整員の交代があった。

2)　供与機材

微小破壊観測用センサー、高感度歪計、広帯域地震計、能動震源と受振用加速度計、動的応力変化計、傾斜計、データレコーダー等が Moab Khotsong 鉱山, Cooke 4 鉱山、及び KDC West 鉱山の観測サイトに設置されたほか、国立地震観測網ステーションが 10 基増設された。

3)　本邦研修

2012 年 11 月に、科学産業研究評議会（Council for Scientific and Industrial Research：CSIR）より 1 人の研究者が、東北大学及び東京大学地震研究所における高精度震源決定のための短期研修に参加した。

4)　現地業務費

日本側はプロジェクト活動実施のための活動費の一部を負担している。2010 年 8 月から 2013 年 1 月までの現地業務費の合計は、587 万ランドで、内訳はローカルコンサルタント委託費、物品購入費、旅費・交通費などとなっている。

（南アフリカ側）

1)　カウンターパートの配置

プロジェクトディレクター、プロジェクトマネジャーは科学技術省（Department of Science and Technology：DST）、CSIR から任命されている。中間レビューの時点では、JCC での承認に基づいて、CSIR、地球科学評議会（Council for Geoscience : CGS）、Witwatersrand 大学から 30 人の研究者がカウンターパートとして、また鉱山会社等から 11 人の技術者がプロジェクト活動に従事している。

2)　現地業務費

CSIR と CGS はプロジェクト活動実施のための活動費を負担し、2010 年‐2011 年の合計は、それぞれ 160 万ランド、80 万ランドとなっている。

２－２　成果・活動実績

詳細な活動実績については、添付資料（Joint Mid-term Review Report）中の「活動レベルの進捗

表」及び「対象鉱山のプロジェクト状況表」で記載している。

（成果 1）

- 対象 3 鉱山で、予定の探査ドリリングが 2012 年 9 月までに全て終了した。（合計約 70 本、総延長約 2.8km）。探査ドリリングは、JICA 予算でなく別予算（科学研究費補助金）を利用して行われた。岩石コア試料と孔内観察により、対象 3 鉱山ごとに、観測のターゲットとなる想定地震断層の位置が特定された。
- Cooke 4 鉱山（及び Mponeng 鉱山）で採取した掘削コア試料の一部は、物性や破壊特性を室内実験により計測・解析するため 2012 年 5 月に日本に輸出された。残りの試料は、Witwatersrand 大学岩盤工学部において圧列試験等の室内実験に供される予定である。

（成果 2）

- 探査ドリリング孔内に設置された観測機器は次のとおり。

a) Cooke 4 鉱山では、想定震源を取り囲む領域に、24 台の微小破壊観測用センサー及び 3 台の加速度計を三次元的に埋設し、データレコーダーの設置と合わせて、2010 年 12 月から 2 年以上微小破壊活動の観測が続いている。

b) Moab Khotsong 鉱山では、その他の研究予算（科学研究費補助金）を用いて、類似の微小破壊観測網を構築中である。データレコーダーが 2013 年 2 月に設置され、微小破壊活動の観測は 2013 年 4 月から開始される予定である。

c) 採掘に伴う岩盤変形観測のため、想定地震断層上に、高感度歪計（Cooke 4 鉱山では 2010 年 12 月、Moab Khotsong 鉱山では 2011 年 11 月、KDC West 鉱山では 2012 年 8 月）、傾斜計（Moab Khotsong 鉱山では 2013 年 1 月、KDC West 鉱山では 2012 年 6 月及び 11 月）、広帯域地震計（Cooke 4 鉱山）の設置が進み、Cooke 4 鉱山では完了、Moab Khotsong 鉱山でも約 80%の設置が完了している。

- 今後設置予定の機材としては、Moab Khotsong 鉱山における広帯域地震計（1 台）と傾斜計（1 台）、及び Moab Khotosong 鉱山と KDC West 鉱山における採掘現場の閉塞監視のための観測システムである。閉塞監視システム設置の遅れは、装置の開発と製造会社を探すのに時間がかかったことが主な原因である。
- 微小破壊観測網、傾斜計、歪計による観測は、先に行われた“南アフリカにおける日独地下微小破壊観測プロジェクト”（Japanese – German Underground Acoustic Emission Research in South Africa Project：JAGUARS Project）や“南アフリカ金鉱山における半制御実験プロジェクト”（Semi-controlled Experiment in South African gold mines：SeeSA）といったプロジェクトの成果を踏まえて展開されている。

（成果 3）

- ドリリング孔内に設置された観測機器は次のとおり。

a) Cooke 4 鉱山では、想定地震断層を挟んで直線上に、能動震源 1 台と受振用加速度計 3 台を埋設し、能動信号を用いた透過弾性波形の記録による断層の状態のモニタリングが行われている。

- 今後設置予定の機材としては、Moab Khotsong 鉱山における受振用加速度計（3 台）で、能動震源（2 台）については既に埋設済である。

- 前震的微小破壊活動を観測することにより、後続する将来の本震断層を検出できる可能性がある。これまでに、高感度・高密度の微小破壊観測センサーを用いた微小破壊の震源決定により、掘削面の前方岩盤内の地震発生リスクが高いと思われる面状構造を描き出すことに成功している。また、モニタリングシステム（ハードウェア）と自動震源決定システム（ソフトウェア）を合わせた総合システム構築の道筋が見え始めた。微小地震記録からの地震時の応力降下量推定など、描き出された面状構造の応力に関する多くの情報が得られることで、応力計算機予測モデルの較正と高度化にも貢献できる。

- 国際岩盤力学学会が提唱する日本の応力測定手法（円錐孔底ひずみ法）を、より小さい口径（BX size : 直径 60mm）でより容易に行えるように改良して、2013 年 1 月に Mponeng 鉱山（南アフリカの実測値としては最も深い 3.4km）、2 月に Tau Tona 鉱山（M1.5 の被害地震発生地点のすぐ近くの深さ 3.0km）での応力測定に成功した。Tau Tona 鉱山の応力（145 MPa, 4000 μstrain）は、前者よりも有意に大きいことが示された。

（成果 4）

- ドリリング孔内に設置された観測機器は次のとおり。

a) 震源断層極近傍で破壊前線の通過に伴う動的応力変化と断層変位を計測するための動的応力変化計（断層すべりと応力の急激な変化を観測する加速度計と高容量の歪計）が開発された。Cooke4 鉱山、KDC West 鉱山で掘削孔と断層の交差部を特定し、2010 年 12 月及び 2012 年 1 月に、それぞれの断層直近に動的応力変化計を埋設し、観測の継続、データの蓄積が進んでいる。

- 南アフリカ側の活動として、採掘現場における強振動記録システムを調達し、まもなく Moab Khotsong 鉱山及び KDC West 鉱山に 1 セットずつ設置する予定である。

（成果 5）

- CGS により金鉱山地域の南アフリカ国立地震観測網（South African National Seismograph Network : SANSN）設置が進行中であることから、これと同じ仕様の地表地震観測所（強震計）を、Cooke4 鉱山及び KDC West 鉱山が位置する Far West Rand 地域の地表に、2012 年 7 月までに 10 点すべての設置が完了した。

- CGS の Silverton データ・センターに、2012 年 7 月までにソフトウェア「Antelope」を始めとする地震解析システムが導入された。

２－３　プロジェクト目標に向けた進捗

プロジェクト活動の前半では、対象 3 鉱山において、ターゲット断層の 3 次元的な地質構造を把握しそれを取り囲む震源至近距離観測網の構築が行われた。Cooke 4 鉱山では、観測網の展開が 2010 年 12 月には完了し、ほぼ 2 年以上のデータ収録が続いている。Moab Khotsong 鉱山でも、日本側の活動のための機材の設置は約 80%完了し、南アフリカ側の活動のための機材（傾斜計、採掘現場の閉塞監視のための観測機器、強震計）もここ数週間のうちには設置される予定である。KDC West 鉱山での観測網設置もまもなく完了予定である。また鉱山地域である Far West Rand 地区の地表では、プロジェクトによる 10 観測点の増強が 2012 年 7 月には完了し、SANSN として機能している。

地震の準備・発生の理解促進に関しては、Cooke4 鉱山では、鉱山独自の地震観測よりも遥かに高感度・高精度の微小破壊観測用センサー網により、地震発生リスクが高いと思われる面状構造を描き出すことに成功し、その準静的拡大も捉えることができている。

金鉱山地震の災害リスク管理体制の改善については、改良された応力測定方法（円錐孔底ひずみ法）は一連の応力測定を 2.5 時間以内に完了できたことから、従来の応力測定と比べて極めて安価で鉱山内で実用可能な初めての応力測定手法となることが期待されている。

２－４　実施プロセス

日本側研究者と南アフリカ側研究者は、5 つの成果ごとに 5 つのグループに分かれて活動を進めている。鉱山技術サービス会社のスタッフ 3 人が、現在 JICA とローカルコンサルタント契約を結び、サイト・マネジャーとして観測機材設置等でプロジェクト活動を補助している。プロジェクト事務所は CSIR ではなく CGS に設置されている。

第３章　評価５項目に基づくレビュー

３－１　妥当性

下記の理由により、プロジェクトの妥当性は高いと判断される。

1) 震源として予想される断層に接近し、その至近距離に事前に立体的に観測網を配置して鉱山地震の発生を待ち構え、地震の準備と発生のメカニズムを詳細に観察できる環境は、地下約 1～3km の大深度を持つ南アフリカ金鉱山においてのみである。プロジェクトは、2012 年に発表された論文[1]に要約されているとおり、鉱山地震の発生位置や大きさの予測に利用できるような物理的パラメーター（応力、歪速度、傾斜率、微小破壊率、震源パラメーター、電磁放射率、マイクロクラック密度など）の変化が観測できる、という前提の上に立っている。プロジェクトでは、自然の地質構造の中での実際の地震において、こうした変化を初めて検証できる可能性がある。また、こうして得られる鉱山地震の発生構造の研究成果は、自然地震の解明にも資することが期待されており、本プロジェクト共同研究の意義は大きい。

2) プロジェクトは地震の準備と発生についての理解を深めるだけでなく、高感度観測網を設置して得られる情報によって金鉱山地震の既存の災害リスク管理体制の改善も目指しており、南アフリカ社会のニーズにも応えている。南アフリカでは、1990 年代から、民間の鉱山技術サービス会社である IMS〔Institute of Mine Seismology（旧 ISS International 社）〕の地震観測システムと、その観測結果に基づいて地震パラメーターを算出して危険度ランクを示す地震リスク評価スキームが広く使われている。Geophone（地震計）を用いた、その地震観測システムの感度は M>-1 である。一方、プロジェクトで設置した微小破壊観測用センサーの感度は M>-4 であり、併せて 100m 四方の岩石の中に傾斜計、歪計、受振用加速度計などが設置されている。かってない規模の高精度・高感度観測網を想定震源の至近距離で構築し、そこから得られるデータにより、プロジェクトは南アフリカの既存の地震発生予測スキームの高度化に貢献することも目指している。

3) 南アフリカの政府担当機関である鉱物資源省（Department of Mineral Resources：DMR）や鉱山保健安全評議会（Mine Health and Safety Council：MHSC）は、更に深度の大きい鉱脈において安全で経済的な採掘を進めていくことの重要性を強調している。MHSC は中間レビューにおいて初めてプロジェクトの内容・進捗を知らされたが、研究成果が鉱山の安全性向上にかかる実用的な技術につながることに大きな関心を持っている。また、MHSC によると、本プロジェクトは鉱山の安全性向上に貢献する南アフリカ唯一の国際協力プロジェクトとのことである。

4) プロジェクトは、実施機関である CSIR 鉱山イノベーションセンター（Center for Mining Innovation：CMI）及び CGS の研究方針・ニーズと整合している。CSIR/CMI では、「鉱山

[1] DURRHEIM, R.J. and OGASAWARA,H.　Can mine tremors be predicted? Observational studies of earthquake nucleation, triggering and rupture in South African Mines, in *Proceedings of the Second Southern Hemisphere International Rock Mechanics Symposium,* The Southern African Institute of Mining and Metallurgy, Johannesburg, 2012. Pp.327-343.

における心身への影響評価」、「リアルタイムのリスク管理技術の促進」、「新たな採掘方法の開発」の 3 つのテーマに基づいて研究が行われている。プロジェクトが貢献している鉱山地震に関わる研究は、「リアルタイムのリスク管理技術の促進」のテーマに含まれる。Witwatersrand 大学は、2012 年 9 月に「ウィッツ鉱業研究所（Wits Mining Research Institute：WMRI）」を設立し、鉱業セクターと関連部門の持続性を高めるための研究を進めている。CGS についても、2010 年以前は地震観測所が数ケ所しかなかったが、その後「南アフリカ国立地震観測網（SANSN）」として 50 ケ所以上の観測所を設置しており、うち 10 ケ所はプロジェクトにより設置されたものである。

5) 科学技術は、日本と南アフリカの 2 国間協力における重点分野の 1 つであり、2013 年 3 月 1 日に開催された「第 12 回日・南ア・パートナーシップ・フォーラム」においても、前日の 2 月 28 日に貿易投資、開発、科学技術の 3 つの作業部会が開催され、実務レベルの議論が行われている。科学技術セッションでは、2 国間の共同研究開発プロジェクトに関する進捗が確認された。また、日本政府の対南アフリカ共和国への国別援助方針（2012 年 12 月）の事業展開計画においても、同プロジェクトは、重点分野「産業人材・高度人材育成支援」のなかの「相互協力を通じた高度人材育成プログラム」の中に位置づけられている。

３－２　有効性

下記の理由によりプロジェクトの有効性は中程度と判断される。

1) 全体として、プロジェクト活動は成果 1～5 の各レベルで着実に進展している。ドリリング工事（合計約 70 本、総延長約 2.8km）、孔内のスコーピングと清掃、観測機器の設置、データの収集までの一連の作業は複雑で手間のかかる工程であるが、プロジェクトは現時点までで機材設置をほぼ終えており、地震観測のためのデータを収集し始めている。中間レビュー時点では、プロジェクト期間内でのプロジェクト目標の達成を阻害する特段の要因は認められない。鉱山の採掘計画が変更されないこと、鉱山ストライキが起こらないこと、ターゲットとしている大きさ（M2 レベル）の地震が発生すること、等の幾つかの外部条件はあるものの、協力期間内のプロジェクト目標達成が見込まれる。

2) プロジェクトは JICA、独立行政法人科学技術振興機構（Japan Science and Technology Agency：JST）からの予算に加えてその他の研究予算も同時に活用してプロジェクト活動を進めており、目標達成に向けた有効性を高めている。ドリリング工事の実施や一部の観測機器の購入については、科学研究費補助金、「地震及び火山噴火予知のための観測研究計画」予算も活用された。

3) プロジェクト目標に含まれる研究成果の社会実装については、中間レビューを契機にその具体的な道筋・アプローチについての議論が始まったばかりである。今回、中間レビューの中で様々な可能性が提案されたので、今後その実現に向けて議論を進めていくことが重要である。

4) 2010 年 2 月に署名された MoU に添付されたマスタープランには指標が設定されていないため、プロジェクトは、プロジェクト終了時の達成指標を明確に設定することで、更に高

い有効性が期待できる。

３－３　効率性

下記の理由により、プロジェクトの効率性は高いと判断される。

1) 2010 年 2 月 26 日に署名された MoU に添付のマスタープランについては、内容は明瞭であり、プロジェクト実施機関の間での目標・成果・活動に対する理解度は高い。2012 年の鉱山ストライキ期間中は坑内への立ち入りが出来なかったため、2012 年 5 月 9 日の第 2 回 JCC にて承認された活動計画から幾つかの遅れは見られるものの、プロジェクトの進捗は順調である。

2) 日本側の投入は効果的に使われており、南アフリカ側からも高い評価の声がきかれた。2010 年の MoU の中で、JICA が行うべき投入として、専門家派遣、供与機材、本邦研修が記載されている。日本側研究者は、プロジェクト実施に対して高いコミットメントを持って臨んでおり、例えば日本側チーフアドバイザーは、プロジェクトに従事するため実質上の研究休暇をとり、プロジェクト開始以降の 2.5 年間で南アフリカ滞在日数は 341 日に達している。予定された機材の調達は、業務調整員、CSIR、立命館大学の努力により 2012 年中に全て完了した。本邦研修については、2012 年 11 月に、CSIR より 1 名の研究者が、東北大学及び東京大学地震研究所での短期研修に参加した。2013 年には、Witwatersrand 大学の岩盤工学部より 2 名の研究者が、独立行政法人産業技術総合研究所での研修に参加予定である。

3) MoU にて合意された南アフリカ側の投入（カウンターパートの配置、事務所スペースと設備、プロジェクト実施に必要な経費）についても、日本側と同様に効果的に使われている。30 名の研究者がプロジェクトに関わっているが、南アフリカ側のカウンターパートの変更は最小限であり、日・南アフリカの研究者間の協力関係は非常に安定している。ただし、カウンターパートの中には、その他の業務との兼ね合いからプロジェクトに関わる時間が十分取れていないという指摘もあった。CGS と CSIR は、ともに独自予算からプロジェクトの活動費の一部を支出している。

4) プロジェクト実施の効率性が高いのは、鉱山会社からプロジェクト活動への理解・協力が得られているためでもある。調査サイトのある鉱山を持つ鉱山会社は、プロジェクトに対して機材の設置場所の提供、通気パイプの設置、プロジェクトのための竪抗エレベーターの稼働等の便宜供与を図ってきている。鉱山会社からはまた研究協力者として 11 人の技術者がプロジェクト活動に従事している。

5) 日本側研究者、南アフリカ側研究者の間のコミュニケーションは非常に良好である。プロジェクトはこれまで 2 回の JCC を開催しており（第 1 回 2011 年 4 月 19 日、第 2 回 2012 年 5 月 9 日）、DMR、日本大使館、JST からのオブザーバー参加もあった。成果ごとに分かれている 5 つの研究者グループ間のコミュニケーションについては、成果 1～4 のグループ（CSIR と Witwatersrand 大学）と成果 5 のグループ（CGS）の間のやり取りはそれほど密ではないことが指摘された。これはプロジェクトにおいて地表地震観測網と地下観測網と

の連結は意図されていないためである。現時点では、両グループは情報交換のためのやり取りを維持している。

6) プロジェクトの促進要因としては、主に次の 3 点が挙げられた。

- 鉱山会社の経営陣や岩盤工学の現場従事者からの、プロジェクト活動の実施に対する理解と多大な支援
- プロジェクトが雇用したコンサルタント〔(鉱山技術サービス会社である) OHMS (Open House Management Solutions Ltd.)、Seismogen のスタッフ〕の機材設置等に関する働き
- 日本側研究者、南アフリカ側研究者、鉱山会社との間の長年の良好な研究協力関係

7) 他方、次の点がこれまでのプロジェクトの阻害要因として挙げられた。

- 鉱山ストライキとそれに伴う入坑停止
- 鉱山内でのケーブルや機材の盗難
- 貴金属を含む岩石標本を日本に送るための手続きと認可の遅れ

３－４　インパクト

プロジェクトのインパクトは、上位目標に向けた進展の観点からは、中間レビュー時点ではまだ低いと判断される。しかしその他については、幾つかの重要なインパクトが認められる。

1) プロジェクト成果の鉱山での採用・活用といった上位目標に向けた進展は、今後プロジェクトの後半において徐々に発現してくることが見込まれる。プロジェクト活動の前半では、対象 3 鉱山における観測サイトの決定、観測機器の調達、震源至近距離観測網の構築が活動の中心であった。観測網の設置を通して、鉱山技術サービス会社（OHMS 及び Seismogen）の技師、技術者や CSIR の研究者が知識と経験を得ることができた。

2) 現時点での重要なインパクトとしては、本プロジェクトに関わる研究者に対して、民間会社 IMS が主催する国際セミナーでの講演など、国際会議での発表依頼が増えていることが挙げられる。この他にも、チリ（2010 年）及びオーストラリア（2012）での大深度高応力下における鉱山セミナー、アメリカ地球物理学秋季会議（2012 年）、南アフリカにおける南半球国際岩盤力学シンポジウム（2012）、中国における岩盤力学・新開発シンポジウム（2012）等で、プロジェクト研究内容に関する講演が行われた。IMS が主催する年次の国際セミナーでの講演は 2009 年から続いており、今年は 2013 年 3 月 18～19 日にオーストラリアのホバートで開催され、プロジェクトマネジャーとチーフアドバイザーが参加する予定である。

3) プロジェクトで導入された幾つかの技術については、既に鉱山会社、鉱山技術サービス会社が独自での利用を検討していることも、インパクトの 1 つとして挙げることが出来る。具体的には、微小破壊観測用センサーについては鉱山会社が自社の鉱山の 1 ケ所に設置を検討しており、改良応力測定方法（円錐孔底ひずみ法）については、鉱山技術サービス会

社が日本から技術者を招聘しての試験的な実施を予定している。

4) プロジェクトが支援した CGS のデータ解析センターは、Far West Rand 地域だけでなく、KOSH（Klerksdorp-Orkney-Stilfontein-Hartebeestfontein）地域、Central Rand 地域の地表地震観測網にも利用されている。

３－５　持続性

以下の理由により、プロジェクトの持続性の見込みは比較的高いと判断できる。

1) プロジェクトの内容は CSIR/CMI 及び CGS の業務と合致していることから、体制的な観点からは継続・発展に適したものとなっている。ただしプロジェクト関係者からは、鉱業セクター関連の政策に一貫性が欠けていること、現在進行中の鉱山国有化に関する議論、鉱山の所有会社の頻繁な交代（それにともなう鉱山名の変更）、鉱山研究者の減少などに対する言及があり、南アフリカの金鉱業は全体としては顕著な衰退傾向にあることが指摘された。政府や民間企業の鉱業に関連する研究活動への投資もここ 20 年で大きく減少している状況にあるが、こうした傾向の中にあって、CSIR/CMI と CGS のプロジェクト活動に対するコミットメントは高い。

2) 技術的な観点からは、特に設置機材の持続的な利用を検討する必要がある。プロジェクトで供与し岩盤中に設置されたセンサーやケーブル等の観測機材は、モルタルで埋設されているため、当初の観測目的が終わっても回収・再利用されることはない。センサーは近傍で採掘活動が行われている数年間は観測に利用されるが、採掘が他の場所へ進んでしまった段階で当初の役割を終える予定である。ただし、データレコーダーについては埋設されていないため、回収・再利用される。一部のセンサーは、閉山後の地震観測のため CGS が引き続きデータ収集に利用することを検討している。CGS の地表地震観測所については、全て CGS の予算によるメンテナンス、データ収集が行われており、その持続性に問題はない。

3) 人材的な観点では、CSIR は、予算の削減はあるものの現在の人員レベルの維持を見込んでいる。一方 CGS は、地球科学に関する法律の改正（2010 年）に基づいて、近年は正規職員の人員増が続いており、鉱山地震学に関してもより多くの知見の集積が期待される。CSIR、CGS によれば、プロジェクトは若手研究者育成の良い機会となっており、両機関の人材的な能力強化にも寄与している。

4) CSIR の予算は、その半分以上を政府機関、民間セクターとの研究契約締結に拠っていることから、予算的な観点からは、安定した持続性が見込めるわけではない。CSIR は、DST を通して政府から年間研究費を受け取っているが、これは全体予算の 40％程度である。残りの予算については、中央・地方・市町村レベルの政府機関、民間セクター、南アフリカ国内や海外の資金支援団体（例えば MHSC）との研究契約から来ている。こうした中で、これまで鉱山安全管理の研究支援を行ってきた MHSC は、近年は基礎研究への資金支援は行っていない状況である。

5) 鉱山会社、鉱山技術サービス会社が、プロジェクトで導入された観測手法の有効性を認め

て、一部を自社システムに取り入れ始めている。今後プロジェクト成果が実用的な観測モデルにつながった場合、利用される可能性は高いと考えられる。

第４章　科学技術視点からの評価

総合評価（A+：初期の計画をやや上回る取り組みが行われており、大きな成果が期待できる。）

地震発生過程の研究への貢献について、現時点ではまだブレークスルーに至る展望にはやや欠けるところがあるものの、日本国内では不可能ともいえる地下深部での観測データの取得が進み、貴重なデータが得られつつあることは高く評価できる。今後の鉱山掘削の進展につれて、これまでに構築された観測網の中で比較的規模の大きい地震の発生も予想されていることから、新たな発見の可能性は持続している。

一方、当初は少し不安視された研究活動を通した鉱山安全面への貢献については、研究成果の活用という面も含めて、応力測定法の改良により鉱山活動の安全評価の高度化に貢献しつつある。それに地表における地震観測網の整備なども含め、安全面への貢献は当初の期待以上である。

研究面でさらなる進展があれば、最終的には S 評価も十分に望める。AE に関して膨大なデータが取得されているが、現状では従来の地震学分野での一般的データ処理に終わっている感がする。貴重なデータであるがゆえに、もう少しきめ細かい解析を望みたい。

第５章　結論及び提言

プロジェクトの進捗は概ね順調であり、特に大きな課題は認められなかった。研究成果の社会実装については、今回の中間評価の議論の中で様々な可能性が示唆された。

大別すると以下の通り。

- 研究論文に基づく鉱山会社の自主規定（Security Code）に対する提言
- 現在、南アフリカの鉱山で導入されている安全管理システムを管理運営する民会会社 SMI の監視システムの改善を通じた安全管理体制の向上
- Chamber of Mining[2]、Mining Qualifications Authority[3]等資格付与・研修実施機関におけるプロジェクト成果の活用
- 第三国研修などによる、近隣諸国への普及

これらの可能性の中からどれが一番実現性が高いかは、中間評価時点で確定することは非常に困難であるものの、政府内の担当組織のうち、DMR、MHSC、Chamber of Mining、鉱山資格局（Mining Qualifications Authority：MQA）などは重要な機関となると思われる。これらの組織とこれまで情報共有はあまり行われてこなかったことから、プロジェクト成果についての情報共有を図る必要がある。また各組織の ToR も含めて、実際にどのような可能性があるかを今後検証していく必要がある。JCC での議論を受け、DST から DMR に対して働きかけを行うことが検討されている。

また供与機材については、地中に固定されている歪計等を回収することは困難であり、採掘現場も移動することから、プロジェクト終了後継続して使用される可能性はほとんどない。一方で、プロジェクトによって設置された 3 鉱山の観測網のうち、プロジェクト終了時には閉山となる見込みが高いものについては、閉山後の鉱山洪水の監視のために CGS が観測体制を引き継ぐ可能性が示唆された。現時点ではデータの回収にプロジェクト関係者は注力しているが、プロジェクトの最終段階までにはプロジェクト終了後の機材や観測データの管理体制について方針を定める必要がある。今回の JCC でプロジェクト関係者はこの必要性を認識しており、今後関係者間で議論されることが期待できる。

本中間評価を通して行われた提言は以下の通り。

1) プロジェクト・デザイン・マトリックス（Project Design Matrix：PDM）

　プロジェクトは、プロジェクト終了時の達成指標を明確に設定することで、更に高い有効性が期待できるが、2010 年 2 月に署名された MoU に添付されたマスタープランには指標が設定されていなかった。終了時評価では、プロジェクトの達成度は主に指標の達成度合に基づき判断される。中間レビューは、これまでの成果・活動の進捗確認に基づき、プロジェクト終了時における現実的で実現可能な目標のイメージを関係者間で共有して、指

[2] 民間鉱山会社の代表によって作られている業界団体。環境、健康、Skill Development、安全に関する部局があり、DMR、MHSC の Committee へ参加している。

[3] 鉱業セクターに対する人材育成を担当する組織。対象は鉱夫からエンジニアまで多岐にわたる職業訓練セクターからのインプットを受けて Strategy、研修コースデザインを行っており、実際の研修は関係組織と共同実施をしている。

標として設定する良い機会である。

中間レビューでの議論の結果、既にマスタープランに含まれているプロジェクト目標、成果、活動のほか、指標、外部条件の記載を加えた PDM 案が作成された。本 PDM 案は JCC での議論を通して最終化し、承認されるべきである。

2) 研究成果の社会実装

金鉱山地震の災害リスク管理体制の改善に資する研究成果の社会実装については、今回の中間レビューにおいてプロジェクトのメンバーとの間で議論され、様々な可能性が示唆された。プロジェクトはこれらの可能性の実現に向けて関係者と議論を深めていく必要がある。

地球規模課題対応国際科学技術協力（Science and Technology Research Partnership for Sustainable Development：SATREPS）は、共同研究の促進とともに、そこで得られた知見の社会への還元も目的としている。坑内災害の軽減に向けては、研究成果としての観点からは、プロジェクトは少なくとも鉱山地震の準備と前駆変化を検知できる現実的な方法があるのかどうかを決定し、それが査読付きの論文や国際的な専門家会議で学術的に認められることが前提である。一方、既存のシステムの改良といった実用技術の観点からは、プロジェクトは災害リスク評価に利用できる改良応力測定方法（円錐孔底ひずみ法）を、既に 2 つの鉱山と 2 つの鉱山技術サービス会社に移転できている。このように、学術論文による発表を経なくとも移転できる坑内災害の軽減に資する技術もあることも踏まえて、中間レビューでは幾つかの具体的な道筋・アプローチが議論された。

- 微小破壊観測用センサー、高感度歪計等の観測網が鉱山地震の発生予測観測に有用であることが証明された場合は、鉱山会社が利用できるような実用的な観測網仕様の提案。
- 学術論文としての承認を踏まえて、鉱山会社が各自定めている「安全管理規則（Code of Practice）」改訂に際しての提言を、鉱山経営会社の団体である鉱山会議所（Chamber of Mines）の鉱山労働安全保健チーム（Mining Industry Occupational Safety and Health：MOSH）、大深度鉱山における岩盤工学の現場従事者、労働組合、DMR、鉱山保健安全監督局（Mine Health and Safety Inspectorate：MHSI）に提出。
- 改良応力測定方法（円錐孔底ひずみ法）の測定に基づく、応力計算機予測モデルの高度化。
- 鉱山のための教育・訓練支援を行う MQA の教科課程の中に、プロジェクトの実施により得られた知識・知見を反映。また、アフリカの地球科学研究者への研究・研修を支援する AfricaArray といった国際的なイニシアティブを通しての知識の普及。
- 南アフリカ鉱山で導入されている安全管理システムを開発・提供する民間会社 IMS によるプロジェクト成果の採用を通しての、鉱山会社の災害リスク管理体制の改善。IMS は、鉱山での岩盤工学に関する手法・技術の、世界最大の研究開発、技術サービス会社である。

3) 政府機関との情報共有

中間レビューでは政府関係機関はプロジェクトの成果に高い関心を持っていることも確認されたため、ワークショップ、セミナー、JCC などの機会を通して、DMR、MHSC、MQA などの関係機関との情報共有を進めていくことが重要である。

4) 研究予算の獲得支援

鉱山安全管理研究に対する資金支援が大幅に削減されてきていることから、政府関係機関は、新たな予算や研究基金に対する研究機関のアクセスを支援していくことが望まれる。

添付資料 A.1　面談者リスト

1　南アフリカ側			
1)　カウンターパート機関及び協力機関			
1	Prof. Ray Durrheim	CSIR/Witwatersrand Univ.	2/26
2	Dr. Alexander Milev	Principal Scientist, CSIR	2/26
3	Mr. Benon M Kagezl	Senior Research Engineer, CSIR	2/26
4	Dr. Jan Kuijpers	Technical Consultant, Rock Engineering, CSIR	2/26
5	Mr. Van Zyl Brink	Competence Area Manager, Real Time Risk Management, CSIR	2/26
6	Mr. Pieter Share	MSc Witwatersrand Univ. / CSIR	2/26
7	Mr. Gideon Ferreira	CSIR	2/26
8	Mr. Siyanda Mngadi	Student, Witwatersrand Univ.	2/26
9	Mr. Geroge Henry	CSIR	2/26
10	Dr. Declan Vogt	Strategic Research Manager, CSIR	2/26
11	Dr. Halil Yilmaz	Senior Lecturer, School of Mining Engineering, Wits Univ.	2/26
12	Mr. Tawanda Zvarivadza	Research Student (Junior Lecturer), School of Mining Engineering, Wits Univ.	2/26
13	Mr. Ali Sarfraz	PhD Scholar, Wits Univ.	2/26
14	Mr. Simon Sebothoma	Honours Student, Wits Univ.	2/26
15	Prof. Fred Cawood	Head of School, School of Mining Engineering	2/26
16	Mr. Daniel Fale	Seismic Department, Goldfields	2/27
17	Mr. Jomo	Seismic Department, Goldfields	2/27
18	Mr. Richard Masetue	Seismologist, Wits Univ and Goldfields	2/27
19	Mr. Shaun Murphy	Vice President of Geotechnical, Anglogold Ashanti	2/27
20	Mr. Gerhard Hofmann	Senior Mine Sesmologist, Anglogold Ashanti	2/27
21	Mr. Johan Egelbrecht	Moab Khotsong	2/28
22	Mr. Peter Watsoal	Moab Khotsong	2/28
23	Mr. Stephan van Aswegen	Moab Khotsong	2/28
24	Mr. Vlok Visser	Director, OHMS	2/28
25	Mr. Tony Ward	Ezulwini Shaft Rock Engineer, Director, Seismogen	3/1
26	Mr. Luiz Ribeiro	Geotchnical Systems Administrator, MCSE, Seismogen	3/1
27	Mr. Kevin Riemer	Group Seismologist, Sibanye Gold (ex. GoldFields), Driefontein Gold&Mine	3/1
28	Mr. Phil Piper	Managing Director, Groundwork	3/4
29	Dr. Artur Cichowicz	Senior Specialist, SeismologyUnit, CGS	3/5
30	Mr. Robert Kometsi	Seismic Instrumentation, CGS	3/5
31	Mr. David Ngobeni	Seismic Moment Tensor Solutions	3/5
32	Mr. Denver Birch	3DEC (3D-Distinct Element Code) Modelling, CGS	3/5

33	Mr. Ganesh W. Rathod	Seismic Hazard, UDEC (Universal Distinct Element Code), CGS	3/5
34	Mr. Azangi Mangongolo	Seismologist, Seismology Unit, CGS	3/5
2)	政府関係機関		
1	Mr. Navin Singh	Chief Research & Operation Officer, MHSC	2/26
2	Mr. Thabo Dube	DMR (Acting CEO, MHSC)	2/27
3	Mr. David Molapo	Chief Financal Officer, MHSC	2/27
2	日本側		
1)	プロジェクト		
1	Prof. Hiroshi Ogasawara	College of Science and Engineering, Ritsumeikan Univ.	2/25
2	Mr. Jun Takashima	Project Coordinator	2/25
3	Mr. Raymond Vermeulen	Site Manager, OHMS	2/27
4	Mr. Gilbert Morema	Underground Site Manager, Seismogen	2/27
5	Mr. Thabang Masakale	Site Manager, OHMS	3/1
7	Dr. Takashi Satoh	Active Fault and Earthquake Research Center, GSJ/AIST	3/11
8	Dr. Yasuo Yabe	Associate Professor, Graduate School of Science, Tohoku University	3/11
2)	日本大使館及び JICA 南アフリカ事務所		
1	Ms. Yuko Kanto	Project Formulation Advisor	2/24
2	Mr. Mpho Pekane	Program Officer	3/6
3	Mr. Masao Shino	Representative	3/6
4	Mr. Toshiyuki Nakamura	Chief Representative	3/7
5	Mr. SxEKI Tomohiro	Senior Representative	3/7
6	Mr. Ken Okaniwa	Minister, Embassy of Japan	3/7
7	Mr. Yasushi Naito	Counselor, Embassy of Japan,	3/7
8	Mr. Tomohide Yamada	First Secretary, Economic Division, Embassy of Japan	3/7
9	Ms. Namiko Yamada	Special Researcher for Economic Affairs, Embassy of Japan	3/7

添付資料 A.2　PDM 案（仮訳）

プロジェクト名：（科学技術）鉱山での地震被害低減のための観測研究プロジェクト
協力期間：5 年間（2010 年 8 月～2015 年 8 月）
実施機関：DST、CSIR、CGS、Witwatersrand 大学、立命館大学、東京大学、AIST
受益者：実施機関の研究者、プロジェクトサイトの鉱山会社、鉱山技術サービス会社、鉱山労働者

Version 1: 2013 年 3 月

プロジェクト要約	指標	指標の入手手段	外部条件
【上位目標】 プロジェクトにより開発された地震リスク評価手法と管理体制が南アフリカ及び世界の鉱山で利用される。	-	-	
【プロジェクト目標】 地震の準備と発生についての理解が深まり、金鉱山地震の災害リスク管理体制が改善される。	1. プロジェクトの成果が少なくとも 5 つの国際的な専門家会議で報告される。 2. 鉱山会社が各自定めている「安全管理規則（Code of Practice）」改訂に際しての提言が、鉱山会議所（Chamber of Mines）鉱業労働安全保健チーム（MOSH）、岩盤工学の現場従事者、労働組合、鉱物資源省（DMR）鉱山保健安全監督局（MHSI）に提出される。 3. 少なくとも 2 つの移転された技術が南アフリカ鉱山で採用される。 4. 少なくとも 4 人の若手研究者が、プロジェクトに関係する研究において上級学位を取得する。	プロジェクト報告書 ヒアリング	CSIR、CGS、鉱山会社が、プロジェクト終了後も独自に活動を継続する。
【成果】 1. 震源の岩石の性質が明らかになる。	1-1 観測のための地震想定断層（3 ケ所）が特定される。 1-2 震源の岩石の性質に関する研究報告書（1 件）が発表される。	プロジェクト報告書 研究報告書	プロジェクト目標に向けて、それぞれの成果が十分に.達成される。
2. 鉱山地震の準備と前駆変化への理解が深まる。	2-1 観測サイト（3 ケ所）が構築される。 2-2 地震の準備と前駆変化に関する論文（3 本）が発表される。	プロジェクト報告書 学術誌	鉱山会社の協力が継続する。

3. 鉱山地震の発生を予測する精度が向上する。	3-1 応力変化と岩盤不安定性に関する論文（3 本）が発表される。 3-2 鉱山会社が利用できるような地震予測観測網の実用的な仕様が設計される。	プロジェクト報告書 学術誌	
4. 鉱山地震による採掘坑内での地震被害を予測する精度が向上する。	4-1 地震想定断層上の動的応力変化に係る論文（少なくとも 1 本）が発表される。 4-2 地震動予測のための情報に関する論文（2 本）が発表される。（地表及び採掘現場）	プロジェクト報告書 学術誌	
5. 地震の震源決定及び被害予測の精度が向上する。	5-1 データ・センター改善と自動データ解析に関する CGS 報告書（1 本）が発表される。 5-2 地表におけるより正確な地震動予測のために得られるパラメーターに関する CGS 報告書（3 本）が発表される。	プロジェクト報告書	
【活動】 1.1 想定震源域で岩石試料を採取する。 1.2 実験室で岩石試料の物性を調査する。 2.1 想定震源域の周辺で微小破壊観測システム、岩盤変形観測装置、及び高感度長周期地震計を設置する。 2.2 想定震源域での微小破壊活動を観測する。 2.3 想定震源域での応力蓄積、緩和の兆候を観測する。 2.4 観測結果を解析し、本震発生前の前駆現象とその特性を明らかにする。 3.1 微小破壊活動によって発生する多数の小さな地震のデータから想定震源域の詳細な応力の時空間分布や岩盤の安定度を評価する。 3.2 上記 2-2, 2-3 及び 3-1 を用いて、南アフリカ金鉱山で用いられている地震危険度評価を較正し、リ	【投入】 （日本側） 1) 専門家派遣 - 震源の岩石分析 - 震源近傍観測 - リスク評価 - 震源の動的破壊過程 - 地表地震観測網（SANSN） 2) 供与機材 - 微小破壊、岩盤変形、動的破壊観測 - 地表地震観測 - データ解析 - 事務用機材 - その他必要な機材 3) 本邦研修 4) 現地活動費		1. 鉱山の採掘計画が変更されない。 2. 鉱山ストライキが起こらない。 3. ターゲットとする大きさの地震が発生する。

スク評価手法を改善する。 4.1 想定震源域の極近傍に、断層すべりと応力の急激な変化を観測する加速度計、低感度歪計を設置する。 4.2 上記 4-1 による観測データを解析し、震源での岩盤の破壊と強震動の生成の過程を明らかにする。 4.3 想定震源域付近の採掘域に強震計、地震計を設置し、採掘域での地震動を観測する。 4.4 震源近傍と採掘域での地震動を比較して地震動の増幅特性を明らかにする。 4.5 動的応力変化、断層変位の観測結果と既存の室内実験結果を比較し、動的破壊過程の相似則を解明する。 5.1 Far West Rand 鉱区に、新たな地表地震観測所を設置する。 5.2 地球科学評議会 Silverton 事務所のデータ・センターの地震解析システムを改善する。 5.3 鉱山地震による地表部の地震動を予測するモデルを開発・検証する。	（南アフリカ側） 1) カウンターパートの任命 - 震源の岩石分析 - 震源近傍観測 - リスク評価 - 震源の動的破壊過程 - 地表地震観測網（SANSN） 2) 事務スペースと設備 - JICA 専門家の職務のための事務スペース・設備 - 機材設置のための土地・スペース - その他必要な設備・施設 3) プロジェクト活動費 4) 鉱山会社の協力	 【前提条件】

DST（Department of Science and Technology 科学技術省）、CSIR（Council for Scientific and Industrial Research 科学産業研究評議会）、CGS（Council for Geoscience、地球科学評議会）、AIST（National Institute of Advanced Industrial Science and Technology 産業技術総合研究所）, MOSH（Mining Industry Occupational Safety and Health, Chamber of Mines 鉱山会議所の鉱業労働安全保健チーム）、SANSN（South African National Seismograph Network 南アフリカ広域地震観測網）, MOU（Memorundum of Understanding 覚書）, MHSI（Mine Health and Safety Inspectorate, Department of Mineral Resources 鉱物資源省鉱山保健安全監督局）

付　属　資　料

協議議事録（Minutes ofMeeting）及び Mid-term Review Report

MINUTE OF MEETINGS
BETWEEN
THE JAPANESE MID-TERM REVIEW TEAM
AND
THE AUTHORITIES CONCERNED OF THE GOVERNMENT OF SOUTH AFRICA
ON
JAPANESE TECHNICAL COOPERATION FOR
THE PROJECT FOR OBSERVATIONAL STUDIES IN SOUTH AFRICAN MINES TO MITIGATE SEISMIC RISKS
IN THE REPUBLIC OF SOUTH AFRICA

The Japanese Mid-term Review Team (hereinafter referred to as "the Team"), organized by Japan International Cooperation Agency (hereinafter referred to as "JICA") headed by Mr. Hideo Eguchi visited South Africa from February 24, 2013 to March 14, 2013 for the purpose of conducting the Mid-term Review on the Japanese technical cooperation for the Project for Observational Studies in South African mines to Mitigate Seismic Risks (hereinafter referred to as "the Project").

During its stay, the Team exchanged views and had a series of discussion with the South African authorities concerned. And the Joint Coordinating Committee (hereinafter referred to as "JCC") was held on March 13, 2013.

After discussions in respect of recommendations and issues for the successful implementation of the Project, the JCC approved the mid-term review report as attached hereto (Appendix 1) and the respective representatives of the South African side and the Japanese side agreed to the matters referred to in the documents attached hereto and forward it to the respective Governments.

Pretoria, March 13, 2013

Mr. Hideo Miyamoto
Leader
Mid-Term Review Team
Japan International Cooperation Agency

Mr. Llanley Simpson
Director
Mining and Mineral Processing
Department of Science and Technology
The Republic of South Africa

Appendix 1

Joint Mid-term Review Report

For

the Project for Observational Studies in South African Mines to Mitigate Seismic Risks

13th March, 2013
Joint Mid-term Review Team

Abbreviations

AIST	National Institute of Advanced Industrial Science and Technology
CCBO	Compact Conical-ended Borehole Overcoring technique
CGS	Council for Geoscience
CMI	Center for Mining Innovation (CSIR)
COM	Chamber of Mining
CSIR	Council for Scientific and Industrial Research
C/P	Counterpart
OECD-DAC	Organisation for Economic Co-operation and Development - Development Assistance Committee
DMR	Department of Mining Resources
DST	Department of Science and Technolgy
IMS	Institue of Mine Seismology (former ISS: Integrated Seismic Systems International Led.)
JAGUARS project	Japanese – German Underground Acoustic Emission Research in South Africa Project
JCC	Joint Coordinating Committee
JICA	Japan International Cooperation Agency
JST	Japan Science and Technology Agency
KOSH	Klerksdorp-Orkney-Stilfontein-Hartebeestfontein
MOSH	Mining Industry Occupational Safety and Health (Chamber of Mines)
MHSC	Mine Health and Safety Council
MoU	Memorandum of Understanding
MQA	Mining Qualifications Authority
OHMS	Open House Management Solutions Ltd.
PDM	Project Design Matrix
SAGA	South African Geophysical Association
SAIMM	The Southern African Institute of Mining and Metallurgy
SANIRE	South African National Institute of Rock Engineering
SANSN	South African National Seismograph Network
SATREPS	Science and Technology Research Partnership for Sustainable Development
SeeSA	Semi-controlled Experiment in South African gold mines
WMRI	Wits Mining Research Institute (Witwatersrand University)

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Chapter 1: Outline of the Mid-term Review

1.1 Background

The Republic of South Africa is rich in mineral resources with many mines of gold, platinum and coal. The mining industry contributes to the employment of 500,000 workforces, about 60% of which are underground workers engaged in the mining of minerals in stopes and faced with the risk of mine disaster. Mine disaster has been a big social issue in the country, but administrative guidance and self-reliant efforts of mining company towards enhanced mine safety has realized the decrease of casualties: from 1.00 - 1.20 per 1,000 persons in late 1980s (the number of victims were 677 - 855 person/year) to 0.56 – 0.75 per 1000 persons in early 2000s (the number of victims were 246 – 290 person/year). In recent years, however, the trend of casualty decrease is stalled.

About 40% of the casualty and death of miners is presumably attributed to fall-of-ground accidents not always but often caused by "mine tremor" - a quake resulting from abrupt failure of bedrock by excess stress induced by mining activities. The mine tremor not only triggers fall-of-ground accidents in the mining stopes and developments, underground but also sometimes damages buildings on the surface.

The deeper the depth of shafts is, the greater the risk of mine tremor becomes. Gold mines in South Africa face high risks because many of them in South Africa are deeper than 3,000 m or mine remnants in high stress. At abutments of mining, rock mass is often unable to endure the excess stress and abruptly fails, thus inducing earthquakes. As such, in order to further decrease the victims of mine disaster, it is very important to assess the risk of mine tremor more precisely, and adjust mining plans or confine mining activities based on the risk assessment.

In South Africa, in-mine seismic monitoring and stress modeling, which have been commercially available internationally (the former was developed in South Africa), and practical seismic hazard assessment is operational. However, the assessment has stagnated because of limited understanding of earthquakes. To enhance the hazard assessment, observational studies of mine tremor have been conducted by Japanese researchers over the past 19 years in deep gold mines, which included monitoring significantly more sensitive and stable or higher in capacity than civil engineering or geotechnical monitoring and much closer distance to hypocenters than in-mine seismic monitoring. The fine details that can never be elucidated in other than South African gold mines have suggested that the enhancement of hazard assessment is feasible to some extent. With this background, *the Project for Observational Studies in South African Mines to Mitigate Seismic Risk* started in August 2010 under the JICA/JST cooperation scheme of SATREPS (Science and Technology Research Partnership for Sustainable Development). Being allowed much denser monitoring networks in three experimental sites than those in the previous researches, the Project aims at much better understanding of the preparation and generation of earthquakes that have been wanted over years.

In February 2013, at the halfway of the cooperation period, the Project is required to undergo the Mid-term review in accordance with the Article V of the Memorandum of Understanding signed for the Project in February 2010.

1.2 Objectives of the Mid-term Review Study

The objectives of the Mid-term review are to:

1) conduct a joint review by the team consisting of Japanese and South African reviewers;

2) confirm actual inputs, activities and the degree of achievements of the outputs, and the prospect of achieving the project purpose;
3) assess the Project based on the five evaluation criteria - Relevance, Effectiveness, Efficiency, Impact and Sustainability;
4) make recommendations on the measures to be taken during the remaining cooperation period and beyond in consultation with agencies concerned; and
5) confirm the results of the review above with South African authorities and agree on the minutes of meetings.

1.3 Outline of the Project

The Master Plan in the MoU dated 26th February 2010 sets forth the outline of the Project. (Annex 1) The Plan of Operation approved at the 2nd JCC meeting on 9 May 2012 describes the latest activity plan. (Annex 2)

1) Project Purpose
Understanding of the preparation and occurrence of earthquakes is enhanced, and the risk management mechanism of mining-induced earthquakes is improved.

2) Output
1. Rock properties at seismic sources are elucidated.
2. Understanding of the preparation and forerunners of earthquakes in gold mines is enhanced.
3. Reliability of seismic hazard assessment in gold mines is improved.
4. Reliability of strong ground motion predictions in gold mines is improved.
5. Estimation of the locations of seismic events and damage assessment of seismic disasters become more accurate.

1.4 Member of the Mid-term Review Team

The review was conducted by the team composed by the following members:

(Japanese Side)

Name	Position	Title
Mr. Hideo MIYAMOTO	Leader	Senior Advisor to the Director General, Global Environment Department, JICA
Ms. Yuriko DOI	Survey Planning	Disaster Management Division II, Global Environmental Department, JICA
Mr. Hiroyuki OKUDA	Evaluation and Analysis	Tekizaitekisho, LLC
Mr. Masayuki SATO	Observer	Principal Researcher, Research Partnership for Sustainable Development Division, JST

(South African Side)

Name	Position	Title
Mr. Llanley Simpson	Leader	Director, Mining and Mineral Processing, DST
Ms. Lisa du Toit	Project Evaluation	Director, Development Partnerships, DST

Ms. Eudy Mabuza	Project Evaluation	Deputy Director, Development Partnerships, DST

1.5 Schedule of the Mission

The schedule of the mission is attached (Annex 3)

1.6 Methodology of the Mid-term Review

The Mid-term Review is carried out in accordance with "the JICA New Guideline for Project Evaluation, Ver. 1 (June 2010)", which mainly follows "the Principles for Evaluation of Development Assistance, 1991" issued by Organization for Economic Co-operation and Development – Development Assistance Committee (OECD-DAC).

The Master Plan with the statement of the Project Purpose, Outputs and Activities in the MoU was used as the basic reference point for the review. As a framework to collect and sort out relevant data and information as prescribed in the JICA Guideline, two types of grid – Grid of Project Progress and Evaluation Grid - were prepared in reference to reports and documents on the Project. The Grid of Project Progress was completed by the Project in preparation for the Mid-term review. To collect information for the Evaluation Grid, questionnaires were prepared and forwarded in advance of the review mission to the counterpart organizations. During the review mission, the team conducted interviews with counterparts based on the questionnaire, hearings with related organizations, and visited project sites. (Annex 4)

Findings and information from reports, interviews, questionnaire survey and site visits were collected and analyzed in the grids. The team confirmed the achievements, assessed the Project based on the five criteria, and made recommendations.

The criteria used for the evaluation are the following five criteria: relevance, effectiveness, efficiency, impact and sustainability.

Relevance	Relevance is reviewed by the validity of the Project Purpose in light of South Africa's development policies and needs as well as Japanese cooperation policies.
Effectiveness	Effectiveness is assessed to what extent the Project is achieving the Project Purpose, clarifying the relationship between the Project Purpose and Outputs.
Efficiency	Efficiency is analyzed with emphasis on the relationship between Outputs and Inputs in terms of timing, quality, and quantity.
Impact	Impact examines direct effects extended by the Project, mainly the advancement towards achieving the Overall Goal. The analysis also includes positive/negative and expected/unexpected influence caused by the Project.
Sustainability	Sustainability is assessed in terms of institutional, financial, and technical aspects by examining the extent to which the achievements of the Project will be sustained after the Project is completed.

Chapter 2: Achievement of the Project

2.1 Results of Input

(Japanese side)

1) Dispatch of Japanese Experts/Researchers

Following the signing of MoU on 26th February 2010, the Project started in August 2010 when the Project

Coordinator arrived at his post. Until March 2013, eight Japanese researchers have visited South Africa 34 times, totaling 749 days. There was a change of Project Coordinator assigned by JICA in November 2012. (Annex 5)

2) Provision of Machinery and Equipment

Equipment for monitoring of micro-fracturing, rock deformation, seismic ground motion, and seismic monitoring system were procured and installed in 3 mines: Moab Khotsong, Cooke 4 (former Ezulwini) and KDC West (former Driefontein). (Annex 6)

3) Counterpart Training in Japan

One researcher from CSIR attended a short-term training at Tohoku University and Tokyo University in Japan in 2012. (Annex 7)

4) Local Operational Costs

Japanese side has provided a part of necessary expenses for carrying out project activities. The total of local operational costs from August 2010 to January 2013 is 5,873,544 ZAR, including local consultant fees, travel expenses/allowances, and purchase of equipment and consumables. (Annex 8)

(South African side)

1) Assignment of Counterpart Personnel

Project Director and Project Manager are assigned from DST and CSIR, respectively. As of the Mid-term Review, 30 researchers are listed as counterpart personnel: 18 from CSIR/Witwatersrand University and 12 from CGS. There are also 11 collaborating personnel from mining companies involved in the Project. (Annex 9)

2) Local Operational Costs

CISR and CGS has borne a part of running expenses necessary for Project implementation, the amounts of which to date are 159,714 ZAR and 80,846 ZAR, respectively. (Annex 8)

2.2 Project Progress and Achievement

Achievements and progress of the Project are examined in detail in the Grid of Project Progress (Progress at the Activity Level) and Project Status at the Target Mine: Cooke 4, Moab Khotsong and KDC West. (Annex 10 and 11)

And project members wrote papers and did presentations in conference and meeting. All papers and presentations are shown as Annex 12.

(Output 1)

- All planned drilling was completed by September 2012: totaling more than 70 holes and more than 2.8km in length, in the three mines. The expenses for the drilling were borne by other Japanese funds. For each target mine, an anticipated seismic source (hypocenter fault) was accurately located based on the geological features intersected by those holes.
- Core specimen from the seismic source of Cooke 4 (and of Mponeng mine) was shipped to Japan by May 2012 for specialized tests such as measurement of elastic properties, fracture parameters/characteristics and stress

constrained by cores. School of Mining Engineering, Witwatersrand University, will conducts laboratory experiments in South Africa of core specimen from the seismic source of the three target mines.

(Output 2)

- In those holes were installed the following sensitive sensors:
  a) Surrounding the hypocenter fault in Cooke 4, the installation of 24 sensitive acoustic emission sensors, 3 accelerometers, and a AE recorder were completed by December 2010, and data has since been accumulated to monitor the activities of micro fracturing and identify potential seismic sources.
  b) In Moab Khotsong, a similar acoustic emission monitoring network is being established with AE sensors and a AE recorder procured by another Japanese fund. The monitoring is scheduled to start in April 2013.
  c) On the hypocenter faults, sensitive strainmeters (Cooke 4 in December 2010; Moab Khotsong in December 2011; and KDC West in August 2012), tiltmeters (Moab Khotsong in January 2013; and KDC West June and November 2012), and Broad-band seismometer (Cooke 4) have been installed to monitor the accumulation and release of stress and to compare the data with existing stress modeling.
- Equipment yet to be installed is one broad-band seismometers and one tiltmeter in Moab Khotsong. Closure meter systems are also yet to be installed in Moab Khotsong and KDC West; it took time to develop the system and found a company to manufacture it.
- Acoustic Emission monitoring network, tiltmeter monitoring, strainmeter monitoring of the Project are built upon the previous works of JAGUARS, SeeSA, and other projects.

(Output 3)

- In those holes were installed the following sensitive sensors:
  a) In a line intersecting the hypocenter fault in Cooke 4, one transmitter and three receivers (accelerometers) was installed to monitor change in elastic wave transmitting through the fault.
- Equipment yet to be installed is 3 receivers (accelerometers) in Moab Khotsong where 2 transmitters have already been set up.
- It was confirmed that the AE network of the Project clearly delineated multiple planner distributions of AE that evolved with time. They can be weak planes of potentially impending earthquakes. Identifying weak plane is the first step to enhance seismic hazard assessment, which has been successfully achieved.
- It was proven that the Project can estimate stress drop for abundant AE. The Project can expect that fundamentally much dense information of stress will be available, which can contribute to calibrate stress modeling or discuss the quality of other indirect method to estimate stress on the plane of concern or imminence of earthquake.
- A Japanese stress measurement technique which International society of Rock Mechanics suggested was implemented in South African gold mines. With the special tools which was originally available only in Japan, modified CCBO (compact conical-ended borehole overcoring) technique in BX size (60mm in diameter) was tested successfully in January and February 2013 at Mponeng mine (at 3.4km depth with minimal mining) and at Tau Tona mine (at 3.0km depth near a M1.5 damage) all at mine's own cost. It was revealed that the Tau Tona stress (145 MPa, 4000 μstrain) was much larger than others. It was also larger with significant difference

than the predicted values of existing computer modeling although the Project must discuss with great care if this resulted from a technical problem.

(Output 4)

- In those holes were installed the following high-capacity sensors that would not be clipped even for very dynamic change;
  a) On the hypocenter faults at Cooke 4, three dynamic rupture sensors assembled by an expert with high-capacity acceleration sensors and strain gauges were installed in December 2010 and date has since been monitored to fully record dynamic stress change at seismic rupture front. Another four dynamic rupture sensors were installed at KDC West in January 2012 and has since been recording the data.
- Stope strong motion recording system (10 seismic transducers) has been procured and scheduled to be installed in a few weeks in the stope of Moab Khotsong and KDC West for 1 set (5 seismic transducers) each.

(Output 5)

- Ten surface CGS national stations was set up in Far West Rand area, where Cooke 4 and KDC West are situated, by July 2012 to constitute the South African National Seismograph Network (SANSN)
- A new seismogram analysis computer system and new routines for processing data using Antelope software for the surface CGS national stations were also establshed by July 2012.

2.3 Progress towards the Project Purpose

The Project has focused on the installation of moniting equipment in the first two years at the three target mines. At Cooke 4, planned sensors were installed by December 2010 and underground data has been accumulated for about two years. At Moab Khotsong, about 80% of underground installaion for Japanese activities has been completed and that for South Afrcian activity (tilemeter, closure meter system, and seismic transducers) is planned to be completed in a few weeks. At KDC West, strainments, dynamic rupture sensors, tiltmeters were set up and the installation of other equipment is also planned to be finshed soon. CGS surface national stations and new seismogram analysis computer system are operational since July 2012.

One of preriminary findings which lead to enhanced understanding of the earthquakes is that the AE monitoing system of the Project finely delinieated the weak planes of concerns and could contstrain stress and strengh on one of the planes. The most important steps to enhance seismic hazard assessment is to identify a weak plane of concern more accurately and constrain stress and strengh on the plane, followed by the caliburation of stress modeling for mine-wide application. Fundamental technical problem that caused less frequent stress measurement was solved.

Regarding improved risk management mechanism, CCBO technique in BX size is proved to be much faster and easier than the conventional overcoring techniques and it can complete the cycle of procedures necessary for an overcoring – including shaping the borehole-end conically, gluing a 16-element strain cell, and overcoring – within 2.5 hours. The biggest advantage of CCBO is that it can be done quickly, and hence it can be much cheaper and be an afforable method of stress measurement for the first time at mines.

2.4 Implementation Process

Japanese and South African researchers have divided into 5 groups corresponding to 5 outputs. Three local consultants contracted by JICA are currently working for the Project as site managers, having greatly facilitated the installation of monitoring equipment at target mines for both Japanese and South African researchers. The project office is housed in CGS.

Chapter 3: Review by the Five Criteria

3.1 Relevance

The relevance of the Project is high.

1) The project is unique in that the South African mines provide (unlike any other environment in the world) access to the near hypocenter and opportunities to observe the possible preparation and forerunners of earthquakes. The hypothesis of the Project is summarized in a paper published in 2012[1]; there are measurable changes in some or all of the following physical parameters that can be used to predict the time and location of mining-induced earthquakes: stress, strain rate, tilt rate, acoustic emission rate, seismic source parameters, electromagnetic emission rate, and microcrack density. The Project aims at revealing the precursory phenomena, which have never been observed before, by establishing an intensive monitoring network in the vicinity of impending seismic source, i.e. identified faults near mining activities. It is also expected to advance our understanding of natural earthquakes .
2) The project purpose is not only to enhance the understanding of preparation and occurrence of earthquakes, but also to improve procedures to manage and mitigate the risk posed by mining-induced earthquakes. The South African mines have operated IMS seismic systems since the 1990s and make use of standard IMS procedures to assess seismic hazard. The sensitivity threshold on most mines is about Magnitude -1 using geophones installed at least a few hundred meters apart from each other. The sensor networks installed by the Project are far more sensitive, the threshold is Magnitude -4 achieved using Acoustic Emission sensor, and equipped with additional sensors such as tiltmeters, strainmeters and transmission lines installed within a volume of at most 100m on all sides. The Project will examine if this additional information obtained with the sensitive network can provide any reliable indication of changes in seismic hazard. Should any of the methods prove to be practically viable, then the project findings can directly feed into mines' risk management systems.
3) Government authorities emphasize the importance of safe and cost-efficient mining, to which the Project can contribute when its research findings are applied and utilized in mines. According to the DMR, the government intends to extend the life of gold mines but the main issue is to reach deeper ore without exposing mine workers to risks. MHSC, contacted in the first time during the Mid-term Review, also shows interest in the Project as the research results can be applied to improve the safety of mining activity. MHSC recognizes that this is the only international cooperation by bi-lateral agency in South Africa that can contribute to the improvement of mine

[1] DURRHEIM, R.J. and OGASAWARA,H. Can mine tremors be predicted? Observational studies of earthquake nucleation, triggering and rupture in South African Mines, in *Proceedings of the Second Southern Hemisphere International Rock Mechanics Symposium,* The Southern African Institute of Mining and Metallurgy, Johannesburg, 2012. Pp.327-343.

safety.

4) The project is aligned with the needs and expectation of counterpart organizations: CSIR/CMI, CGS and Witwatersrand University. Research at CSIR/CMI takes place in three areas - Human factors, Real-time risk management, and Novel mining techniques – and the Project contributes to studies in the second area. Witwatersrand University established WMIR in September 2012 to advance the sustainability of the mining sector and affected societies. As for CGS, the project is also fully aligned. Before 2010, CGS had only a few observational stations in the mining districts. Starting from 2010, CGS has now installed more than 50 stations, 10 of which were established by the Project in Far West Rand area in 2012.

5) Science and Technology is one of prioritized areas in the bilateral cooperation between Japan and South Africa. A Science and Technology session was held on 28 February 2013, a day before the 12th South Africa – Japan Partnership Forum on 1March 2013, which was a bilateral cooperation mechanism to strengthen relations in the areas of trade and investment, developmental assistance, political dialogue and science and technology. SATREPS was noted with appreciation during the session. Also, in the Rolling Plan of Japan's ODA policy for South Africa, the Project is included in Science & Technology and Climate Change Program under the priority area of Human Resource Development for Growth Initiative.

3.2 Effectiveness

Effectiveness of the Project is medium.

1) Overall, the Project is making a steady progress towards achieving the Project Purpose. The management of drilling (more than 70 holes and greater than 2.8km in length), scoping (with a borehole camera) and cleaning of those holes, installation of monitoring equipment and data acquisition underground are complex and wearisome processes. The Project, however, has almost completed the installation of monitoring equipment by now, and has started accumulating necessary data for seismic analysis. At the Mid-term review, there are no immediate obstacles observed that can keep the Project from achieving its goal. As such, the Project is likely to achieve the Project Purpose by the end of cooperation period. There are, however, several important assumptions involved towards the goal such as 1) mining plans at the monitoring sites remain unchanged, 2) severe strikes that stopresearch activity do not take place at target mines, and 3) seismic events with large enough magnitudes occur within the range of the sensor array – M2 events (source faults of about 100m across) are the targets of the Project.

2) The project is effective in that it has mobilized other funding sources and synthesized them towards the achievement of project purpose. The Japanese activities of the Project have been supported by the co-financing from other Japanese funds (Grants-in-Aid for Scientific Research, and MEXT's Observation and Research Program for Prediction of Earthquakes and Volcanic Eruptions) for procurement and installation of monitoring equipment. The South African activities have been supported by the DST, CSIR, CGS and NRF. Mining companies have provided significant in-kind support,

3) The Project has just started discussion about ideas/approach for the research findings to be applied for the implement of risk management system through Mid-term Review. This is a part of the Project Purpose and important for the overall goals of the Projects.

3.3 Efficiency

The efficiency of the Project is high.

1) Master Plan of the Project in the MoU signed on 26 February 2010 is clear and well understood among those who are implementing the Project. Project activities are being advanced generally in accordance with the Plan of Operation approved at the 2nd JCC meetings on 9 May, 2012. There were some delays of planned activities due to the strikes at the three target mines in 2012, during which no entry to the project monitoring sites was allowed.

2) Inputs to the Project from the Japanese side are effective and highly appreciated by the South African side. The MoU decides the measures to be taken by JICA: dispatch of Japanese experts, provision of machinery and equipment, and training in Japan. Japanese researchers have shown a great level of commitment to the Project; for example, the Japanese Chief Advisor is effectively on five-year sabbatical to be fully engaged in the Project and has devoted as many as 341 days in South Africa since the beginning of the Project. All the procurement of necessary equipment was completed by the end of 2012 with the efforts of Project Coordinator, CSIR and Ritsumeikan University. As for training, one South African researcher so far has attended training in Japan, and in 2013, two lecturers of the School of Mining Engineering, Witwatersrand University, are scheduled to participate in training at AIST.

3) Inputs of South African side as agreed in the MoU are no less effective than those of Japanese side- assignment of counterpart personnel, office space and its facilities, and running expenses necessary for the project implementation. Thirty researchers are engaged in the project as counterparts at the time of Mid-term review. It is notable that there is low turnover of the counterpart personnel and the cooperating relationship between the Japanese and South African researchers is very stable. However, some of the counterpart indicates that they have not been able to devote as much time to the project as they expected because of their competing duties. CGS and CSIR, as implementing agencies, have managed their budget in order to undertake project activities. CGS has also provided office space for the Project.

4) Efficiency of project implementation is high also because of the cooperation from mining industry. The mining companies of the monitoring site have provided the Project with great support, convenience and facilities. Engineers from the mining companies have been coopted to the Project as collaborating researchers.

5) The communication between Japanese researchers and South African researchers is excellent. The Project is being implemented based on the consultation and discussion between the two sides. The Project has so far held two JCC meetings, on 19 April 2011 and 9 May 2012, with the participation of observers from DMR, the Embassy of Japan, and JST. As for the communication among the five research groups, it is indicated that the interactions between Output 1-4 (CSIR/Wits Univ.) and Output 5 (CGS) was not intense because the connection of underground and surface monitoring networks is not intended in the Project. At present, those two groups sustain the communication in the Project for the exchange of information.

6) There are many promoting factors identified for the Project advancing to its goal:

- the Project has received great support from mine management and rock mechanics practitioners;
- local consultants from OHMS and Seismogen, contracted by JICA, have performed well;
- a long history of collaboration of researchers with mining companies and service providers has helped the Project tremendously.

7) On the other hand, some hindering factors are also identified that have affected project progress:

- Industrial action (strikes) at the mines;
- theft of cables and equipment within the mine;
- delays in obtaining permits to hold rock specimens that may contain precious metals and to transport the rock specimens to Japan;

3.4 Impacts

The impact of the Project is still low at the time of Mid-term Review with respect to the Overall Goal, but some other significant impacts have already been achieved.

1) Progress towards achieving the Overall Goal has not been observed as yet at the time of Mid-term Review, but this is expected in the next two years of the cooperation period. To date, the main efforts of the Project were devoted to the establishment of the research sites, such as identifying monitoring sites, procuring the equipment and initiating underground monitoring. While establishing monitoring network, South African technicians and engineers at companies such as Seismogen, OHMS and CSIR, gained valuable experience and knowledge.
2) One of the notable impacts is that the Project scientists have been invited to speak at several international meetings: annual IMS seminar since 2009, Deep and High Stress Mining Seminars in Chile (2010) and Australia (2012), American Geophysical Union Fall Meeting (2012), Southern Hemisphere International Rock Mechanics Symposium in South Africa (2012), and the New Development Rock Mechanics Symposium in China (2012). This year, the IMS seminar will be held on 18-19 March at Hobart, Australia, to which the Project Manager and the Chief Advisor are invited.
3) Some technologies introduced by the Project have already been considered for application by a mining company and a rock engineering service provider. An acoustic emission network is planned to be set up in another mining area by a mining company, and a demonstration of CCBO technique under the supervision of Japanese engineer is planned by the geotechnical service company.
4) The surface network installed by the Project in Carletonville area is operational and the new Data Processing Center is servicing two additional networks in mining areas (KOSH and Central Rand areas).

3.5 Sustainability

The prospect of sustainability of the Project is relatively high.

1) Institutional arrangement is suitable for the continuation and development of project activities. The Project is aligned with the mission, role and responsibility of both CSIR/CMI and CGS. It is, however, widely indicated by those involved in the Project that the South African mining industry is in decline, by referring to regulatory uncertainty, debate about nationalization of mines, threats of industrial action/strike, frequent change of ownership and name of mines, and decreasing number of mining researchers. Over the past 20 years, there has been a drastic reduction in the investment in mining-related research in South Africa, both by government and industry. In spite of such trend as above, the commitment of CSIR/CMI and CGS are high as leading institutions.
2) From a technical point of view, mainly in term of continued use of installed equipment, it should be noted that it is nearly impossible to recover most sensors and cables for underground because they are permanently grouted in the rocks. These sensors are operational for a few years while mining activities are conducted nearby and will finish

its initial role when the mining stopes move to other areas. Data recorders can be used for other projects. CGS is considering taking over a part of underground equipment to collect data to conduct research on the difference between mining-induced and flood-induced earthquakes after the mine is closed. As for the 10 seismic station installed by the Project, the CGS is covering all costs associated with maintenance and data communication. The Project chose its equipment specifications to be compatible with South African standards for effective maintenance.

3) As for human resources, CSIR expects to maintain capacity at the current level in spite of budgetary cutback in the recent years. At CGS, the number of permanent staff is growing and CGS is expecting more expertise in mining seismology in line with the Geoscience Amendment Act (2010). CSIR and CGS indicates that the project is providing an excellent environment for training young scientist and post-graduate students, which contribute to the capacity development.

4) The prospect of sustainability from a financial viewpoint is still uncertain because the continuation of project work at CSIR largely depends on obtaining new research contracts. CSIR receives an annual government grant, through DST, which accounts for about 40% of its total budget. The remainder comes from research contracts with governmental departments at national, provincial and municipal levels, the private sector and research funding agencies in South Africa (e.g. MHSC) and abroad. MHSC presently focuses on the application of scientific knowledge, thus having stopped research funding.

5) Some private companies have recognized the effectiveness of the observation method that is used by the project and have started to import it into their existing systems. This is a remarkable achievement and indicates the possibility of outcome utilization.

Chapter 4: Recommendation

1) Project Design Matrix (PDM)

The Project can become more effective by establishing verifiable indicators. However, the Master Plan attached to the MoU doesn't include Indicators. The level of project performance needs to be assessed by Indicators at the time of terminal evaluation. The Mid-term Review is a good opportunity to assess the project progress so far, and discuss and agree on such indicators by foreseeing the targets to be reached in the next two years.

As the result of the Mid-term Review discussions, a draft PDM is designed with indicators and important assumptions in addition to Project Purpose, Outputs and Activities which were already defined at the Master Plan. Mid-term Review mission suggested JCC to finalize the draft PDM and approve it.

The Project needs to put efforts to achieve these indicators during the remaining of cooperation period.

2) Outreach for the application of research results

Towards the second half of cooperation period, the Project is required to be more strategic about how research findings can be utilized for improvement of mine's risk management mechanism. This is a part of the Project Purpose In the Mid-term Review, there were several discussions about ideas/approaches for the implementation of research findings to risk management systems. Project members also submitted suggestions.

SATREPS aims not only at the promotion of research cooperation but also at the application of research findings to realize developmental, social benefits. From an academic research viewpoint, the prerequisite is that the Project should, at the very least, be able to determine if there is any practical way that can detect forerunners of rockbursts, and that the research results should be acknowledged in academia through the publication of peer-reviewed papers and at international professional meetings. On the other hand, from a practical engineering viewpoint, the Project has already transferred modified overcoring technique successfully to two mines and two geotechnical consulting companies. This is a practical tool that can contribute to seismic risk assessment.

As such, some ideas/approaches for the application are discussed during the Mid-term Review as follow:

- If the network of acoustic emission and other sensors is proved to be helpful in observing precursory phenomena, then the Project can formulate functional specifications of the monitoring systems and procedures for mines to be able adopt for themselves.
- After publication in scientific journals, the Project can submit formal recommendations on "leading Code of Practice" to MOSH (a team within Chamber of Mines - mining industry employers' organization), rock mechanics practitioners at deep mines, organized labor, and Mine Health and Safety Inspectorate (DMR).
- With conducting more CCBO survey, the Project can help improve the stress computer modeling.
- Knowledge developed by the Project can be included in training conducted by the Mining Qualifications Authority, a statutory body for education and training for the South African mining and minerals sector. International/regional initiative such as AfricaArray, which supports trainings and research for geoscientist in Africa, can also be an arena for knowledge transfer.
- IMS is the world's largest research, development and service provider of methodologies/technologies on seismic rock mass response to mining. Uptake of the improved hazard management system by such a private organization can, in effect, help transfer technologies to mines and geotechnical consulting companies.

This discussion is just started. The Project needs to continue to clarify potential of each idea with stake holders.

3) To share information with related governmental organization

According to the results of the interviews, it was confirmed that some public organizations are very interested in the Project outputs. Therefore it is very important to share the progress with related organizations outside of project, namely DMR, COM, MHSC, MQA etc. because the Outcomes of this Project can be also utilized into these organization's activities.

The Project has already a good communication network amongst research institutes. This should be expanded to the other related organizations, An understanding of the potential of the Project outputs to support their activities should be promoted through occasions like workshops, seminars and the JCC.

4) Support for acquiring Research Budget

It is mentioned in this Mid-Term Review report in section 3.5 Sustainability, 4) that a budgetary cutback for research by South African Government will give negative impact on sustainability of the Project's output. Responsible organizations in government can support research institution to get access to new budgets or research funds to continue to research activities.

Annex 1: Master Plan

1. Project Purpose

Understanding of the preparation and occurrence of earthquakes is enhanced, and the risk management mechanism of mining-induced earthquakes is improved.

2. Outputs

(1) Rock properties at seismic sources are elucidated.

(2) Understanding of the preparation and forerunners of earthquakes in gold mines is enhanced.

(3) Reliability of seismic hazard assessment in gold mines is improved.

(4) Reliability of strong ground motion predictions in gold mines is improved.

(5) Estimation of the locations of seismic events, and damage assessment of seismic disasters become more accurate.

3. Activities

(1)-1 Observe and collect rock samples at seismic sources and its surroundings

(1)-2 Investigate rock properties in laboratory

(2)-1 Install monitoring systems for micro-fracturing and rock deformation, and sensitive long period seismometers in the vicinity of impending earthquake sources

(2)-2 Monitor the activities of micro fracturing

(2)-3 Monitor the accumulation and release of stress in and around the impending earthquake source

(2)-4 Analyze the monitored data to clarify the forerunning phenomena and its characteristics

(3)-1 Evaluate spatiotemporal changes in stress and rock mass stability based on the data produced by mine's microseismic network

(3)-2 Upgrade the scheme of seismic hazard assessment by calibrating existing schemes with the data obtained through the activities 2-2, 2-3 and 3-1

(4)-1 Install accelerometers and high capacity strainmeter in the vicinity of impending earthquake sources to monitor the dynamic slip and stress change

(4)-2 Analyze the data obtained through the activity 4-1 to clarify the process of rock mass failure and strong motion generation

(4)-3 Install strong motion meters and geophones in underground working places to monitor strong motion at disaster sites

(4)-4 Compare strong ground motions at the source with those at damage sites to clarify the characteristics of site amplification of strong motion

(4)-5 Compare the monitored dynamic stress change and fault slip with existing lab-experimental results to clarify the scaling relationship in dynamic rupture process

(5)-1 Install seismic stations in the Far West Rand mining district (Carletonville area) on the surface to monitor surface ground motion caused by mine tremors

(5)-2 Upgrade the Data Center in the Silverton offices of the Council for Geoscience

(5)-3 Develop and validate a parametric model that will be capable of predicting strong ground motion

Annex 2: Plan of Operation

Activity	2010		2011				2012				2013				2014				2015		
	Aug-Sep	Oct-Dec	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec	Jan-Mar	Apr-Jun	Jul
1 Source rock property (Output 1: Rock Property group)																					
1-1. On-site observation	━	━	━	━	━	━	━	━				━	━	━	━	━	━	━			
1-2. Laboratory analysis				━	━	━	━	━	━	━	━	━	━	━	━	━	━	━	━		
2 Sensitive close monitoring (Output 2: Deformation group)																					
2-1. Array development	━	━	━	━	━	━	━	━	━												
2-2. Micro fracturing monitoring		━	━	━	━	━	━	━	━	━	━	━	━	━	━						
2-3. Rock deformation monitoring		━	━	━	━	━	━	━	━	━	━	━	━	━	━						
2-4. Analysis								━	━	━	━	━	━	━	━	━	━	━	━		
3 Hazard assessment (Output 3: Hazard assessment group)																					
3-1. Mine seismic data re-evaluation						━	━	━	━	━	━	━	━	━	━	━	━	━	━		
3-2. Upgrade assessment scheme						━	━	━	━	━	━	━	━	━	━	━	━	━	━		
4 Strong motion (Output 4: Strong motion group)																					
4-1. Install on-fault rupture sensors		━	━	━	━	━	━														
4-2. Source motion analysis							━	━	━	━	━	━	━	━	━	━	━	━	━		
4-3. On-site monitoring										━	━	━	━	━	━	━	━	━	━		
4-4. Site motion analysis											━	━	━	━	━	━	━	━	━		
4-5. Scaling law														━	━	━	━	━	━		
5 Extension of the SANSN (Output 5: Surface cluster)																					
5-1. Installation of a cluster of seismic station						━	━	━	━												
5-2. Upgrade seismological Data Center						━	━	━	━												
5-3. Strong ground motion prediction									━	━	━	━	━	━	━	━	━	━	━		
JCC (as project management activity)				○				○			○										

This is the PO approved at the2nd JCC meeting on May 09, 2012

Mid-term Review (Jan-Mar 2013)

Annex 3: Schedule of Review Mission

Date		JICA Mr. Miyamoto (Leader)	JICA Ms. Doi (Survey Planning)	Consultant Mr. Okuda (Evaluation & Analysis)	JST Mr. Sato (Observer)	South African Reviewers
23 Feb	Sat			22:05 Dep Japan		
24	Sun			16:25 Arrival JNB EK763 Move from JNB to Pretoria (19:30) Meeting with Ms. Kanto from JICA SA Office		
25	Mon			(09:30 - 15:30) Meeting with Prof. Ogasawara & Mr. Takashima @ Project Office (CGS Room 306)		
26	Tue			06:30 Move to JNB (08:50 - 10:00) Meeting at MHSC (10:30 - 12:30) CSIR CMI interview (Project Manager Prof. Durrheim, Dr. Milev and their team) (14:30 - 16:00) Wits Univ interview (Dr. Durrheim and his team)		
27	Wed			(08:00 - 09:00) Interview with Mr.Thabo (DMR) @ MHSC (11:30 - 12:00) Visiting Goldfields (13:15 – 15:00) Hearing at Anglogold Ashanti Rock Engineering Department Move to Stilfontein (17:30) Briefing with Mr. Raymond and Mr. Gilbert for MK mine		
28	Thu			(05:30 - 14:00) Moab Kotsong pick-up by Mr. Raymond from guest house (14:00 - 16:00) OHMS interview Move to Fochville		
1 Mar	Fri			(05:15 - 12:00) Cooke 4 visit (12:30 – 13:15) Seismogen Hearing (14:00 – 15:00) Goldfield hearing		
2	Sat			Report Preparation		
3	Sun			Report Preparation		
4	Mon			Move from Carletonville to JNB (14:00 - 15:30) Ground Work hearing		
5	Tue		Dep. Japan	Move from JNB to Pretoria (10:00 - 12:30) CGS Courtesy call & Interview (Dr. Cichowicz and his team) (14:00 - 15:30) Meeting at Project Office (CGS Room #306)	Dep. Japan	
6	Wed		Arr. Pretoria	(09:00 - 11:00) Draft Report Preparation @ JICA SA Office (12:00 - 13:00) DST for explanation of draft report (Ms. Lisa & Ms. Eudy)	Arr. Pretoria	(12:00 - 13:00) Meeting for Report
7	Thu		(11:00) JICA SA Office (14:00 - 15:00) Coutesy call to Embassy of Japan			
8	Fri		Site visit to CGS	(10:30 - 14:30) Report writing and Pre-meeting @ JICA SA Office	Site visit to CGS	
9	Sat	Dep. Japan	Writing up the Report			
10	Sun	Arri. Fochville	Move from Pretoria to Fochville			
11	Mon	(08:30 - 09:00) Goldfields Seismic Monitoring Centre? (09:30 - 17:30) Seminar participation				
12	Tue	Pre-JCC meeting (13:30 - 14:30) Meeting at JICA (15:00 – 16:00) Meeting at DST				(13:00 - 15:00) Meeting with the Japanese team
13	Wed	(10:00 - 12:30) JCC at DST (12:30 - 16:00) Post-JCC meeting at CSIR (Pretoria)			(17:00) Dep. Pretoria	
14	Thu	(09:30 - 10:30) Reporting JICA SA Office (10:30) Dep. Pretoria, Arr. JNB Airport (13:50) Departure JNB EK762				
15	Fri	Arr Tokyo				

Annex 4: List of Interviewees

1	South African Side		
1)	Counterpart and Collaborating Organizations		
1	Prof. Ray Durrheim	CSIR/Witwatersrand Univ.	2/26
2	Dr. Alexander Milev	Principal Scientist, CSIR	2/26
3	Mr. Benon M Kagezl	Senior Research Engineer, CSIR	2/26
4	Dr. Jan Kuijpers	Technical Consultant, Rock Engineering, CSIR	2/26
5	Mr. Van Zyl Brink	Competence Area Manager, Real Time Risk Management, CSIR	2/26
6	Mr. Pieter Share	MSc Witwatersrand Univ. / CSIR	2/26
7	Mr. Gideon Ferreira	CSIR	2/26
8	Mr. Siyanda Mngadi	Student, Witwatersrand Univ.	2/26
9	Mr. Geroge Henry	CSIR	2/26
10	Dr. Declan Vogt	Strategic Research Manager, CSIR	2/26
11	Dr. Halil Yilmaz	Senior Lecturer, School of Mining Engineering, Wits Univ.	2/26
12	Mr. Tawanda Zvarivadza	Research Student (Junior Lecturer), School of Mining Engineering, Wits Univ.	2/26
13	Mr. Ali Sarfraz	PhD Scholar, Wits Univ.	2/26
14	Mr. Simon Sebothoma	Honours Student, Wits Univ.	2/26
15	Prof. Fred Cawood	Head of School, School of Mining Engineering	2/26
16	Mr. Daniel Fale	Seismic Department, Goldfields	2/27
17	Mr. Jomo	Seismic Department, Goldfields	2/27
18	Mr. Richard Masetue	Seismologist, Wits Univ and Goldfields	2/27
19	Mr. Shaun Murphy	Vice President of Geotechnical, Anglogold Ashanti	2/27
20	Mr. Gerhard Hofmann	Senior Mine Sesmologist, Anglogold Ashanti	2/27
21	Mr. Johan Egelbrecht	Moab Khotsong	2/28
22	Mr. Peter Watsoal	Moab Khotsong	2/28
23	Mr. Stephan van Aswegen	Moab Khotsong	2/28
24	Mr. Vlok Visser	Director, OHMS	2/28
25	Mr. Tony Ward	Ezulwini Shaft Rock Engineer, Director, Seismogen	3/1
26	Mr. Luiz Ribeiro	Geotchnical Systems Administrator, MCSE, Seismogen	3/1
27	Mr. Kevin Riemer	Group Seismologist, Sibanye Gold (ex. GoldFields), Driefontein Gold&Mine	3/1
28	Mr. Phil Piper	Managing Director, Groundwork	3/4
29	Dr. Artur Cichowicz	Senior Specialist, SeismologyUnit, CGS	3/5
30	Mr. Robert Kometsi	Seismic Instrumentation, CGS	3/5
31	Mr. David Ngobeni	Seismic Moment Tensor Solutions	3/5
32	Mr. Denver Birch	3DEC (3D-Distinct Element Code) Modelling, CGS	3/5
33	Mr. Ganesh W. Rathod	Seismic Hazard, UDEC (Universal Distinct Element Code), CGS	3/5
34	Mr. Azangi Mangongolo	Seismologist, Seismology Unit, CGS	3/5
2)	Relevant Organizations		
1	Mr. Navin Singh	Chief Research & Operation Officer, MHSC	2/26
2	Mr. Thabo Dube	DMR (Acting CEO, MHSC)	2/27
3	Mr. David Molapo	Chief Financal Officer, MHSC	2/27
2	Japanese Side		
1)	Project		
1	Prof. Hiroshi Ogasawara	College of Science and Engineering, Ritsumeikan Univ.	2/25
2	Mr. Jun Takashima	Project Coordinator	2/25
3	Mr. Raymond Vermeulen	Site Manager, OHMS	2/27
4	Mr. Gilbert Morema	Underground Site Manager, Seismogen	2/27
5	Mr. Thabang Masakale	Site Manager, OHMS	3/1
7	Dr. Takashi Satoh	Active Fault and Earthquake Research Center, GSJ/AIST	3/11
8	Dr. Yasuo Yabe	Associate Professor, Graduate School of Science, Tohoku University	3/11
2)	Embassy of Japan & JICA South Africa Office		
1	Ms. Yuko Kanto	Project Formulation Advisor	2/24
2	Mr. Mpho Pekane	Program Officer	3/6
3	Mr. Masao Shino	Representative	3/6
4	Mr. Toshiyuki Nakamura	Chief Representative	3/7
5	Mr. SEKI Tomohiro	Senior Representative	3/7
6	Mr. Ken Okaniwa	Minister, Embassy of Japan	3/7
7	Mr. Yasushi Naito	Counselor, Embassy of Japan,	3/7
8	Mr. Tomohide Yamada	First Secretary, Economic Division, Embassy of Japan	3/7
9	Ms. Namiko Yamada	Special Researcher for Economic Affairs, Embassy of Japan	3/7

Annex 5: Dispatch of Japanese Experts/Researchers

As of Mar 2013

Group (Output)	Name	Duration in South Africa (days of stay)									Total Days
		1st year (Aug 2010 - Mar 2011)			2nd year (Apr 2011 - Mar 2012)			3rd year (Apr 2012 - Mar 2013)			
		1st (4th)	2nd	3rd	1st (4th)	2nd (5th)	3rd	1st	2nd	3rd	
Output 1	Dr. Takashi SATO							5/2 - 5/13 (12)	3/10 - 3/15 (6)		(18)
Output 2	Dr. Masao NAKATANI	10/3 - 10/30 (28)	12/1 - 12/23 (23)	2/6 - 2/27 (22)	4/3 - 5/30 (58)	3/11 - 3/27 (17)		4/8 - 5/7 (30)	12/1 – 12/23 (23)		(221)
		3/12 - 3/31 (20)									
Output 3	Dr. Hironori KAWAKATA				4/9 - 4/20 (12)	10/29 - 11/7 (10)					(22)
	Mr. Yasuyuki KANOU	11/13 - 11/28 (16)									(16)
Output 4	Dr. Yasuo YABE	10/3 - 10/21 (19)	12/7 - 12/20 (14)	3/9 - 3/14 (6)	10/28 - 11/21 (25)			5/2 - 5/13 (12)	12/8 – 12/24 (17)	3/10 - 3/15 (6)	(99)
	Mr. Takashi NAKAYAMA	10/3 - 10/21 (19)									(19)
Output 5	Dr. Hiroshi OGASAWARA	9/19 - 10/14 (26)	11/12 - 12/11 (30)	1/7 - 1/29 (23)	4/10 - 4/23 (14)	5/16 - 6/17 (33)	7/15 - 9/30 (78)	4/17- 5/28 (42)	1/12 – 2/3 (23)	2/24 – 3/15 (20)	(341)
		2/27 - 3/13 (15)			11/11-11/27 (17)	11/30 - 12/19 (20)					
	Mr. Shigeru NAKAO	11/30 - 12/12 (13)									(13)
Total											(749)

Project Coordinator	Mr. Koichiro MIYARA	Aug 2010 - Aug 2012
	Mr. Jun TAKASHIMA	Nov 2012 - Present

Hired by the Project	Name	Company	Position and Period
Local consultant	Mr. Raymond Vermeulen	Open House Management Solutions Ltd	Site Manager - Moab Khotsong (Oct 2010 – Mar 2013)
	Mr. Martin Lotz	Open House Management Solutions Ltd	Site Manager (Oct 2010 – Apr 2011)
	Mr. Sifiso Khambule	Open House Management Solutions Ltd	Technician (Oct 2010 – Apr 2011), Site Manager (May 2011 – Apr 2012)
	Mr. Thabang Masakale	Open House Management Solutions Ltd	Technician (Oct 2010 – Dec 2011), Site Manager - Cooke 4 (May 2012 – Mar 2013)
	Mr. Khanya Luthuli	Open House Management Solutions Ltd	Technician (Oct 2010 – Dec 2011)
	Mr. Wian Blom	Open House Management Solutions Ltd	Technician (May 2011 – Sep 2011)
	Mr. Gilbert Morema	Seismogen CC	Underground Site Manger (Oct 2010 – Mar 2013)

Annex 6: Provision of Machinery and Equipment

As of February 2013

Item No.	Description in A4	Make / Specification	In-charge Researchers	Delivery Status	Relating Output	Cooke 4	Moab Khotsong	KDC West	Kloof	Progress
1	Multi-type Recorder	National Instrument / BTO	Dr. Kawakata	2/2	2,3	1	(1)	0	0	
2	Sensitive strain-meter	Techno Sugaya Ltd/ NBHS42-3C	Dr. Ogasawara	10/10	2,3	2	3	3	(2)	
3	Low-power recorder	Hakusan Kogyo / LS-7000XT	Dr. Ogasawara	1/1	2,3	1	0	0	0	Completed
4	Broad-band seismometer	Kinemetrics / SBEPI	Dr. Naoi	2/2	2	1	(1)	0	0	
5	Dynamic rupture recorder	National Instrument / BTO	Dr. Yabe	1/1	4	0	0	1	0	Completed
6	Dynamic rupture amplifier	National Instrument / BTO	Dr. Yabe	1/1	4	0	0	1	0	Completed
7	Dynamic rupture sensor	Assembled by Dr. Yabe	Dr. Yabe	7/7	4	3	0	4	0	Completed
8	Transmission unit	GMuG / Tailor Made	Dr. Kawakata	3/3	3	1	(2)	0	0	
9	Transmitter	GMuG / Tailor Made	Dr. Kawakata	3/3	3	1	(2)	0	0	
10	Accelerometer power supply	GMuG / Tailor Made	Dr. Nakatani	33/33	2	21	(12)	0	0	
11	AE recorder	GMuG / Tailor Made	Dr. Nakatani	1/1	2	1	0	0	0	Completed
12	AE main amp.	GMuG / Tailor Made	Dr. Nakatani	3/3	2	3	0	0	0	Completed
13	Groutable AE sensor	GMuG / Tailor Made	Dr. Nakatani	30/30	2	30	0	0	0	Completed
14	Borehole camera	Raax Co.Ltd / Smart Camera	Dr. Ogasawara	1/1	1	0	1	0	0	Completed
15	Overcoring tools	Akema Boring Co.Ltd	Dr. Ogasawara	1/1	1,3	0	1	0	0	Completed
16	Installation rods	Techno Sugatani Ltd.	Dr. Ogasawara	1/1	2,3,4	0	1	0	0	Completed
17	Off-line data logger	Kinemetrics / Granite	Dr. Milev	1/1	2	-	1	-	-	Completed
18	Seismic transducers	SM6	Dr. Milev	10/10	4	-	(5)	(5)	-	
19	Borehole tiltmeter	Applied Geomechanics	Dr. Milev	4/4	2	-	1(1)	2	-	Completed
20	Closure meter system	CSIR	Dr. Milev	2/2	2	-	(1)	(1)	-	
21	Seismic system software	Kinemerics / Antelope	Dr. Cichowicz	1/1	5	-	-	-	-	CGS, Completed
22	RAID system	Kinemetrics / Data Center Hardware	Dr. Cichowicz	1/1	5	-	-	-	-	CGS, Completed
23	Accelerometer	Kinemetrics / ES-T								
	23-1. Accelerometer for SANSN		Dr. Cichowicz	10/10	5	-	-	-	-	West Rand, Completed
	23-2. Accelerometer 3A25k		Dr. Nakatani	5/5	2	3	2	0	0	Completed
	23-3. Accelerometer 3A10k		Dr. Kawakata	2/2	3	2	0	0	0	Completed
	23-4. Accelerometer 3A10k		Dr. Kawakata	1/1	3	0	1	0	0	Completed
24	Data Acquisition System	Kinemetrics / Q330 A	Dr. Cichowicz	10/10	5	-	-	-	-	Completed
25	Field Processor	Kinemetrics / Marmot	Dr. Cichowicz	10/10	5	-	-	-	-	Completed
26	Lightening Protection	Kinemetrics / Protection	Dr. Cichowicz	10/10	5	-	-	-	-	Completed
27	Modem	CGS / EWON	Dr. Cichowicz	12/12	5	-	-	-	-	Completed
28	Power component	CGS	Dr. Cichowicz	10/10	5	-	-	-	-	Completed
29	Office equipment									
	A3 B/W photo copy		Miyara	1/1		-	-	-	-	Completed
	A3 color laser printer		Dr. Nakatani, Miyara	3/3		-	-	-	-	Completed
	A3 Scanner		Dr. Nakatani	2/2		-	-	-	-	Completed
	Laptop PC		Dr. Ogasawara	2/2		-	-	-	-	Completed

Annex 7: Training in Japan

As of Feb 2013

Scheme Term	Name	Organization	Period (Departure and Arrival)	Visited Institutions and Courses
Short-term	Mr. Thabang Ephraim Setlabosigo Kgarume	Researcher, CSIR	4 Nov 2012 – 23 Nov 2012	Tohoku University (micro fracturing and locating earthquake sources), Tokyo University (management of observation data and discussion on analysis method)
Long-term	-	-	-	-

Annex 9: Assignment of Counterpart Personnel (and Collaborating Researchers)

As of March 2013

Name		Position	Organization	Responsibility in the Project	Period
1	Ray Durrheim		CSIR/Wits Univ.	Project Manager, Output 1 leader, Output 3 leader, Output 4	Jun 2009 -
2	Thabang Kgarume		CSIR	Output 1, 2, 3	Oct 2009 -
3	Jan Kuijpers		CSIR/Wits Univ	Output 1	Oct 2009 -
4	George Henry		CSIR	Output 1	Oct 2009 -
5	Halil Yilmaz		Wits Univ	Output 1	Oct 2009 -
6	G. Oniyide		Wits Univ	Output 1	May 2012 -
7	Tawanda Zvarivadza		Wits Univ.	Output 1	May 2012 -
8	P. Mosakoa		Wits Univ.	Output 1	May 2012 -
9	S. Letlotla		CSIR	Output 1	May 2012 -
10	Alex Milev		CSIR	Output 2 leader, Output 4 leader	Jun 2009 -
11	Pieter Share		CSIR	Output 2,3	May 2011 -
12	Richard Masethe		Gold Fields/ Wits Univ.	Output 2, 3, 4	Oct 2009 -
13	Jonas Machake		CSIR	Output 2, 4	Jun 2009 -
14	B. Kagezi		CSIR	Output 2, 4	May 2012 -
15	Gideon Ferreira		CSIR	Output 4	May 2012 -
16	Lynsy Linzer		Wits Univ	Output 4, 5	Oct 2009 -
17	A. Yenwong-Fai		Wits Univ.	Output 4	Oct 2009 -
18	H. Uzoegbo		Wits Univ.	Output 4	Oct 2009 -
19	Artur Cichowicz		CGS	Output 4, Output 5 leader	Jun 2009 -
20	Denver Birch		CGS	Output 2, 5	Jun 2009 -
21	S. Zulu		CGS	Output 5	Apr 2010 -
22	Eldridge Kgawane		CGS	Output 5	Oct 2009 -
23	Gerhard van Aswegen Jnr		CGS	Output 5	Oct 2009 -
24	Paul Adamos		CGS	Output 5	Oct 2009 -
25	Robert Kometsi		CGS	Output 5	Oct 2009 -
26	Leonard Tabane		CGS	Output 5	Oct 2009 -
27	Linda Akromah		CGS	Output 5	Oct 2009 -
28	Lizelle Labuschagne (Brink)		CGS	Output 5	Oct 2009 -
29	Timothy Molea		CGS	Output 5	Oct 2009 -
30	Briar Zulu		CGS	Output 5	Apr 2011 -
31	Johan Oelofse		Moab Khotsong mine	Output 2	Jun 2009 -
32	Jerry Wienand		KDC West mine	Output 2	Jun 2009 -
33	Anthony K.Ward		Cooke4 mine	Output 2	Jun 2009 -
34	Steve Spossiswoode		Individual Consultant	Output 3, 4, 5	Oct 2009 -
35	Shaun K. Murphy		AngloGold Ashanti Ltd.	Output 1, 3	Jun 2009 -
36	Gerhard Hoffman		AngloGold Ashanti ltd.	Output 3	Jun 2009 -
37	Kevin Riemer		Sibanye Gold Ltd.	Output 3	Jun 2009 -
38	Patrick Lenegan		Sibanye Gold Ltd.	Output 3	Jun 2009 -
39	Nin Naicker		Sibanye Gold Ltd.	Output 3	Jun 2009 -
40	Dave Roberts		AngloGold Ashanti ltd.	Output 1	Oct 2009 -
41	Gerrie van Aswegen		Institute of Mine Seismology	Output 1	Jun 2009 -

This is a counterpart list updated during the Mid-term Review from the one attached to the minutes of 2nd JCC meeting (9 May 2012)

Annex 10: Grid of Project Progress (Progress at the Activity Level)

As of Feb 2013

Higher Level Post-project Objectives: Apply the seismic hazard assessment and control schemes developed in this project in deep South African mines and worldwide

Project Objectives: Understanding of the preparation and occurrence of earthquakes is enhanced, and risk management mechanism of mining-induced earthquakes is improved

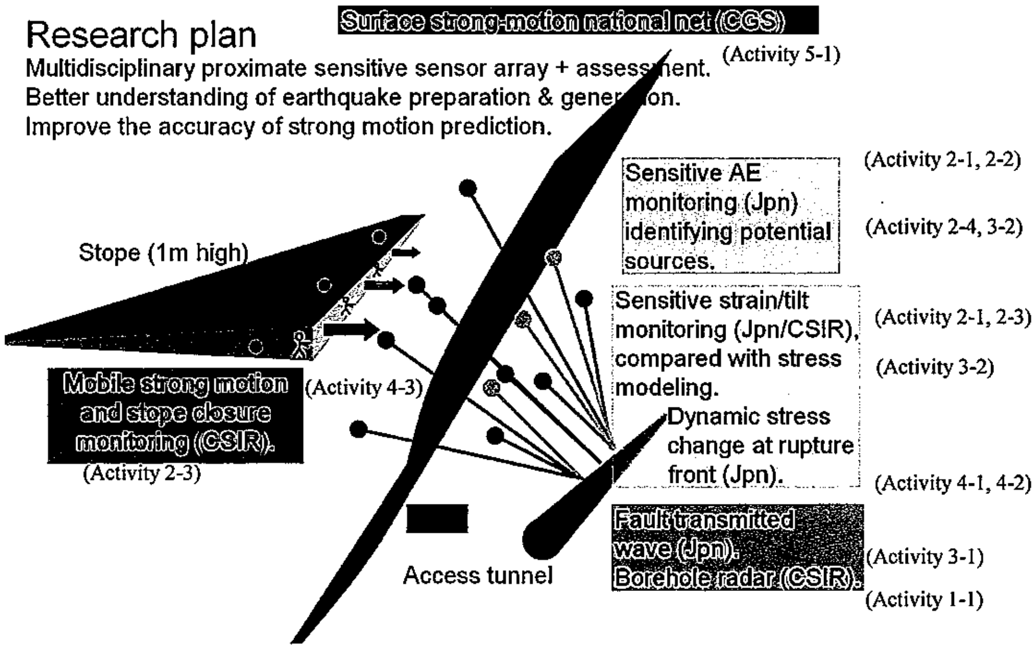
Indicator : The number of experimental sites and the quantity of knowledge that are obtained only by closed proximity monitoring in South African gold mines and contribute to improve systems to mitigate seismic risk

Activity	Achievement since the project was launched in August 2010	Researchers (Japanese side) (South African side)	Advance rate (%) Actual/Plan	Activity to be taken in the future
Output 1:Rock properties at seismic sources are elucidated **Indicator 1-1**: On-site observation and sample collection (Cook 4, KDC West, Moab Khotsong, and Mponeng mine) and the number of paper (one) **Indicator 1-2**: The number of lab investigations (two) and papers (one submitted)				
1-1. Observe and collect rock samples at seismic sources and its surroundings	The number and total length of the holes drilled in the proximity of anticipated hypocentral areas: about 70 holes and about 2.8 km respectively. Those intersecting the anticipated hypocenter fault: more than ten and several holes. Borehole scoping: almost all. Photo log of drilled core: almost all. The number of anticipated hypocenter faults of M2-3 accurately located : 3 The variety of mining scenarios or earthquake occurrence condition to be able to study : 3	Satoh, Nakatani, Yabe, Kawakata, Ogasawara, Lei Durrheim, Milev	100/100	-
1-2. Investigate rock properties in laboratory	The plans of lab experiments for rock specimen collected from earthquake source: the measurement of elastic properties, fracture parameters and characteristics, stress constrained by cores. The rock specimen exported to Japan: (a) The 80m core intersecting a M2 earthquake source at 3.4km depth at Mponeng mine. (b) The selected cores (about 10m long in total) of drilling intersecting anticipated seismic faults at 1km depth at Cooke 4 mine. The cores we could carry out lab-tests: (a)	Satoh, Lei, Yabe, Kawakata, Otsuki, Ogasawara Roberts, Durrheim, Yilmaz	20/50	Lab experiments for the core samples of KDC West and Moab Khotsong. Taking implementation of the outcome into consideration, apply the obtained data to upgrade seismic risk assessment scheme (for example, elastic moduli will be used to convert measured strain to stress; the constrained stress will be used to calibrate stress modelling) Fosterage South African younger researchers Prompt lab experiments of our core sample in South Africa
Output 2:Understanding of the preparation and forerunners of earthquakes in gold mines is enhanced **Indicator 2-1**:The number of monitoring network (Cooke 4, Moab Khotsong, KDC West mines; published one related paper) **Indicator 2-2**: Micro fracturing monitoring (Cooke 4 and Moab Khotsong mine; published one related paper) **Indicator 2-3**: Rock deformation monitoring (Cooke 4, KDC West, Moab Khotsong and other mines; published two related papers) **Indicator 2-4**: Data analyses of the sensitive close monitoring (published one related paper; three papers in preparation)				
2-1. Install monitoring systems for micro-fracturing and rock deformation, and sensitive long	Cooke 4 mine: Completed the installation plan (the sensors currently in operation are several tens of AE sensors, several acceleration sensors, two strainmeters, one broadband seismometer)	Nakatani, Ogasawara, and others Kgarume and others	100/100 100/100	

period seismometers in the vicinity of impending earthquake sources	Moab Khotsong mine: Installed are all planned three strainmeters (three), two third of the planned AE sensors (several tens). Two tiltmeters, two broadband seismometers, stope closure system are to be installed. KDC West mine: Completed the installation; three strain meters and two tiltmeters. Stope closure system is to be installed.	Nakatani, Ogasawara Milev and others Ogasawara Milev and others	70/100 20/100 100/100 80/100	Complete the installation of AE sensors and broad band seismometers. Complete the installation of tiltmeters and stope closure meters. Complete the installation of a stope closure system.
2-2.Monitor the activities of micro fracturing	Cooke 4 mine: AE has been monitored since 2011. Moab Khotsong mine: to be started by the 2nd quarter of 2013.	Nakatani and others Kgarume and others	60/70 60/70	At the both mines, seismicity is getting active in the near future, being monitored until the seismicity will cease.
2-3. Monitor the accumulation and release of stress in and around the impending earthquake source	Cooke 4 mine: Strain has been monitored since the end of 2010. Established an automatic reporting system (currently not in operation because of the shaft cable problem). KDC West mine: Strain has been monitored since the end of 2011, and Tilt since the end of 2012. Moab Khotsong mine: started monitoring two strainmeters at 95L since the end of 2012. Assisted South Deep mine to monitor strain. Planned to assist strain monitoring at KDC East mine. Transferring Japanese technology to measure in-situ rocks stress in a procedure modified most suitably for South African gold mine working condition. Succeeded measurements at Moab Khotsong mine.	Ogasawara and others Ogasawara and others Milev and others Ogasawara and others Milev and others Ogasawara and others Ogasawara and others	80/70 60/70 60/70 40/70 20/70 50/No 50/No	Get the automatic reporting system in operation Get the automatic reporting system in operation. Start stope closure monitoring Start strain monitoring at 98L, and establish an automatic reporting system. Start monitoring of tilt at 95 and 98 levels, and stope closure monitoring. At the above three mines, the seismicity is getting active in the near future. Monitor the data associated with the seismicity. Start Kloof mine monitoring. Increase the number of measurements. Establish a structure in South Africa to procure necessary tools and carry out measurement. On the above topics, write papers (some of the papers might be published after the project period only).
2-4. Analyze the monitored data to clarify the forerunning phenomena and its characteristics	Mponeng mine: found very clear forerunning strain change for an M0 earthquake. Cooke 4 mine: AE: Completed locating some of the monitored events and estimating the magnitudes. Found (1) very small fracturing prevailing on some existing weak planes, (2) AE activities that suggest quasi-static development of fracture in areas with high differential stress. Manuscripts for three papers are now in preparation. Strain: Moab Khotsong mine: AE:	Katsura, Ogasawara Nakatani, Naoi, Murakami Ogasawara and others Nakatani, Naoi, Murakami Kgarume	50/0 50/30 50/30 0/30 0/30	Increase the number of case studies and write papers. Wait for target events as seismicity is getting active. Analyze data increasing with time. Same as above. Same as above. Same as above.

	Strain: Tilt: Stope closure: <u>KDC West mine:</u> Strain: Tilt: Stope closure: <u>Other mines:</u>	Ogasawara and others Milev and others Milev and others Ogasawara and others Milev and others Milev and others Ogasawara	5/30 0/30 0/30 20/30 10/30 0/30 5/No	Same as above. Same as above. Same as above. Same as above. Same as above. Same as above. Same as above. Write papers on the above topic (some of the papers might be published after the project period only).
Output 3: Reliability of seismic hazard assessment in gold mines is improved. **Indicator 3-1:** The number of papers on the studies on stress change and rock mass instability (published one; one in preparation). **Indicator 3-2:** The number of papers on upgrading the scheme of hazard assessment (published one; one in preparation).				
3-1. Evaluate spatiotemporal changes in stress and rock mass stability based on the data produced by mine's microseismic network	Installation of transmitter, receiver (accelerometer), transmission unit, and multi-type recorder at Cooke 4 (and to be installed at Moab Khotsong) Could estimate stress drops in higher accuracy for the accelerograms obtained at Mponeng mine. The variance of the stress drop in a narrow spatio-temporal range (<1day, <100m?) were acceptably small, which could contribute to estimate spatio-temporal distribution of stress drop. A paper is in preparation.	Kawakata, Nakatani, Yabe, Wada, Naoi, Doi, Murakami	30/40	Analyze data being obtained at Cook 4 and Moab Khotsong mine. Write papers on the above topic (some of the papers might be published after the project period only).
3-2. Upgrade the scheme of seismic hazard assessment by calibrating existing schemes with the data obtained through the activities 2-2, 2-3 and 3-1	Found AE activities cluster at Cook 4 mine. So, for each cluster, started estimating stress drop, activity of microfructuring and the magnitude-frequency relationship, which will contribute to calibrate existing seismic risk assessment. Attempted to constrain stress and strength on a M2 seismic fault based on stress modelling (published one paper). However, introducing in-situ stress data, the analysis has to be upgraded.	Naoi, Nakatani, Murakami, Kawakata, Doi Ogasawara Hofmann	5/40 10/40	Analyze AE data at Cooke 4 and Moab Khotsong mines. Analyze the data of fault-transmitting-wave experiments at Cooke 4 and Moab Khotsong mines. Analyze any spatio-temporal relationship between larger seismic events and the above data. Increase the number of case studies. Write papers on the above topic (some of the papers might be published after the project period only).
Output 4: Reliability of strong motion predictions in gold mines is improved **Indicator 4-1:** On-fault monitoring of dynamic stress change (Cooke 4 and KDC west mines; published 2 papers; 1 in preparation) **Indicator 4-2:** The number of papers on analyses of observed strong motion (some are in progress) **Indicator 4-3:** The number of papers on monitoring of strong motion at underground stope in gold mines (to be started in 2013; published one paper to describe the scope of the monitoring) **Indicator 4-4:** The number of papers on site motion analysis. **Indicator 4-5:** Number of papers on scaling law.				

Indicator 5-3: The number of papers on the obtained parameters to better predict strong ground motion on surface				
5-1. Install seismic stations in the Far West Rand mining district (Carletonville area) on the surface to monitor surface ground motion caused by mine tremors	Completed the installation of the planned 10 stations. The number of surface stations in the Far West Rand district became 10 times larger than before. Strong motion at the Far West Rand now can be recorded without being clipped. In-mine underground seismic networks have been unable to fully record strong motion.	Cichowicz, CGS	100/100	-
5-2. Upgrade the Data Center in the Silverton offices of the Council for Geoscience	Installed a new seismogram analysis computer system that enables CGS to locate more than before and within accuracies better than before. Establishing new routines for processing data using Antelope system, which involves retraining a group of analysts.	Cichowicz, CGS Group	100/100	-
5-3. Develop and validate a parametetric model that will be capable of predicting strong ground motion	Surface soil velocity structure was investigated (one report; one paper).	Cichowicz, CGS Group	10/0	Develop and validate a parametetric model that will be capable of predicting strong ground motion. Write papers on the above topic (some of the papers might be published after the project period only).



Annex 11: The Project Status as at February 2013

Gold Mine Name		Cooke 4 (ex. Ezulwini)	Moab Khotsong	KDC West (ex. Driefontein)
Owner		Gold One	Anglogold Ashanti	Sibanye Gold (ex. Gold Fields)
Ore body at experimental site		Several reef packages 10s of metres thick	Single thin tabular reef (<2m), many faults	Single thin tabular reef (<2m), few faults
Mining Scenario		Extraction of shaft pillar, 400 m dia.	Extensive scattered mining	Sequential grid mining
Depth		About 1 km	About 3km	About 3km
Concern		Instability of faults in the shaft pillar	Instability of large faults	Instability of dip pillar
Fault Characteristics		Fault gouge a few 10s of cm thick	Fault zone, a few 10s of meter thick	Fault gauge a few cm thick
Applicability of Research to Mining		Final stage mining e.g. shaft pillars	Mining in highly faulted districts	Sequential grid mining at depth
Japanese Activity				
Source Rock Property Analysis	Output 1 (Dr. Sato)	Core specimen from the seismic source shipped to Japan for specialized test.	-	-
Sensitive Acoustic Emission Monitoring	Output 2 (Dr. Nakatani)	A few tens out of 30 AE sensors (#13) and 3 accelerometer (#23-2) in operation. AE Recorder (#11) in operation	Installed 3/4 of a few tens out of AE sensors (*, **) and 2 accelerometers (#23-2) AE Recorder (*) was installed on 28 Feb 2013.	-
Sensitive Strain Monitoring	Output 2,3 (Dr. Ogasawara)	2 strainmeters (#2) installed in December 2010, and currently in operation	3 strainmeters (#2) installed in December 2011 and 2 are currently in operation	3 strainmeters (#2) installed in August 2012 and currently in operation
Slow fault slip	Output 2 (Dr. Naoi)	1 Broad-band seismometer (#4) in operation	1 Broad-band seismometer (#4) to be installed. Another Broad-band seismometer (*) to be installed	-
Fault Transmitted Wave (Velocity & attenuation)	Output 3 (Dr. Kawakata)	1 Transmitter (#8, #9), 2 Receivers (#23-3 Accelerometer) and another 1 Receiver (**) in operation (#1)	2 Transmitters (#8, #9) installed. 1 Receiver (#23-4, Accelerometer) and another 2 Receivers (**) to be installed (#1)	-
In-situ Stress Measurement with Geological Drilling	Output 1,3 (Dr. Ogasawara)	Planned	Completed with overcoring tools (#15)	Planned
Dynamic Stress Change at Rupture Front	Output 4 (Dr. Yabe)	3 Dynamic Rupture Sensor (#7) near fault in operation	-	4 Dynamic Rupture Sensor (#7, #5, #6) near fault in operation
South African Activity				
Source Rock Property Analysis	Output 1 (Dr. Durrheim)	Core specimen from the seismic source to be analyzed at Wits Univ	Core specimen from the seismic source to be analyzed at Wits Univ	Core specimen from the seismic source to analyzed at Wits Univ.
Borehole Radar	Output 1 (Dr. Durrheim)	-	Survey completed (Procured with CSIR budget)	-
Sensitive Tilt Monitoring	Output 2 (Dr. Milev)	-	1 tiltmeter (#19) installed Another 1 tiltmeter (#19) to be installed	2 tiltmeters (#19) in operation
Stope Closure Monitoring	Output 2 (Dr. Milev)	-	1 set (#20 closure meter system) to be procured	1 set (#20 closure meter system) to be procured
Stope Ground Motion	Output 4 (Dr. Milev)	-	1 set accelerometers (#18 5 Seismic transducers) to be procured	1 set accelerometers (#18 5 Seismic transducers) to be procured
Surface ground motion	Output 5 (Dr. Cichowicz)	Ten surface CGS national stations were completed by JICA in Far West Rand area. (#24, #25, #26, #27,#28)	5 accelerometers (#23-1) CGS own network is not yet completed	Ten surface CGS national stations was completed by JICA in Far West Rand area. (#24, #25, #26, #27,#28)
Status of Project activity as at February 2013		Have accumulated underground data for about 2 years	Completed drilling and 80% of underground installation	Completed Japanese installation

The number in the parenthesis is the item number of machinery and equipment as listed in the Annex 7.
(*) Procured with Japan Grants-in-Aid for Scientific Research
(**) Procured with MEXT's Observation and Research Program for Prediction of Earthquakes and Volcanic Eruptions

Annex 12: A list of publications and presentations

1. Reviewed Papers

1. [INVITED] Ogasawara, H., H. Kawakata, H. Ishii, M. Nakatani, Y. Yabe, Y. Iio, and The Research Group for the Semi-controlled Earthquake-generation Experiments at Deep Gold Mines, South Africa, Semi-controlled Earthquake-generation Experiments in Deep Gold Mines, South Africa – Monitoring at Closest Proximity to Elucidate Seismogenic Process-, Zisin (Journal of the Seismological Society of Japan), 61, S563-S573, 2009.
2. Ogasawara, H., R.J. Durrheim, M. Nakatani, Y. Yabe, A. Milev, A. Cichowicz, H. Kawakata, H. Moriya, JST-JICA SA research group, a Japanese - South African collaboration to mitigate seismic risks in deep gold mines, Proceedings of 1st Hard Rock Safe Safety Conference, South African Institute of Mining and Metallurgy, 115-134, 2009.
3. Durrheim, R.J., H. Ogasawara, M. Nakatani, Y. Yabe, A. Milev, A. Cichowicz, H. Kawakata, H. Moriya and the JST-JICA SA research group, Observational study to mitigate seismic risks in mines: a new Japanese –South African collaborative project, Proceedings of South African Geophysical Association Biennial Technical Meeting and Exhibition, 73-79, 2009.
4. Yabe, Y., J. Philipp, M. Nakatani, G. Morema, M. Naoi, H. Kawakata, T. Igarashi, G. Dresen, H. Ogasawara, and JAGUARS, Observation of numerous aftershocks of an Mw 1.9 earthquake with an AE network installed in a deep gold mine in South Africa, Earth Planets Space, 61, e49-e52, 2009.
5. Durrheim, R.J., H. Ogasawara, M. Nakatani, Y. Yabe, A.M. Milev, A. Cichowicz, H. Kawakata, H. Moriya, and SATREPS Research Group, Observational studies to mitigate seismic risks in mines: a new Japanese - South African collaborative research project, The proceedings of the fifth International Seminar on Deep and High Stress Mining, 6-8 Octobér 2010, Santiago, Chile, Australian Centre for Geomechanics, 215-226, 2010.
6. Cichowicz, A., D. Birch, and H. Ogasawara, Multi-Channel Analysis of Surface Waves: Inversion Strategy, Proceedings of the thirteenth International Conference on Civil, Structural and Environmental Engineering Computing, Edited by: B.H.V. Topping and Y. Tsompanakis, Civil-Comp Press, Stirlingshire, 2011, doi:10.4203/ccp.96.205.
7. Naoi, M., M. Nakatani, Y. Yabe, G. Kwiatek, T. Igarashi, and K. Plenkers, Twenty thousand aftershocks of a very small (M2) earthquake and their relation to the mainshock rupture and geological structures, Bulletin of the Seismological Society of America, 101 (5), 2399-2407, 2011, doi: 10.1785/0120100346.
8. Durrheim, R.J., H. Ogasawara, M. Nakatani, Y. Yabe, A.M. Milev, A. Cichowicz, H. Kawakata, O. Murakami, M. Naoi, N. Yoshimitsu, T. Kgarume, and the SATREPS Research Group, a Japanese - South African collaboration to mitigate seismic risks in mines: establishment of

experimental sites, Proceedings of the sixth International Seminar on Deep and High Stress Mining, 23-30 March 2012, Perth, Australia (ed. Yves Potvin), Australian Centre for Geomechanics, pp.173-187.

9. 【Invited】Durrheim, RJ, Mitigating the risk of rockbursts in the deep hard rock mines of South Africa: 100 years of research, In Extracting the Science: a century of mining research, J. Brune (editor), Society for Mining, Metallurgy, and Exploration, Inc, ISBN: 978-0-87335-322-9, pp. 156-171, 2012.
10. Ogasawara, H., H. Kato, G. Hofmann, and P. de Bruin, Trial of the BX conical ended borehole overcoring stress measurement technique, Proceedings of the second Southern Hemisphere International Rock Mechanics Symposium, South African Institute of Mining and Metallurgy, 15 May 2012, Sun City, South Africa, pp. 169-179, 2012.
11. Durrheim, R.J. and H. Ogasawara, Can mine tremors be predicted? Observational studies of earthquake nucleation, triggering and rupture in South African mines, Proceedings of the second Southern Hemisphere International Rock Mechanics Symposium, South African Institute of Mining and Metallurgy, 16 May 2012, Sun City, South Africa, pp. 327-343, 2012.
12. Ledwaba, L.S., J.B. Scheepers, R.J. Durrheim, and S. Spottiswoode, 2012, Seismic damage mechanism at Impala platinum mine. In Proceedings of the Second Southern Hemisphere Rock Mechanics Symposium, Symposium Series S71, South African Institute of Mining and Metallurgy, ISBN 978-1-920410-27-8, pp. 367-385.
13. Hofmann, G., H. Ogasawara, T. Katsura, and D. Roberts, An attempt to constrain the stress and strength of a dyke that accommodated a ML2.1 seismic event, Proceedings of the second Southern Hemisphere International Rock Mechanics Symposium, South African Institute of Mining and Metallurgy, 16 May 2012, Sun City, South Africa, pp. 436-450, 2012.
14. 【Invited】Riemer, K., and R.J. Durrheim, Mining seismicity in the Witwatersrand Basin: monitoring, mechanisms and mitigation strategies in perspective, Journal of Rock Mechanics and Geotechnical Engineering. 2012, 4 (3): 228–249.
15. Ogasawara, H., H. Kato, G. Hofmann, and P. de Bruin, Trial of the BX conical ended borehole overcoring stress measurement technique, J. South African Institute of Mining and Metallurgy, 102 (8), pp.479-753, 2012.
16. Yoshimitsu, N., H. Kawakata, A. Yamamoto, H. Ogasawara, and Y. Iio, Temporal changes in attenuation of S waves through a fault zone in a South African gold mine, Geophysical Journal International, doi: 10.1111/j.1365-246X.2012.05678.x, 2012.
17. Moriya, H., M. Naoi, M. Nakatani, O. Murakami, T. Kgarume, A.K. Ward, R. Durrheim, J. Philipp, Y. Yabe, H. Kawakata, and H. Ogasawara, Detection of mining-induced fractures around a stope in Ezulwini gold mine, South Africa, by using AE events with similar waveforms, Proc. 21th Int. Acoustic Emission Sym., Jap. Soc. for Non-Destructive Inspection,

Tokyo, 2012. 181-186.

18. OGASAWARA, H., H. KATO, G. Hofmann, P. de Bruin, and K. Sakaguchi, Trial of a downsized ccbo technique optimized for South African highly stressed deep levels gold mines, Proc. 13th Symp. Jpn. Soc. Rock Mech., pp.465-470, 2013.
19. Cichowicz, A., D. Birch, and H. Ogasawara, Non-invasive method of estimation of stiffness of near surface material using surface wave, Geotechnical and Geophysical Site Characterization4 (Coutinho & Mayne, eds), Taylor & Francis Group, London, pp. 1321-1325, 2013.

20. 2. Presentations at scientific meetings
21. 2.1 Invited presentations

22. Ogasawara, H. and Research Group for SeeSA (Semi-controlled Earthquake-generation Experiment in deep South African gold mines), Monitoring, Prediction and Control of Seismic Activity in deep South African gold mines, Programme and Abstracts, The Seismological Society of Japan, 2009 Fall meeting, D11-06, October 21, 2009, Kyoto, Japan.
23. Nakatani, M., Semi-controlled Earthquake-generation Experiment in deep South African gold mines, the 124th Fukada Geological Institute seminar, January 15, 2010, The Fukada Geological Institute, Tokyo, Japan.
24. Ogasawara, H., C. Srinivasan, A. Cichowicz, O. Goldbach, K. Bosman, Water-ingress induced seismicity in mines in Japan, India and South Africa, ICDP Workshop "Scientific Deep Drilling to Study Reservoir Triggered Earthquakes at Koyna, India", 21 March 2011, Hyderabad, India.
25. Ogasawara, H., Keynote: the great eastern Japanese earthquake and tsunami of 11 March 2011 and the research we are doing in South African gold mines, AfricaArray Workshop 2011, 21 November 2011, University of Witwatersrand, Johannesburg, South Africa.
26. Riemer, K., and R.J. Durrheim, Mining seismicity in the Witwatersrand Basin: monitoring, mechanisms and mitigation strategies in perspective, International Top-level Forum on Engineering Science —Safe Construction and Risk Management of Major Underground Engineering, 18-19 May 2012, Wuhan, China.
27. Durrheim, R.J., A keynote address: Observational studies in South African mines to mitigate seismic risks, The Fourth International Conference on New Development in Rock Mechanics & Engineering (NDRM2012), 14-17 September 2012, Shenyang, China.

2.2 Oral presentation at scientific meetings （Japanese domestic 7, International 10)

1. Nakatani, M., M. Naoi, Y. Yabe, H. Ogasawara and JAGUARS, Acoustic Emission Measurements in the Vicinity of a M2 Earthquake Rupture in a Deep Gold Mine in South

Africa, French-Japanese International Workshop on Earthquake Source, 5 October 2009, Paris, France.

2. Ogasawara, H., R.J. Durrheim, M. Nakatani, Y. Yabe, A. Milev, A. Cichowicz, H. Kawakata, H. Moriya, T. Satoh, SATREPS, A Japanese-South African Collaboration for Observational Study to Mitigate Seismic Risks in Mines, Programme and Abstracts, The Seismological Society of Japan, 2009 Fall meeting, A31-01, October 23, 2009, Kyoto, Japan.
3. Milev, A., R.J. Durrheim, M. Nakatani, Y. Yabe, H. Ogasawara, JAGUARS Research Group, and SATREPS, SA Gold Mine Research Group, Joint South African and Japanese studies of rock mass behavior around deep level mining in South Africa, Programme and Abstracts, The Seismological Society of Japan, 2009 Fall meeting, A31-02, October 23, 2009, Kyoto, Japan.
4. Naoi, M., M. Nakatani, G. Kwiatek, K. Plenkers, Y. Yabe and JAGUARS group, Aftershock activity of a M2 EQ in a deep South African gold mine - spatial distribution and magnitude-frequency relation -, Programme and Abstracts, The Seismological Society of Japan, 2009 Fall meeting, A31-02, October 23, 2009, Kyoto, Japan.
5. Ogasawara H., R. Durrheim, M. Nakatani, Y. Yabe, A. Milev, A. Cichowicz, H. Kawakata, H. Moriya, T. Satoh, S. Murphy, A. Ward, G. Morema, M. Kataka, R. Vermeulen, G. van Aswegen, Research Group of SATREPS, A Japanese - South African Collaboration for Observational Studies to Mitigate Seismic Risks in Mines (2), ABSTRACTS, Japan Geoscience Union Meeting 2010, SSS020-13, May 26, 2010, Chiba, Japan.
6. Durrheim, R.J., H. Ogasawara, M. Nakatani, Y. Yabe, A.M. Milev, A. Cichowicz, H. Kawakata, H. Moriya, and the SATREPS research group, Observational studies to mitigate seismic risks in mines: a new Japanese - South African collaborative research project, The proceedings of the fifth International Seminar on Deep and High Stress Mining, 6-8 October 2010, Santiago, Chile.
7. Ogasawara, H., M. Nakatani, Y. Yabe, H. Kawakata and SATREPS Research Group, Fault instability monitoring at South African mines, ISS Mini Seminar at Western Levels, South Africa, 19 November 2010, Western Levels, South Africa.
8. Milev, A.M., Yabe, Y., Naoi, M., Nakatani, M., Durrheim, R.J., Ogasawara, H., Scholz, C.H., Coseismic and aseismic deformations of the rock mass around deep level mining in South Africa - Joint South African and Japanese study, Abstracts S34B-05 presented at 2010 Fall Meeting, AGU, 13-17 December 2010, San Francisco, USA.
9. gasawara, H., R. Durrheim, M. Nakatani, Y. Yabe, A. Milev, A. Cichowicz, H. Kawakata, O. Murakami, M. Naoi, H. Moriya, T. Satoh, Research Group, Semi-controlled earthquake-generation experiments in South African gold mines (2010), ABSTRACTS, Japan Geoscience Union Meeting 2011, SSS029-07, May 23, 2010, Chiba, Japan.
10. Ogasawara, H., Monitoring of Stress Build-up and Instability on Faults, Institute of Mine

Seismology, 2011 Seminar on the future of monitoring seismic rock mass response to mining, 23 May 2011, Hermanus, South Africa.

11. Ogasawara, H., Multidisciplinary monitoring of flooding induced seismicity in Japan and what we can do in South Africa, Council for Geoscience 4th Annual Seismology Workshop on Fluid-induced seismicity, 16 August 2011, Council for Geoscience, Pretoria, South Africa.
12. Ogasawara, H., R. Durrheim, M. Nakatani, Y. Yabe, A. Milev, A. Cichowicz, H. Kawakata, O. Murakami, M. Naoi, H. Moriya, T. Satoh, SATREPS research group. Observational studies of earthquake preparation and generation to mitigate seismic risks in mines, IUGG, 3 July 2011, IUGG, Melbourne, Australia.
13. Kawakata, H., N. Yoshimitsu, M. Nakatani, J. Philipp, I. Doi, M. Naoi, T. Ward, G. Morema, V. Visser, S. Khambule, T. Masakale, A. Milev, R. Durrheim, L. Ribeiro, M. Ward, H. Ogasawara, Monitoring transmitted waves across a fault with a high potential for mining induced earthquakes – the Ezulwini gold mine in South Africa, Programme and Abstracts, The Seismological Society of Japan, 2011 Fall meeting, D21-08, October 13, 2011, Shizuoka, Japan.
14. Ogasawara, H., G. Hofmann, D. Roberts, S. Nakao, H. Kato, Attempts to constrain stress and strength in seismogenic volumes at deep South African gold mines, Programme and Abstracts, The Seismological Society of Japan, 2011 Fall meeting, C22–03, October 13, 2011, Shizuoka Japan.
15. Durrheim, R.J., H. Ogasawara, M. Nakatani, A. Milev, A. Cichowicz, H. Kawakata, Y. Yabe, O. Murakami, M. Naoi, H. Moriya, and T. Satoh,. Observational Studies of Earthquake Preparation and Generation to Mitigate Seismic Risks in Mines, Abstracts S41D-058 presented at 2011 Fall Meeting, AGU December 2011, San Fransisco.
16. Durrheim, R.J., H. Ogasawara, M. Nakatani, Y. Yabe, A.M. Milev, A. Cichowicz, H. Kawakata, O. Murakami, M. Naoi, N. Yoshimitsu, and T. Kgarume, Establishment of SATREPS experimental sites in South African gold mines to monitor phenomena associated with earthquake nucleation and rupture, Sixth International Seminar on Deep and High Stress Mining 2012, 9:00, 30 March 2012, Perth, Australia.
17. Ogasawara, H., H. Kato, G. Hofmann, P. de Bruin, A modified CCBO technique optimised for regular geological drilling procedures in South African gold mines, ACG Stress Measurement Workshop, 31 March 2012, Perth, Australia.

2.3 Posters presented at scientific meetings (Japanese Domestic 7, International 3)

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Annex 13: Evaluation Grid (Information and Data for the 5 Criteria)

Evaluation Criteria	Evaluation Question	Source	Information through Questionnaire, Interview and relevant reports
1. Relevance	1.1 Development of policies/programs of the country associated with seismic risk mitigation.	DMR	- The government position is the extension of the life of mines: how we can reach deeper ore without putting mine workers more risks and cost-efficient. The Project can contribute the industry more profitable. - DMR could arrange a session convening mining company to make them aware of the research activity. - DMR can also recommend to the Minister, in future.
		MHSC	- MHSC can't directly contribute to the Project but continues to be an interested stakeholder in term of how the project results can be applied. What MHSC want to support is mineral production safely and economically, and not fundamental research. - MHSC has stopped research funding; we have to use already-gained knowledge into implementation first, then we will find what we will study more. - Chamber of Mine, through MOSH (Mining Industry Occupational Safety and Health), not conducting research but promoting dissemination of technology among companies, may give the Project access to mine managers for technology transfer. - From the national perspective, this is the only project MHSC is aware of which is working on the improvement of mine safety. MHSC initiated a project to monitor mining-related seismicity in Central Rand and KOSH (Klerksdorp-Orkney-Stilfontein-Hartebeestfontein), but this is for mines closed and flooded - MHSC's budget is about 1/5 of the Project budget, which is 70 million ZAR for five years (JICA, JST and Grand-in Aid for Scientific Research and others combined)
		CGS	- The Geoscience Amendment Act (2010) accepted by Parliament, CGS has become the custodians of all seismological (geo-scientific) data in South Africa.
	1.2 Importance of the research	CSIR/Wits	- The main avenue of the Project was summarized in a paper published by Dr.Durrheim and Dr.Ogasawara (2012). The hypothesis is that there are measurable changes in some or all of the following physical parameters that than be used to predict the time and location of mining-induced ruptures: stress, strain rate, tilt rate, acoustic emission rate, seismic source parameters, electromagnetic emission rate, and microcrack density. - Past attempts to observe precursory phenomena in South Africa mines have already been reviewed, as these studies provide the baseline for the project present experiment. The Project hopes that the array of sate-of-the-art instruments will reveal precursory phenomena that have hitherto been obscured by noise, as well as co-seismic rupture phenomena that have never been observed in the near-field. - The Project givens us a unique opportunities to have access to near hypocenter of mining-induced earthquakes and to see forerunners which has never been observed before. - Installation for integrated system for quasi-static and dynamic monitoring will contribute significantly in understanding mine induced seismic events in all instances.
		Gold Fields (Driefontein)	- The project, for example stress measurement, is very relevant for the mining industry. A big mine such as Driefontein which normally has 50 panels (mining front) of 30 m long, thus taking out significant amount of rock. Mining is a primary cause to induce earthquakes. - The project tells a lot of strain and data for numerical modeling, and leans more about earthquake source area.
	1.3 Alignment of the Project with the needs and expectation of the implementing organizations.	CSIR/Wits	- The Project is fully aligned with the CSIR's needs. Research of CSIR CIM takes place in three areas; 1) Human factors (heat stroke death, silicosis from dust, noise-induced hearing loss); 2) Real-time risk management (sensor and communication system, "AziSA" to manage risk such as rock falls, rock bursts and seismic events, and mining process optimization) 3) Novel mining (such as mechanization/automation, improved ore-body information to lower mining costs)
		Wits Univ.	- WMRI (Wits Mining Research Institute) was launched in September 2012 to advance the sustainability of the mining sector and affected societies. It aims to serve as Africa's leading multidisciplinary research in all technical, social and economic aspects of mining, helping the key part of SA economy to reach its potential.
		CGS	- The Project is fully aligned. Before 2010, CGS had only a few stations in the mining districts. Starting from 2010, CGS had installed more than 50 stations in the mining districts. The new station are in KOSH area (25 stations), Far West Rand area (12 stations, 10 of which were sponsored by JICA Project) and Central Basin area (12 stations already installed and 5 in the process of installation)
	1.4 Changes of structure/staff of the implementing organizations that may affect the Project	CSIR/Wits	- There are several turnover of counterpart personnel of CSIR and Wits University

	implementation.		
	1.5 Priority areas of the Government of Japan for the cooperation to South Africa.	Hearing (Project, JICA)	- Science and Technology session was held on 28 February 2013, a day before the 12th South Africa – Japan Partnership Forum on 1st March 2013, which was a bilateral cooperation mechanism between Japan and South Africa. - Science and Technology is one of prioritized areas and SATREPS is drawing strong attention of South African government.
2. Effectiveness	2.1 Progress and prospect of completion of each output.		
	Output 1 – Rock properties at seismic sources are elucidated.	CSIR/Wits	- No problems are anticipated. All planned boreholes have been drilled and logged and core specimen has been stored. The MTS (Material Testing Systems) rock testing machine at Wits Univ has been refurbished. A permit to conduct research on rocks has been obtained and rock specimens are exported to Japan for specialized testing. Research students for rock testing in Wits University have been recruited - Two researchers of CSIR with MSc will be registered for PhD to work on the Project. - The number of testing could be: 3～4 different rock types X 5 repetition X 3 sites = about 60 rock testing.
	Output 2 – Understanding of the preparation and forerunners of earthquakes in gold mines is enhanced.	CSIR/Wits	- Installation of monitoring equipment and data acquisition for underground is complex and tedious process. It also has to comply the production cycles and mini-specific cultural and economic situation. This part is not easily predictable and can cause delays. - South African activity for Output 2 & 4 are conducted at only two site: Moab Khotsong and KDC West. There are some delays in Output 2 & 4 in term of equipment installation. - During 2012 there were strikes on all three target mines. The mines are operational again, but it's possible that the industrial action could recur. - It is also possible that mine management could adjust/change mining plans, which may affect the collection of intended data from the monitoring network. This is the biggest concern (in particular for Moab Khotsong)
		OHMS	- Anglogold Ashanti has rock engineering department, but seismology is outsourced to IMS which is responsible for the maintenance of monitoring software and hardware. - OHMS has 14 technicians in the Seismic Department, 7 out of which are working in this office. Out of the 7, only Mr. Raymond and Mr. Thabang are working for the Project. (Previously maximum 4 OHMS technicians worked for the projects) - The last equipment will be installed next month at Moab Khotsong as soon as the planned place is cleaned up of rocks and debris. - IMS designs and delivers seismic equipment (geophones) and it's almost monopoly in the world.
	Output 3 – Reliability of seismic hazard assessment in gold mines is improved.	CSIR/Wits	- This output depends on the availability of data. Progress could be affected if there are delays in mining activities near project target area. (see output 3)
		Expert	- Current overcoring requires high quality drilling and intact rock mass of at least 30cm long. It takes at least a few days to complete a cycle of tasks necessary for a single overcoring. - CCBO (compact conical-ended borehole overcoring) technique in BX size (60mm in diameter) was successfully conducted in August and September 2011 at Moab Khotsong (at 3.0km depth), overcoring of 19cm at a distance of about 14m of the hole from the sidewall of the tunnel. The cycle of procedures necessary for an overcoring, including shaping the borehole-end conically, gluing a 16-element strain cell, and overcoring was completed within 2.5 hours. - With the tools procured in South Africa, BX CCBO techniques was conducted in January and February 2013 at Mponeng (at 3.4km depth with minimal mining) and Tau Tona (at 3.0km depth near a M1.5 damage). The Tau Tona stress (145 MPa, 4000 μstrain) was much larger than Mponeng (90 MPa, 2600 μstrain) and Moab Khotsong (80 MPa, 2000 μstrain) - The stress is greater with significant difference than the predicted values of existing numerical computer model. - CCBO requires only 10cm overcoring to complete stress relief; it is faster and easier than current techniques and may enable a successful overcoring in heavily fractured condition. - The CCBO techniques was transferred to the people from two mines (Anglogold Ashanti) and two geotechnical consulting companies (Seismogen and Ground Work)
		Gold Fields (KDC West)	- The company already has a good hazard assessment system, monitoring seismic events of Driefontein with about 30 geophones placed 2-3 km in underground at the Central control room. - The company has "Short Term Seismic Hazard Ratings Table" and the ratings system is different from company from company as there are still lots of unknown. Gold Fields has their own rating while e.g. Anglogold Ashanti uses IMS rating although both companies uses the IMS seismic monitoring system.. - What we need to do is 1) increase the sensitivity of monitoring system as that of geophones is limited, 2) directly measure the stress. However, these will not be verified until a seismic event occurs.

		OHMS	- Stress measurement was very expensive before, could cost 300,000 ZAR for a single measurement. Now the CCBO could be 3 times cheaper, about 100,000 ZAR and for the first time an affordable method for stress measurement. This instrument can also contribute to more accurate computer modeling.
		Ground Work	- CCBO is faster and can measure the stress with much shorter length. The biggest advantage is that it can be done quickly. With this technique, mine should do more measurement and can modify mining design, size and orientation.
	Output 4 – Reliability of strong ground motion predictions in gold mines is improved.	CSIR/Wits	- The major risk is reliability of in-stope instruments (strong ground motion monitors and ultrasonic closure meters) which are exposed to extremely demanding environmental conditions (high humidity and temperatures, corrosive atmospheres, blasting, water-jetting)
	Output 5 – Estimation of the locations of seismic events and damage assessment of seismic disasters become more accurate.	CGS	- CGS does not see obstacles that could affect the Output.
		CSIR/Wits	- The strong ground motion network is operational, but it cannot be guaranteed that events large enough to produce strong ground motion will occur.
	2.2 Clarification of Indicator 3-2 (status of upgrading the scheme of hazard assessment)	Experts	- The monitoring network developed by the Project covers only about 100m on all sides in the vicinity of earthquake sources out of tens of km square of a mine. Mining companies have already had their monitoring and safety system. - It is not possible for the Project to immediately help improve companies' entire mine-wide monitoring and safety system based on the observation in the very limited area. This intensive monitoring network will not be extended as it is to the entire mine; it requires developing a modified AE network that mines can adopt for themselves.
		CSIR/Wits	- Most South African mines operate IMS seismic systems and make use of standard IMS procedures to assess seismic hazard. The sensitivity threshold on most mines is about M=-1. - The networks of the Project are more sensitive (threshold M=-4) and equipped with additional sensors such as tiltmeters, strainmeters and transmission lines. - The goal of the Project is to test rigorously if this addition information of the Project provides any reliable indication of changes in seismic hazard. - Should any of the methods prove to be practically viable, the Project will publish functional specifications of the systems and procedures required to implement the methods.
		CGS	- Monitoring the seismicity is the first step towards assessment of the seismic hazard and risk in mining districts.
		Seismogen	- Rock burst and fall are the cause of most common injury. The Project will bring about the safety benefit. The Project will also improve seismic monitoring.
	2.3 Clarification of Indicator 5-2 (status of upgrading data Center)	CGS	- The obtained upgrade of national network in the Far West Rand from 1 to 12 stations is significant. CGS is planning to add additional stations in this area to further improve accuracy of location of seismic events. - New Center process seismic data using Antelope software. The most processing is done automatically. The old system allow for manual processing only. Indicator for Output 5 is: 5-1) The number of South African national station installed (10) 5-2) CGS report on upgraded Data Center and a routine data processing (1) 5-3) CGS report on the obtained parameters to better predict strong ground motion on surface (3)
	2.4 Prospect of achieving the Project Purpose (Understanding of the preparation and occurrence of earthquakes is enhanced, and the risk management mechanism of mining-induced earthquakes is improved)	CSIR/Wits	- The Project will mostly achieve the Project Purpose. 1) <u>Understanding of the preparation and occurrence of earthquakes:</u> -The Project sites offer the best opportunity anywhere in the world to make new discoveries regarding the physics of earthquakes. However, rock is highly heterogeneous material and its behavior is difficult to predict. Hence the Project cannot guarantee that large events will occur within the aperture of sensor arrays, and are not absolutely sure that we will make significant discoveries. - Using a state of the art monitoring systems installed in close proximity to a potential seismic source will increase the knowledge of the processes related to mining induced seismic events. - The Project has already gained some new insights into the spatial nucleation of seismic events from acoustic emission (AE) data collected at the Cooke 4 and the analysis of AE and tilt data collected at Mponeng mine in 2007 coupled with stress modeling. 2) <u>Management of the risk posed by mining-induced earthquakes:</u> - The Project focuses on the prediction of rockbursts. At the very least the Project should be able to determine if there is any practical

			way we can detect forerunners of rock bursts. If it proves to be impossible, then risk mitigation will rely on efforts to develop technologies to make excavations rockburst-resistant and to reduce the exposure of mine workers. - This is the most ambitious mine-related seismology project ever conducted. The Project can also contribute to these efforts. - Studies of strong ground motion and rock mass response to that will improve mining layout design and in-stope support system.
		CGS	- As for the activities related to CGS, the project will be fully achieved. CGS is going to develop expertise in mining seismology. CGS is going to mainly focus on routine processing and research activities.
		Anglogold Ashanti (Moab Khotsong)	- What is applied from the Project could be: 1) AE monitoring, 2) Stress measurement. There is a problem that the software is in Japanese. - Anglogold Ashanti Rock Engineering Department was transferred technology of CCBO when it was conducted at Mponeng and Tau Tona mines in January and February 2013, along with Ground Word and Seismogen. - Anglogold Ashanti likes to use the technology and implement the system This could be mentioned by the speaker from the company at the seminar on 11 March 2013.
		OHMS	- Example of technology transferred by the Project is Borehole Camera that can inspect the inside of holes in 100m deep. Dr. Ogasawara, Dr. Nakatani, Dr. Yabe and Mr Raymond(?), Masakale, Khambule designed the camera together.
		Ground Work	- Every mine must have rock engineer by law. Big company such as Anglogold Ashanti has their own rock engineer. Small mine contracts out rock engineering services (e.g. Cooke 4 has contracted Seismogen for rock engineering services.)
	2.5 Clarification of the Indicator for Project Purpose		
	The number of experimental sites	CSIR/Wits	- The Project aims to establish sites on three mines: Cooke 4, Moab Khotsong and KDC West
	The quantity of knowledge that are obtained only by closed proximity monitoring	CSIR/Wits	- Results will be reported at scientific meetings convened by the following professional and scientific organizations: SANIRE (South African National Institute of Rock Engineering), SAIMM (the Southern African Institute of Mining and Metallurgy) and SAGA (South African Geophysical Association), Annual MineSafe Conference etc. - These meeting/seminar are to be not only for scientists but also for practitioners. - The Project expects to publish a total of 6 papers on this topic (4 papers in referred conference proceedings and 2 papers in international journals)
		CGS	- It is difficult to predict a number of scientific papers. CGS has been producing several reports per year and participated in several international conferences but not many papers appeared in scientific journals.
	Improve systems to mitigate seismic risk	CSIR/Wits	- Legislation requires mines in SA to formulate "Code of Practice" in which they describe their standard operating procedures. Mines are required to revise the "Code of Practice" from time-to-time and adopt "leading practices", which are established through the publication of peer reviewed papers, workshops, etc. - The Project will submit formal recommendations on leading practice to MOSH team (Chamber of Mines), rock mechanics practitioners at deep mines, organized labour, and the Mine safety Inspectorate.
		CGS	- Installation of 50 seismic stations in the mining district will require development of new services for hazard/risk assessment by CGS.
		Experts	- There could be two applications of the research findings for public benefits. 1) In case that AE is proved to be helpful in identifying mine induced seismic events, then the Project can propose a modified/simplified AE network that mines can adopt for themselves. 2) CCBO conducted in 7 and 8 February 2013 revealed that the stress was greater with significant difference than the predicted values of existing numerical computer modeling. With conducting more CCBO survey, the Project can help improve the strain computer modeling.
3. Efficiency	3.1 Clarity of the overall plan of the Project. Master Plan and PO	CSIR/Wits	- The overall plan is very clear.
		CGS	- Very clear.
	3.2 Inputs of Japanese side – dispatch of experts/researchers.	CSIR/Wits	- Good: the Japanese experts have shown great commitment, a great level of commitment, to the Project
		CGS	- Administration input and help from Mr. Miyara and now from Mr. Takashima is unique and very valuable.
		Experts	- The principal Japanese researcher, Dr. Ogasawara is effectively on five-year sabbatical to be fully engaged in the Project.
		OHMS	- Japanese experts are very punctual and focus on the finest detail, try to be 100% accurate. Also the payment upon our invoice is very fast. These are rare in South Africa and OHMS very much appreciates it.
		Ground Work	- Dr. Ogasawara is very committed and pro-active to transfer technology. He is very organized and manages the project very well. As a commercial company, it is an absolute pleasure to work with a professor like him.
	3.3 Inputs of Japanese side -- provision of machinery and equipment.	CSIR/Wits	- Good: The Project Coordinator has procured all equipment according to the project plan.
		CGS	- Procurement process is professional. From a researcher point of view any simplification would be greatly appreciated.

	3.4 Inputs of Japanese side – training in Japan	CSIR/Wits	- Satisfactory: So far only two South African (Mr. Spottiswoode and Mr. Kgarume) have visited Japan for training and research activities. This has been appropriate. The number is expected to increase as the Project enters the data analysis and interpretation phase. - Three of the key researchers of the Project have been supported by the Project to present the current output of the project on the international conferences once a year since the beginning of the Project.
		CGS	- Need improvement: This is not satisfactory because of JICA restriction. There is no one in CGS who would be willing to spend several months in Japan without family.
		Experts	- Training in Japan is planned in July-2013 at AIST for two lecturers of the School of Mining Engineering, Wits Univ.
	3.5 Inputs of South African side – assignment of counterpart personnel	CSIR/Wits	- Satisfactory: CSIR is a contract R&D organization, and thus some researchers have not been able to devote as much time to the project as they would like. - Wits staff members carry quite heavy teaching and supervision loads. - Indication of how much time the counterpart personnel spend on the Project: e.g. Dr. Durrheim (10%), Dr. Milev (50%), Mr.Share? (less than 50%)
		CGS	- CGS need only communicate with mining companies to perform its task, and this communication is satisfactory.
	3.6 Inputs of South African side – budget disbursement for the project implementation	CSIR/Wits	- Satisfactory: CSIR, CGS, Wits Univ. and DST have all met their commitment to the Project.
		CGS	- CGS is covering all costs associated with maintenance and data communication of 10 seismic stations sponsored by JICA.
	3.7 Communication (periodical and daily) for project coordination – between South African researchers and Japanese researchers	CSIR/Wits	- Good: communication by the scientific advisor (Dr. Ogasawara), Project leader (Dr. Nakatani, Dr. Yabe) and Project Administrator (Mr. Miyara, Mr. Takashima) has been excellent, exceptionally good.
		CGS	- Communication is perfect.
	3.8 Communication (periodical and daily) for project coordination – among South African organizations	CSIR/Wits	- Satisfactory: At times there have been failures in communication owing to competing commitments. It depends on the availability of time. The activities are not fully funded and in-kind contribution - Good: Beside some shortfalls, the periodical and daily communication was good.
		CGS	- There is low level of activity in this regard because connecting surface and underground network is not planned or an objective of the Project, but only the exchange of information. - The underground network can be connected to the surface network, if requested, as CGS may use the data of magnitude 0 or -1. - Exchange of information with Output 1-4 is expected (such as stress measurement and rock property for 3D modeling and monitoring results for locating seismic events)
	3.9 Promoting/hindering factors that may have affected the Project implementation	CSIR/Wits	1) Promoting factors - The project has received great support from mine management and rock mechanics practitioners. - Local contractors have generally worked diligently and well. - A long history of collaboration with mining companies and service providers has helped the project tremendously. - Prof. Ogasawara's research dates back to 1994. 2) Hindering factors - The Project has had to deal with industrial action at the mines (strike) - Theft of cables and equipment within the mines. - The Project has experienced some delays in obtaining a permit to transport and hold rock specimens that may contain gold from the Precious Metal Regulator. - There also have been some delays in the construction of in-stope closure meter.
		Moab Khotsong	- The strike lasted six weeks. It took two more weeks for various safety checks, and another one weeks before it resumed full production.
		OHMS	- Presence of senior representative of the Project who can negotiate with mine (specifically when Dr. Ogasawara is not in South Africa) could lead to better project management. For example, the Project spent thousands of ZAR to make boreholes in Moab Khotsong, and when it was done, the mine stopped mining and so these holes were just abandoned. This could have been avoided through negotiation at a proper time. - OHMS technicians get paid by JICA on daily rate, not fixed-monthly rate. As such, it is difficult for OHMS to plan or foresee their income.
		Gold Fields	- South Africa has lots of politics and unstable environment. Frequent change of company (and the name). Change of policy of the Government: 6 day off for every fatal accident. The 1 month strike costs 12 billion ZAR for the mining industry.

		Experts	- IMS (ex. ISS), the largest independent research organization on developing methodologies, technologies and services to understand seismic rock mass response to mining has relocated its HQ from Stellenbosch, (South Africa) to Hobart (Australia). - Some Japanese and South African co-financing funds (name:)
4. Impact	4.1 Any positive/negative impact brought about by the Project (e.g. Policy and research development, Poverty reduction, environmental protection, etc.)	CSIR/Wits	- So far the project effort has been devoted to establishing research sites (identify monitoring sites, procure the equipment and initiate underground monitoring). Implementable findings are only expected in the next two years of the five year project. - The South African mining industry is going through a period of turmoil. Debates about nationalizations of mines, strikes and economic cycles have all contributed to this.
		OHMS	- The Project has helped develop OHMS's technicians by giving them much responsibility than usual; that is an excellent development of carrier. Usually technicians are not left with much room of technical development, but the Project always moves into next phase and brings into something new. That way, a technician involved in the Project left OHMS for better carrier opportunity.
		Expert	- Anglogold Ashanti plans to install Acoustic Emission at Mponeng mine. - The Project outcomes have been reported at the international seminar hosted by IMS (ISS) since 199X?. This year, the seminar will be held on 18-19 March 2013 at Hobart, Australia.
		Ground Work	- Ground Work plan to invite Dr. Kato and to conduct CCBO with this supervision as soon as testing sites become available at KDC East (Kloof) mine.
	4.2 Ongoing/possible collaborations, if any, with multi/bi-lateral development partners (UN, NGO, civil society, and private sector).	CSIR/Wits	1) Science plan to address natural hazards in Africa (2007-present) by ICSU Regional Office for Africa 2) Regional Programme for sub-Saharan Africa (2010-present) by Global Earthquake Model (GEM) 3) AfricaArray projects (2005-present) by AfricArray
		CGS	- Observational Seismology by the University of Trieste, Italy, for the exchange of expertise in interpretation of strong ground motion data.
5. Sustainability	5.1 Prospect from institutional viewpoint (e.g. annual plan, operational guideline/MOU among involved organizations)	CSIR/Wits	Relatively High - For CSIR and Wits, mining research is an identified focus. There is no doubt that teaching and research will continue. However, it is difficult to guarantee the scope and focus of the research work. Over the last 20 years there has been a drastic reduction in the investment in mining-related research in South Africa, both by government and by industry. - CSIR CMI has prepared a business plan for FY Mar 2013- Apr 2014.
		CGS	High: Part of CGS responsibility is monitoring seismic activity.
	5.2 Prospect from technical viewpoint (e.g. maintenance of procured equipment, training opportunities and update of expertise/knowledge)	CSIR/Wits	Relatively high - Most sensors and cables installed underground will not be recovered because they are permanently grouted in the rocks. They will not be useful when mining moves to other areas. They will be used only few years while mining is conducted in the area. - Data recorders and tiltmeters will be retrieved and used for other projects. - Surface network (CGS seismic stations) will operate into the future.
		CGS	High - Maintenance of national network has no problem for CGS. - CGS could consider taking over the underground monitoring network and collecting data during its life as CGS is also interested in the difference between the mining and flooding earthquake after closure.
	5.3 Prospect from Human Resource viewpoint (continued assignment of responsible personnel, collaboration with other organizations)	CSIR/Wits	Relatively High - CSIR/Wits hope to maintain capacity at current levels. - It should be noted that there has been a huge decline in mining-related research capacity in South Africa over the past decades. The WMRI seeks to reverse the trend. - This project provides an excellent environment for training young scientists and post-graduate students.
		CGS	High - CGS is going to develop more expertise in mining seismology. - Seismology Department, CGS, has 30 staff members: 5 for electronic laboratory, 6 analyst for data processing, and 20 seismologists) - CGS is lucky to have new face and the number is growing. They are permanent, thus the growth is not on soft money.
	5.4 Prospect from Funding viewpoint (budget allocation for the activities, external financing from private sector/donors)	CSIR/Wits	Relatively high - Continuation of project work at CSIR depends on wining new research contracts from mining companies or the MHSC (or sourcing additional funds to cover the research time spent on the Project). This cannot be guaranteed.
		CGS	Relatively high - CGS has financial support from DMR and private sector. - CGS is going to develop and sell some services (such as training to mining industry on seismic hazard)

Annex 14: Draft PDM

Project Name: The Project for Observational Studies in South African Mines to Mitigate Seismic Risks
Cooperation Duration: 5 years (August 2010 – August 2015)
Implementing Institution: DST, CSIR, CGS, Witwatersrand University, Ritsumeikan University, University of Tokyo, AIST
Target Area and Beneficiary: Researchers of Implementing Institutions, several South African mines and mine workers

Version 1: March 2013

Narrative Summary	Objectively Verifiable Indicators	Means of Verification	Important Assumptions
【Overall Goal】 Apply the seismic hazard assessment and control schemes developed in this project in deep South African mines and worldwide.	-	-	
【Project Purpose】 Understanding of the preparation and occurrence of earthquakes is enhanced, and the risk management mechanism of mining-induced earthquakes is improved.	1. Results of the Project is reported at least 5 international, professional meetings. 2. Formal recommendation on leading Code of Practice is submitted to MOSH team, rock mechanics practitioners, organized labor, and the Mine Health and Safety Inspectorate. 3. At least two transferred technologies are adopted in South African mines. 4. At least four young researchers obtain advanced degree on project related research.	Project report Hearing	CSIR, CGS and mining companies continue self-reliant project activities.
【Outputs】 1. Rock properties at seismic sources are elucidated.	1-1 Three target faults for observation network are identified. 1-2 One survey report of rock properties at seismic sources is published.	Project report Survey report	Each output is fully achieved. Cooperation of mining companies continue.
2. Understanding of the preparation and forerunners of earthquakes in gold mines is enhanced.	2-1 Three monitoring sites are established and monitored. 2-2 Three papers on the preparation and forerunners of earthquakes are published.	Project report Scientific Journal	
3. Reliability of seismic hazard assessment in gold mines is improved.	3-1 Three papers on stress change and rock mass instability are published. 3-2 Functional specifications of the system and procedures required to observe precursory phenomena in mine are designed.	Project report Scientific Journal	
4. Reliability of strong ground motion predictions in gold mines is improved.	4-1 At least one paper on on-fault dynamic stress change is published. 4-2 Two reports on information for better prediction of strong motion are produced. (on surface and at stopes)	Project report Scientific Journal	
5. Estimation of the locations of seismic events, and damage assessment of seismic disasters become more accurate.	5-1 One CGS report on upgraded Data Centre and its routine data processing is published. 5-2 Three CGS reports on the obtained parameters to better predict strong ground motion on surface are published.	Project report	
【Activities】 1.1 Observe and collect rock samples at seismic sources and its surroundings 1.2 Investigate rock properties in laboratory 2.1 Install monitoring systems for micro-fracturing and rock deformation, and sensitive long period seismometers in the vicinity of impending earthquake sources 2.2 Monitor the activities of micro fracturing 2.3 Monitor the accumulation and release of stress in and around the impending earthquake source	【Inputs】 (Japanese side) 1) Dispatch of Experts - Source rock property - Sensitive close monitoring - Hazard assessment - Strong motion - Extension of SANSN 2) Provision of Machinery and Equipment - Equipment for monitoring of micro-fracturing, rock deformation, and seismic motion		1. Mining plans at the monitoring sites remain unchanged. 2. Strike does not take place at target mines. 3. Seismic events big

2.4 Analyze the monitored data to clarify the forerunning phenomena and its characteristics 3.1 Evaluate spatiotemporal changes in stress and rock mass stability based on the data produced by mine's microseismic network 3.2 Upgrade the scheme of seismic hazard assessment by calibrating existing schemes with the data obtained through the activities 2-2, 2-3 and 3-1 4.1 Install accelerometers and high capacity strainmeter in the vicinity of impending earthquake sources to monitor the dynamic slip and stress change 4.2 Analyze the data obtained through the activity 4-1 to clarify the process of rock mass failure and strong motion generation 4.3 Install strong motion meters and geophones in underground working places to monitor strong motion at disaster sites 4.4 Compare strong ground motions at the source with those at damage sites to clarify the characteristics of site amplification of strong motion 4.5 Compare the monitored dynamic stress change and fault slip with existing lab-experimental results to clarify the scaling relationship in dynamic rupture process 5.1 Install seismic stations in the Far West Rand mining district (Carletonville area) on the surface to monitor surface ground motion caused by mine tremors 5.2 Upgrade the Data Center in the Silverton offices of the Council for Geoscience 5.3 Develop and validate a parametetric model that will be capable of predicting strong ground motion	- Equipment for seismic monitoring network on the ground surface - Equipment for data analysis - Office equipment -Other equipment as necessary 3) Training in Japan 4) Local Operational Cost (South African Side) 1) Service of Counterpart and Administrative Personnel - Source rock property - Sensitive close monitoring - Hazard assessment - Strong motion - Extension of SANSN 2) Office Space and its Facilities - Office and facilities for the duties of JICA experts - Land or space for equipment installation - Other facilities as necessary 3) Running expenses necessary for Project Implementation 4) Cooperation and contribution of mining company	enough to collect intended data occur. 【Pre-conditions】

DST(Department of Science and Technology), CSIR(Council for Scientific and Industrial Research), CGS(Council for Geoscience), AIST(National Institute of Advanced Industrial Science and Technology), MOSH(Mining Industry Occupational Safety and Health, Chamber of Mines), SANSN(South African National Seismograph Network), MOU(Memorundum of Understanding), Mine Health and Safety Inspectorate (Department of Mineral Resources)