2018 UPNG Geoscience Convention Volume

Selected full papers and summaries of papers for the Inaugural UPNG Geoscience Convention convened on the 7th September 2018 at the Earth Science Division, School of Natural and Physical Sciences, The University of Papua New Guinea

Theme: “Collaboration and Application of Geoscience Knowledge in PNG – Academia, Government and Industry Update” – An initiative of the 2018 Geoscience Students Association of the University of Papua New Guinea

Venue: UPNG Waigani Campus
Science 3 Building, Room S301 and Open Air Theatre

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FORWARD

The event

The inaugural 2018 UPNG Geoscience Convention with the theme “Collaboration and Application of Geoscience Knowledge in PNG – Academia, Government and Industry Update”, which was an initiative of the 2018 Geoscience Students Association of the University of Papua New Guinea was convened successfully. Although, it was a first of its kind, it was convened with limited funding.

More than 50 people attended the event. Professor Chalapan Kaluwin, Acting Executive Dean, School of Natural and Physical Sciences, gave the opening remarks citing how PNG geoscientists are “conquering” the world over. He opened the event.

Professor Russell Perembo, Discipline Leader and Professor of Geology, and Emeritus Professor Hugh Davies, PNG Chamber of Mines and Petroleum Professor of Applied Geology, also delivered presentations.

Due to time limitations, only nine speakers gave their presentations. The nine speakers spoke on various and interesting topics, including geo-tourism (promoting geological landmarks for tourism), agro-geology (rocks-for-crops), and volcanic activities bringing sulphide mineralisation (ongoing study). Emeritus Professor Davies delivered his last speech.

The afternoon session was conducted at the Open Air Theatre. At that venue, attendees were asked to join in for lunch. The evening program saw final year geology students introducing themselves to the industry people and potential employers. Industry personnel spoke, including those from government organisations - giving encouragements to students, as well as challenges they would encounter when they leave school. It was generally a meet-and-greet session, and all went very well.

Many thought this event would not be possible, but it occurred. All are looking forward to hosting bigger and better events in the future if stakeholders and sponsors continue to support the occasion.

Future Plans

The initial thoughts were to try out this first meeting and see or learn from the outcome. Such an event like this did not occur before, though overseas PNG-based companies were doing similar meetings on an annual, or bi-annual basis here in the country. What they aim to achieve perhaps were different from what this gathering wanted to achieve. The objective has been to combine industry – (mining and petroleum), government organisations, the academia and other stakeholders, to collaborate and promote geoscience education, employment, sustenance, and create other development pathways, not only in education for the young generations to come, but also in standing out amongst the geoscience communities around the world.

The abstracts/summaries and selected full papers are included in this volume. It contains all the presentations (PPTs in PDFs in a separate folder) and expanded abstracts and summaries. The second convention is in plan for next year, and all proceedings from that event will be captured in the second volume. Some attendees have asked to be notified including other stakeholders in advance of future events. This has been acknowledged and would be taken into account for future events.

The Birth of Institute of Geoscientists of Papua New Guinea (IGPNG)

PNG’s economy depends mostly on non-renewable resources. PNG geoscientists are at the forefront of this industry. It is time to look seriously at ways to regroup geoscientists in the country and take stock of PNG’s own human resources, including PNG’s professional well-being and future outlook. On that note, plans are underway
to register a PNG-specific geoscience organisation, under which such events would be hosted, apart from its other functions. This was the greatest idea that born out of this convention.

The name “Institute of Geoscientists of Papua New Guinea” (IGPNG) has been chosen for the organisation’s name. Its logo is shown below, which was selected among other entries, as the winning logo after a competition by public.

![Logo of IGPNG](image)

**SPONSORSHIP**

The sponsors for the inaugural UPNG Geoscience Convention were Kumul Petroleum Holdings Limited, Mineral Resources Authority and K92 Mining Limited as gold sponsors, and Earth Science Division, School of Natural and Physical Sciences (UPNG) as sponsors. The Organising Committee of the 2018 UPNG Geoscience Convention is very grateful for these sponsorships, for without this support, the event would not have been possible.

![Sponsors](image)

**ACKNOWLEDGEMENTS**

The organising Committee of the 2018 UPNG Geoscience Convention and GSA are very grateful for the sponsors who made it possible to stage this event. The presenters, attendees and other stakeholders including industry representatives, government, academic, staff and students of the Earth Science Division are also acknowledged. Hopefully next year’s event will be a much bigger and better one, where the number of supporters/sponsors, attendees and presenters are expected to be higher than this inaugural event.
1. Geology at UPNG

In 1965 the Australian Government decided to open a university in Port Moresby. First classes were enrolled and construction began in 1966. Classes were held in buildings at the old showground on Wards Strip and staff met on the upper floor of the Kriewoldt Building on Hubert Murray Highway at Tabari Place, Boroko.

Professors of all the sciences except geology were appointed in 1966-67. Cliff Ollier, an Englishman who had worked in Africa, was recruited in July 1967. Warren Manser also joined in 1967 as Demonstrator in Geology. The first geology courses were taught as part of preliminary year in 1968. Preliminary year was a bridging program designed to bring students who had not completed 6 years of high school to a standard where they could start studies at University level. Circumstances were not easy. The opening line of a letter from the Vice Chancellor Dr Gunther to Cliff was “Dear Mr Ollier, I am sorry you have no office”. However, gradually things changed and in 1969 staff and students moved to the first of the new buildings on Waigani campus.

Cliff learned in 1968 that the other Professors had met and had decided there was no need for geology to proceed as a separate discipline and that it would be integrated with Chemistry (and later with Agriculture and Geography). When Cliff learned of this, and that there was no prospect of being appointed Professor, he left in 1969 for a position with the University of Canberra. Warren was to stay on as the backbone of the department until 1987.

In 1971 the great copper-gold mine at Panguna came on stream and was immediately highly profitable. Following the successful opening of the Panguna mine a decision was taken to create a Geology Department effective 1 January 1973. Staff were recruited and first geologists graduated in 1975-76. This was also the year when the first students who had received six years of high school at the new national high schools entered the university.

Peter Nixon, a world authority in kimberlites, was appointed first professor in 1976, seconded from University of Leeds. Other staff were: - Warren Manser (who had become Dean of Science), Lloyd Hamilton, Michael Worthing, Charles McNulty, and M.A. Ghani. Salam Malagun and Russell Perembo were recruited as Teaching Assistants (Fig 1). David Haig, a specialist in micropaleontology, was to join later.

The first geology graduate was Bill Searson in 1975, who took his final year at University of Tasmania. He was followed by Peter Igarobai and Murray Ghiyandiwe in 1976, and Robin Moaina, Archie Kasokason and Silas Ambang in 1977. By 1982 the list of graduates comprised: - Michael Eyal, Kase Akiro, Stevie Nion, Martin Thomas, Joe Buleka, Salam Malagun, Wanu Tamu, Jonathan Kepa, Edward Abiari, Stanley Pono, John Kirakar, Saponia Paliau, Moses Napo, Russell Perembo, Robert Sumiaing and Jack Sari.

Three of the first crop of graduates joined the Geological Survey. These were Bill Searson, Robin Moaina and Murray Ghiyandiwe. Peter Igarobai went back to the village to start a small business, and Archie Kasokason joined the University administration. Bill and Robin went on to senior roles in the Public Service and private sector. Two or three years after he started Murray died prematurely of an internal illness.

An average of four geologists per year graduated in 1976-83. Because of the small numbers there was talk of shutting down the program altogether. The problem was that students could not take Geology in their First Year
of study and so became hooked into the other sciences. This was an ongoing problem and was only changed in 2004, when geology became part of the first-year program.

![Image](image-url)

**Fig 1.** Salam Malagun, Warren Manser and Russell Perembo - geology staff in the 1980s.

Peter Nixon returned to his home university in 1979 and there was no replacement until 1983 when Kent Brooks, an igneous petrologist, arrived. Like Nixon he was seconded for a 3-year term from an English University. Kent encountered an anti-geology bias amongst the leaders of the other disciplines. He complained that the others, notably the biologists, were making decisions over drinks at the staff club. This bias still persisted when I arrived 16 years later. Apart from this concern, Kent had a bad start when five months after he arrived he was knocked from his bicycle by a car at the entrance to the University and was laid low for 6 months.

Student numbers started to pick up in 1984 with an average graduating class of 7 for the 6 years to 1989. However, the problem had now become lack of staff. When I arrived in 1989 the entire degree program was being run by two staff — Salam Malagun and Dan de Silva, Russell being still away on studies. In the 1990s saw the increased number of academic staff positions from 5 to 7, and kept most or all of the positions filled, at least until the devaluation of the kina in 2000. The graph (Fig 2) shows how geology was the dominant science discipline in 1990-95.

![Graph](graph-url)

**Fig 2.** Graph showing the number of science graduates in 1990-95.
In 2000 and 2001 the kina was devalued with the result that it became difficult to recruit or retain expatriate staff - triggering a transition to predominantly PNG academic staffing. We lost a lot of expertise (most of the expatriates had PhDs) but adjusted to this and continued to teach the full program (Fig 3).

![Fig 3 (right). Russell Perembo, Hugh Davies and Robert Winn - geology staff in late 1990s.](image)

From the mid-1990s onwards the annual graduating class was consistently in double figures and for some years more than 20. It is now decreasing with the economic downturn. Most but not all graduates were Papua New Guineans but we also had a number of Solomon Islands students, one Vanuatu, and one South African.

Since the 1980s our graduates have been accepted into overseas employment and, in many cases, have risen to senior positions.

Our small geological community has been ravaged by the premature death of many talented people in recent years, including Marie Bera in 2009, David Tau-Loi in 2010, and Kivung Warvakai in a mine accident on Lihir. Ioini Bugave and Herman Patia died from illness in 2011 and 2014 respectively. Marie and Ioini were dedicated teaching staff and Herman a specialist senior volcanologist, so these were big losses. One day we should develop memorials for these pioneers of PNG geoscience.

Geology Department has always had excellent support staff. Raka Numa was our Senior Technical Officer for 29 years until 2003, Josephine Singadan who was the heart and soul of our department from 1987 until she resigned in 2009, and Mackenzie Balolilo, Senior Technical Officer has served with us for 30 years, since 1988. On the academic side we have Professor Perembo, the first PNG geologist to earn a PhD, who continues now as head of department and as a key contributor to our teaching and research program.

2. Geology Research

Our research activities mostly have taken the form of BSc Honours projects, but have included several Masters degrees. PhDs have only been completed at overseas universities. In the accompanying selection of research projects there are several that arise from the recognition of low-angle faults, others that focus on Quaternary tephra stratigraphy and new concepts of local area geology, and one focused on the sedimentary record of pre-historic tsunamis.
2.1 Low-angle Faults

In only the last few years have we recognised the role taken by low-angle faults (Fig 4) in the emplacement and re-organisation of the Marum and Papuan Ultramafic Belt (PUB) ophiolites. Low-angle faults also can be called upon to explain why the configuration of the PUB ophiolite and Owen Stanley metamorphics changes dramatically at 148°30' E; at about this longitude the dominant faults change from moderately steeply dipping in the northwest, to near horizontal in the east and southeast (Davies and Jonda, 2012).

![Fig 4](image_url)

**Fig 4.** An illustration of low-angle faults on Ramu Nickel access road. Rest of low-angle fault images shown as presentation PowerPoint slides 5-13.

2.2 Research into Quaternary volcanic activity

Research into Quaternary tephra stratigraphy began with student projects in West New Britain in the 1990s. Torombe (2006) completed a comprehensive study of tephra in West New Britain and Finisterre Range and most recently Lee (2018) completed a study of Mount Lamington ash exposed in pits at Myola Lakes (Fig 5).

![Fig 5](image_url)

**Fig 5.** Tephra deposit studies in Myola Lakes from Mt Lamington volcano. Rest of images shown as presentation PowerPoint slides 14-19.
2.3 Re-interpreting Port Moresby area geology

Our ongoing study of Nebire Quarry, which has been an excellent field mapping training ground for the last 20 years or so, has progressed to the point where we now recognise that the rocks of the quarry together comprise a faulted fragment of Paleocene Coral Sea Basin oceanic crust and seafloor sediments (Fig 6). The rocks are interpreted to have been elevated and accreted to the early mainland by thrust faulting, then rotated and torn apart by lateral shearing in the Bogoro fault zone (Tevlone, 2017). The rocks of the Behori quarry probably have the same origin (currently under study).

![Image of rock faces of the Nebire quarry geology](image)

**Fig 6.** Illustration of rock faces of the Nebire quarry geology. Rest of images shown as presentation PowerPoint slides on Nebire quarry studies.

2.4 Pre-historic tsunamis on the Aitape coast

In the years immediately following the 1998 Aitape tsunami we sought to establish the earlier history of tsunamis on this coast. We sampled (Fig 7) and dated sand-bearing peat beds that underlie the shoreline sediments at Sissano Lagoon west of Aitape and interpret these to show that there have been two major tsunamis on the coast in the last 1000 years, one at some time in the interval 1150-1240 AD and the other in the interval 1440-1600 AD (Simeon, 2001). The latter is probably the great tsunami that is recalled in legend by two of the coastal communities.

3. Discussion

Research is an essential activity of any university, and the complex geology of our part of the world offers many fascinating research targets. However, the University of Papua New Guinea has limited operational funds, and staff generally have high teaching loads, so it is not easy to maintain research activities. One objective of this short paper is to demonstrate that, despite the restricted funding and the demands of teaching, it is possible to continue research activities; another objective is to illustrate the point that these activities can contribute significantly to PNG geology. Research can be done. It is a matter of setting aside time for research, and of seeking out research opportunities, and keeping an eye out for cooperative ventures.
Fig 7. Photo on work into pre-historic tsunamis on the Aitape coast. Rest of images shown as presentation PowerPoint slides on Aitape coast tsunami studies.

References


Tevlone, A., 2016. Investigation into the geology of Nebire Quarry, a Paleocene phacoid within the Bogoro Shear Zone. The University of Papua New Guinea BSc Honours thesis.


********************************************
**Overview**

Earth Science Division (ESD) has come a long way and needs to re-evaluate itself to ensure it is compatible with the ever-changing local and global visions, objectives, and priorities, amongst others. Two of these contributors are global climate change and sustainable natural resource development.

**School of Natural and Physical Sciences (SNPS) Strategic Framework**

An overview of SNPS strategic framework is shown in the cartoon diagram below (Fig 1).

**Earth Science Division - Vision**

Leading provider of earth scientists of Papua New Guinea (PNG) and the Pacific to the World.

**Earth Science Division - Mission Statement**

Delivering quality geological education, research and services for the advancement of PNG and the World toward sustainable use of human, rock, minerals, petroleum and water resources.

**Strategic Framework**

- To develop sustainable links with other disciplines with the School of Natural and Physical Sciences and UPNG as a whole.
- To promote the vision and aspirations of PNG as a country will surely make the Division relevant in its current and future operations.

A way forward was the independent review of ESD funded by AusAID, conducted by Prof. Crawford from University of Tasmania, Australia. The independent review was undertaken because of the industry perception...
that the Government was not providing adequate for infrastructure and teaching-learning-research items, and the geology graduates are of low quality. The issues and concerns were also deliberated in the PNG Universities Review by Sir Rabbie Namaliu and Prof. Ross Garnaut.

2012-2014 - AusAID Grant of AUD500,000 to support ESD, managed through the PNG Chamber of Mines and Petroleum.

**Objective Views**

Earth Science Division would like to explore alternative options that can enhance and aid its survival and operation at present and in the coming years. One of the best ways of achieving these objectives and visions is to establish partnership with other similar institutions and industry. Earth Science Division is currently in the progress of carefully and critically analyzing how it can recruit and retain highly qualified, experienced staff members. Also maintain the quality of the undergraduate courses, including the postgraduate program and its geology graduates.

**Earth Science Division at Present**

2013 – Appointed professor (with structure) (Fig 2)
2014 - Head of ESD, and Director Centre for Disaster Reduction (CDR)
   i. Staffing (academic – 12 (2 CDR), support – 6 (1 Secretary) (refer PPT presentation for details)
   ii. Restructuring of Science Foundation program (refer PPT presentation for details)
   iii. Postgraduate Diploma in Geohazard and Risk Management
   iv. Collaborative research project
   v. Scholarship and employment
   vi. Total-UPNG MOU action plans

Fig 2. Earth Science Division structure with appointed Professor.

**Staff Development**

- academic staff for higher degree programs
- support staff for degree programs
- staff incentives
- maintain international flavour
- quality assurance
- monitoring and evaluation performance
Teaching and learning

- courses and strand combinations
- open, distance and flexible studies
- quality assurance principles
- recruit high quality students

Research

- quality and productivity
- Research Centre capabilities
- increase postgraduate numbers
- quality assurance

Re-shaping of Geology

- synonymous with mining and petroleum
- PNG’s economic focus for the next 50-100 years
- geology is here to stay as part of UPNG
- heard and spoken at community level
- environment and livelihood of communities
- alliance with PNG’s satellite projects

Timeline for next 5 years

- Year 1-2: review and needs assessment
- Year 3-5: re-shaping of geology
- external review of the progress

Future trend in Geology program

(a). Strengthen collaborative partners – government, industry, NGO
(b). Seek opportunities to develop geology program at regional or provincial centres to align with vision 2050
1. Introduction

This paper gives an overview of geotourism on a global perspective, geotourism development in PNG (with challenges and opportunities), and includes a pilot project undertaken in Boera, Central Province. Some future plans are outlined towards the end.

2. Overview of Geotourism - Global Perspective

- Aimed to provide tourism solutions to climate change through protection of the environment and culture that enhances tourism sustainability in the climate change approach.
- Supports sustainable tourism in line with global aims of green climate.
- Part of ecotourism in most international jurisdictions.
- Starters: Canada, Australia, PNG in pipeline.

Fig 1. Geotourism – tourism of geology and landforms.

3. Geotourism Development in PNG

Background

- MOU signed on 14 March 2018 between the Tourism Promotion Authority (TPA) and Mineral Resource Authority (MRA) in Port Moresby.
- Geotourism - MRA’s Corporate social responsibility for the sustainable management, development and conservation of PNG’s natural resources.
- The geotourism initiative supports the government’s commitment to sustainable tourism in line with global aims of green climate.
- Geotourism builds on the geographical landscapes and describes in detail, the origins and significance of the geographical features, which can be referred to as geosites or geo-conservation sites.
Collaboration Plans

- MRA and TPA to develop mutually beneficial programs, projects and activities to promote tourism growth in PNG through the inclusion of geoscience education for sustainable tourism development and conservation of natural resources for tourism investment, product development, marketing and awareness.
- MRA – Geological Survey Division geologists will play a significant role in the development of the geotourism products and provide in the form of reports, maps, and atlases descriptions of significant geological features. This will promote the conservation and protection of critical landscapes (geo-heritages) and create effective communication through geoscience education on geohazard areas.
- MRA to develop product/sites with help from TPA and Provincial Govt/Districts/ILGs and TPA markets and promotes.
- Introduce geotourism to existing TPA products (e.g. war tracks, surfing, mountain climbing, etc)

4. Geotourism: A New Frontier - Finding the Way

Technical Working Group
- A body comprises of officers from related agencies to oversee, participate and contribute to the growth of geotourism in PNG.
- The group to comprise but is not limited to State Entities, Conservation and Environment Protection Authority (CEPA), Works and Supply Dept, Dept of Provincial and Local Level Government, Dept of Commerce and Industry, Provincial Affairs Dept, Police, Lands, etc, with TPA as Chair and MRA as Deputy Chair.
- Universities and Research Institutions.

5. Summary
- Geotourism is a rapidly growing form of sustainable tourism development.
- Its growth is predicted on fostering geo-conservation, community well-being and local economic benefits.
- Has direct application of PNG due to our unique complex young geology, diverse landscapes and tourism potential.
- Geological landscapes shape who we are and how we live.
Fig 3. Integration of tourism products promoted by geotourism with the Boera example.

**Future Plans and Recommendations**

- Roll out of projects in PNG.
- Mining (Rock) Museum (Laloki 17 Mile).
- Geoheritage Park (complementing Nature Park and Adventure Park).
- Geologist role within TPA and Provincial Administrations (critical to boost tourism and other natural resources development within provinces).
- Tailor tertiary and professional development courses to meet new geotourism endeavours.

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TITLE: CASE STUDY ON MINING AND EXPLORATION, K92 MINING

Trotsky Benjamin
Superintendent – Geology, K92 Mining Inc.

1. K92 Mining Inc

Ownership
- Listed on the Toronto Stock Exchange
- 180 Million Shares, 30 Million Warrants & Options
- Market Capitalization US$150 Million
- Major Shareholders
  - US Institutional Investors (CRH, Jett Capital, Smith)
  - Canadian Institutional Investors (RBC, Sprott, Formula Growth, Palos, Zechner)
  - Other (ERI – London, Makenzie – Singapore, Beaty - Vancouver)
- Acquired the Kainantu Gold-Copper Mine and Project from Barrick in March 2015

Historical background
1970s - Preliminary grassroots exploration by Renison Goldfields
1980s, 1990s - Highlands Pacific (formerly MIM) explored and discovered Irumafimpa
2005 - Highlands Pacific commence mining at Irumafimpa
2007 - Barrick purchase the project for porphyry copper-gold exploration
2008-2009 - Barrick operated Irumafimpa for 7 months
2010-2014 - Mine placed on care and maintenance, Barrick committed to exploration of porphyry copper-gold targets
2015 - K92 Mining purchase the project to recommence mining at Irumafimpa in 2016
2017 August - Major Discovery of Kora North Deposit

2. Geological Setting

Geology - District
- Located within New Guinea Thrust Belt close to its northern contact with the Finistere Terrane.
- Underlain by metamorphosed sedimentary rocks of the Bena Bena formation, overlain by Miocene age sedimentary and intermediate rocks of the Omaura and Yaveufa formations.
- Mid Miocene Akunai intrusive complex – comprises of multiple phases mafic to felsic magma.
- Late Miocene Elandora Porphyry dykes – crowded with feldspar porphyries and diatreme breccia.

Geology – Kora/Irumafimpa

(i) Lithology
- Phylites and Schists are main host lithology
- Barren intermediate intrusive dykes

(ii) Structures
- Indication of strong controlling structures – as early feeder structures and post-mineralized barren displacement structures.
- Understanding structural behaviour key vector in discovering and proving mineralization in this structurally hosted mineralization system.
Fig 1. Regional setting of the K92 mine.

3. Mineralization

Lodes characterized by suite of veins and veining styles – indicative of multi-phase mineralization system

- Sulphide veins – massive/stockwork
- Quartz-sulphide veins – brecciated/buck/vuggy/stockwork
- Gold-copper mineralization hosted in pyrite-chalcopyrite-bornite mineral assemblages

Main Deposits – overview

Fig 2. Main deposits – long view

4. Mining

Underground mining - Kora strategy:

- Establish development drives at 20m inter-levels in the lodes
- Long hole stoping method between inter-levels
- Cut and fill – current mining method
• Ore extraction supported by relevant access, service and extraction drives

5. K92 Going Forward

• Continue Kora drilling campaign to bridge Kora north with Kora Proper/South – including mineralization at depth and other vein targets
• Continue ore extraction of developed ore resource at Kora
• Continue mine development to Kora south
• Active grassroots exploration and green fields drilling happening on K92 Mining’s exploration leases.

Paper PA05-ESD2018
TITLE: AGROGEOLOGY: ROCKS FOR CROPS AND ITS POTENTIAL IN PAPUA NEW GUINEA

Dr Harrison Gedikile
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1. Introduction

There is more than geologists can do to assist in the development of Papua New Guinea and the world. Geologists are needed in many fields such as hydrogeology, geohazard management and disaster risk reduction, energy sector to identify and evaluate potential energy sources (geothermal and hydrocarbon), climate change by using the past geological data to predict future climate, geoheritage and geotourism to add value to our current tourism attractions, engineering geology for infrastructure development, environmental geology to protect our environment, geo-education to continue geoscience education and research, and agrogeology to strengthen the agriculture and food security.

This paper will focus on agrogeology especially on the application of multi-nutrient silicate rocks as fertilisers (rocks for crops).

2. What is agrogeology?

Agrogeology is the application of geology to problems in agriculture, particularly in reference to soil productivity and health. This field is a combination of a few different fields, including geology, soil science, agronomy, and chemistry. The overall objective is to advance agricultural production by using geological resources to improve chemical and physical aspects of soil (https://en.wikipedia.org/wiki/Agrogeology). There are two aspects of agrogeology: (i) Influence of parent material (rocks) on soil development and soil fertility. (ii) Beneficial application of rocks and minerals to enhance productivity of soils (rocks for crops).

The conventional fertiliser industry extracts and processes naturally occurring rocks and minerals to produce soluble fertilizers (except nitrogen). They focus on the three macro-nutrients, N, P and K, and not on secondary nutrients and micro-nutrients. The fertilisers are expensive, unaffordable by most small-scale farmers.

3. Natural mineral and rock-based fertilisers

There are a number of natural mineral and rock-based fertilisers (Van Straaten, 2006). (i) Multi-nutrient silicate rock fertilisers, e.g., fine grained volcanic rocks. (ii) Single-nutrient rock fertilizers, e.g., phosphate rock fertilisers. (iii) Rock fertilisers from rock and mineral waste, e.g., unprocessed mine waste, processed rock and coal waste (e.g., fly ash). (iv) Translocated rock fertilisers: alluvial rock fertilisers, airborne rock fertilisers, e.g., loess and volcanic ash. (v) Specific nutrient rock fertilisers applied with organic residues or biologically modified e.g., microorganisms. (vi) Biofertilisers, organic forms of nutrients extracted from rocks.
This paper will only discuss about the ‘multi-nutrient silicate rock fertilisers’. Studies have shown that phonolithic volcanic rocks has the highest cation release rate (Von Franstein et al., 1988); followed by basaltic rock types. Granite powder has the lowest cation release rate so it is not a good fertiliser. Volcanic rocks have been singled as soil ameliorants (improved the soil), due to fast rate of weathering and fast release of their contained macro- and micro-nutrients.

Examples of the successful application of multi-nutrient mineral and rock-based fertilisers: (a) Mauritius: increased yield of sugar cane (up to 180t/ha of ground basalt) (d’Hotman de Villiers, 1961). (b) Zimbabwe: increased yield of sunflower (5-40t/acre of ground basalt) (Roschink et al., 1967; Gillman, 1980; Gillman et al., 2000, 2002). The application of ground basalt raised pH, increased cation exchange capacities, and enhanced cation levels in soils.

In all examples above, best agronomic performance are the fine grained silica-undersaturated volcanic rocks. For increased plant response to rock fertiliser application, it is important to characterise and evaluate the mineralogy and chemistry of the selected minerals (or rocks) and match the soil and plant requirements. For example; peanut show low yield on calcareous soils due to lack of iron (Fe-chlorosis). So the solution to the problem was to add ground Fe-rich basaltic rocks and lapilli tuff. It resulted in significantly improved iron nutrition, chlorophyll production and growth of peanuts (Barak et al., 1983).

4. Advantages and disadvantages of applying multi-nutrient silicate rock fertilisers

The advantages are: (i) provide a large number of macro- and micro-nutrients and beneficial elements (e.g., K, Ca, Mg, Cu, Zn, Mn and possibly silica (Epstein, 1999); (ii) favourable properties to raise the pH of soils (liming effect); (iii) slow-release fertilisers in nutrient depleted acid soils; (iv) low environmental impact; (v) locally available, some as mine wastes and (vi) they are relatively cheap.

The disadvantages are that silica-rich igneous rocks like granites contain low nutrient concentration and have very low solubility. It also requires high-energy input for crushing and grinding.

5. Potential for “Rocks for Crops” research in Papua New Guinea

There is huge potential for Rocks for Crops research in PNG. The country has a favourable weather and agrogeological setting for multi-mineralic-silicate research. We have good number of geologists that can be tasked to work in this field with the agriculturists and soil scientists. Currently, geologists are not involved in the field of agrogeology but this area has the potential to revolutionise and sustain the agricultural sector especially in addressing soil production and fertility for a sustainable agricultural industry in PNG.

References


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Paper PA06-ESD2018
TITLE: MAFIC MELT INJECTION INTO A SILICIC MAGMA CHAMBER: FIELD INSIGHTS ON THE CAUSE AND TRIGGER OF THE 3,300 B.C.E. CATASTROPHIC ERUPTION OF WITORI VOLCANO, WEST NEW BRITAIN

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Summary

Witori volcano in the Hoskins area of West New Britain has had a very active and destructive history throughout the Holocene. It has had 9 major, caldera-forming eruptions (VEI = 5-6) over the past 5,600 years. The biggest of these eruptions, WK-2 (3.3 ka), had a total estimated eruption volume of 30km$^3$.

Archaeological research has shown that the W-K2 eruption had a devastating impact on the people who were living in the area at that time. The people, who traded obsidian artefacts with the surrounding islands, were completely wiped out after this particular eruption. A new society then migrated into and occupied this region. This latter group specialized in trading with Lapita pottery, which later spread eastwards into the Pacific.

This is proven by obsidian artefacts being found only in and under tephra and pyroclastic deposits from the W-K2 eruption and not in the tephra layers above which were produced by later, less-powerful eruptions. Only Lapita pottery fragments were found in the younger tephras after W-K2.

Recent mapping and field work done in the area has uncovered a small amount of banded pumice in the lowest part of the W-K2 ignimbrite. Unlike the normal, light coloured, rhyolitic pumice of all the Witori eruptions described in previous studies, these pumice clasts have alternating bands of light (rhyolitic) and dark (dacitic-
andesitic) colours. The total abundance of the banded pumice in comparison to the white coloured pumice is around 5% to 95%.

The banded pumice also displays sulphide mineralization within the dark-coloured bands only. Copper sulphides such as chalcopyrite and bornite are disseminated within the dark bands and occur with quartz and pyrite. The banded pumice is only found in W-K2 and not in the products of the other eruptions.

The banded pumice is evidence of magma mixing/mingling. Since it is only found at the very bottom of the W-K2 ignimbrite (>30m thick at 10km away from eruptive centre), it would have been part of the initial eruptive products.

Therefore, I am proposing that a smaller, less evolved (mafic) magma body intruded the larger, already-present, rhyolitic magma chamber of Witori and triggered the catastrophic eruption of 3.3 ka. The injection of this new magma could have also been the cause of the large destructiveness of this eruption compared to all the other eruptions of Witori. The mafic magma could have either come directly from the mantle or structurally diverted from the chamber of one of the numerous surrounding dormant volcanoes.

Laboratory analysis (electron microprobe) is planned to confirm major and trace element compositions of the banded pumice so as to give a better picture of its origin.

Some recommendations would be to do further research and laboratory analysis into the copper sulphide mineralization within the banded pumice and seismic tomography of the areas surrounding the volcano. Witori is still currently active and is surrounded by a population exceeding 30,000 people. At present, there is only one seismic station monitoring the volcanic activity. There is a need for a wider array of seismic stations in order to track and monitor magma movements under the volcano.

Fig 1. Location of Witori and other volcanoes in West New Britain.
Alban Reupana  
Senior Geotechnical Engineer, K92 Mining Inc.

1. Introduction

Geotechnical engineering has diverse applications in a mine setting as it covers all round set-up of the mine including the surrounding communities. As for Kainantu mine it is no different. It is an underground gold mine and has its set-up that are monitored by geotechnical engineers. Their work encompasses the underground component, the residential area, and the main access to the underground, the mill, the surrounding environment and the main tailings storage facility.

This paper will cover three aspects that are encountered in the mining operations: - the rock domain, the major fault zones and the water-bearing structures. The emphasis is on data collection methodology, the data entry into the database system, and interpretation. This information is available for the engineers to use when designing and the implementing of the design.

2. Data collection

The data collection looks at the ways in which the information is gathered. It involves core logging, field mapping and drill log sheets.

2.1 Core logging

The core logging is a specialised skill requiring careful observation and accurate recording of these observations by geologists. The geotechnical core logging is carried out by a geotechnical engineer at the geology core shed. The geotechnical core logging sheet has two sections - the rock mass and the structural component.

The rock mass contains the depth in metres, from and to, the lithology, weathering, the strength, the presence of water column and the rock domain. The structural component constitute the depth in metres and the $\beta$ in millimetres, $\alpha$ in degrees, orientation method, and orientation marker.

In the geotechnical core logging, the information is captured into an excel spread sheet manual by logging. This information is transferred into the spread sheet where it is saved as a CSV Decoma limit. The CSV file is exported into the main database using the Surpac software. The information is then viewed in 3D model, and the area of interest is developed in the Surpac.

2.2 Field Mapping

The field mapping part is the identifying of all the geological and geotechnical aspects of the area with a purpose of preparing a detail geological and geotechnical report and map of the area. Certain parameters are considered during the mapping to ensure it is in detail and accurate. The tools used for geological and geotechnical data compilation are the map of the area, compass and clinometer, survey pick up points, geological hammer, hand held lens, measuring tape, field note books, field camera, safety clothing, and first aid kit.
The field data collection is part of the field mapping and consists of the tools used to collect the geological and the geotechnical data information. This information is used to assist in the interpretation of the rock properties in the area. The information is also utilised in the software analysis as in the DIPS, Unwedge, Examine2D, Phase2, Slide and RS3. Analysis results obtained from the assessment are marked for the area and in other similar settings that appear to have similar geotechnical characteristics.

2.3 Drill Log Sheets

The drill log sheet contains the daily report that holds the date of work and the personnel’s involved. It records the drilling component, size and the casing, the delays and down time details, consumables used, and the time involved, survey details and the comments section. A general assessment of the daily sheet gives a general assessment of the rock type and the ground conditions. For example, a shear rock domain which marks a fault zone would give trouble to drilling. This can be captured in the drill log domain which marks a fault zone would give trouble to drilling. This can be captured in the drill log sheet and confirmed at that depth. A depth where water has been intercepted can be used to project the water-bearing structure.

3. Interpretation

The interpretation involves making inference to the results of the various data analysed. It is the assignment of meanings to various concepts, symbols or objects under consideration. The areas discussed under this heading are the rock domains, the major faults and the water-bearing structures termed locally as the “Purple Rain”.

3.1 Rock Domain

The general rock domain distribution is based on the structure and the surface conditions of the rock exposed. Geological Strength Index (GSI), International Society for Rock Mechanics (ISRM) and the field estimates of strength are some of the tools used to class the area of interest and make projections. The rock domains in the Kainantu mine are classed into three groups: the fresh rock, the transitional and the shear rock domains (Table 1). The GSI is a chart that plots the rock type based on the field assessment of the area, the ISRM is the grading of the rocks mapped and the field estimate of strength looks at the use of the geo-pick to break the rock and the use of the finger to dent the ground.

<table>
<thead>
<tr>
<th>Rock domain</th>
<th>Geology strength index</th>
<th>Field estimate of strength</th>
<th>ISRM Grading</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fresh</td>
<td>50 - 100</td>
<td>Specimen requires many blows to break</td>
<td>R4 – R5</td>
</tr>
<tr>
<td>Transitional</td>
<td>30 - 50</td>
<td>Specimen broken by a single blow</td>
<td>R2 – R3</td>
</tr>
<tr>
<td>Shear</td>
<td>Below 30</td>
<td>Specimen indented by nails</td>
<td>R0 – R1</td>
</tr>
</tbody>
</table>

Table 1. The rock domains, GSI field estimated properties.

Fig 1. Core photos showing the fresh, transitional and shear rock domain towards the end of the tray alignment.
Fig 2. Diagrams showing the general rock domain distribution of the Kainantu underground mine development at the 1185, Kora North.

3.2 Major Faults

Faults are weak areas that have moved over time, a discontinuity in a volume of rock along which there has been movements. In the Kainantu setting the challenges are met when there is a cross cutting fault that intercepts the major shear domain, it is along the intersections where the fall of grounds are reported.

The shear domain is the fault zone that runs north-south and is an extensive geological anomaly (fault) mapped in the Irumafimpa ore zone and extends to the Kora ore zones. It runs parallel to the ore vein and consists of large argillic clay along fault intersections. It is in this area that poses major geological challenges as observed in the 1185_FWD_XC developments where the Mokane faults intercepted the major shear domain and the area undergoes some form of movement. The underground excavation, passing through the shear domain fault to the south showed that the surrounding rock mass has been generally very loose and broken.

The argillic shear zone contains illite, smectite and kaolinite in varying percentages. This shear zone contains substantial amounts of water-sensitive clay minerals and undergoes argillization when it is subjected to water hence, it is sensitive to disintegration and weathering with a high erosion rate.

Fig 3. The shear domain (red) and the Mokane fault (dark) that intersects the shear domain. It is in this setting that poses major geotechnical challenges especially in ground stability.

3.3 Purple Rain

The aquifer in the water-bearing structure “the Purple Rain” appears to be compartmentalised with clay fault structures creating compartments. Strata on the bedrock that was dislocated by faults is aqueous rich.
Permeability is the property of rocks that is an indication of the ability for fluids (gas or liquid) to flow through them. High permeability will allow fluids to move rapidly through rocks. Permeability is affected by the pressure in a rock; it is also the ability of rock to transmit fluids where a pressure gradient exists.

As observed in Kainantu mine, water in development areas are observed along fissures in fresh rock domain and they are narrower fault structures (~ 0.3m). Transitional rock domain appears to be the permeable material as can be seen the “Purple Rain”. This appears quite extensively in the transitional rock domain. The Irumafimpa shear zone, which is mapped as the shear rock domain is predominantly the argillic clay that seals water from seeping. This most probably creates water compartments together with the cross cutting fault structures as observed in the Link structure between ore vein K1 and K2.

**Fig 4.** Purple rain (purple) - the water-bearing structure mapped and projected in wireframes.

4. **Application**

The utilisation of the data that has been interpreted and it is the act of putting these together. Underground mine engineers utilise the information in the design, the surveyors mark the design on the ground, and the operations executed the design.

4.1 **Rock Domain**

The rock domain information is made available to the engineers in the form of string files, digital terrain and block models. This information is used to assist in the design as it helps the engineers appreciate the general rock domain distribution, and the areas classed can be divided into different design application zones.

4.1.1 **Design**

The rock domain information helps the engineers with the design in terms of appreciating the general rock competency in an area of the design. For instance, the fresh rock domain is a competent rock domain therefore plans will be in place to cater for long term infrastructure developments or for areas where shear rock domain will be intercepted, plans will be in place to adequately support the area for potential fall of ground and the impact to operations.

4.1.2 **Long Term infrastructure**

Long term infrastructure development is decided primarily on the fresh rock domain as in the setup of the high voltage power supply station, crib room area, refuge chambers, and the main development access. These are infrastructure set up primarily for the life of mine and the rock domain is used to help engineers design the location.
4.1.3 Development Dimensions

The mine has different meshing standards as: 5.2 m x 5.7 m, 4.2 m x 4.7 m, 3.2 m x 3.7 m and a 2.2 m x 2.7 m. Different application are also made for the cut and fill ground support in the ore zone area and along shear intercepted zones with steel support or the use of W strap and Purling’s are recommended in form of ground support. These are all captured in the design developments.

The fresh rock domain will have the higher dimension values while the transitional rock domain, the medium dimensions values, and the shear rock domain with the lower values. Certain applications will be considered in areas where the fault runs next to the dimensions. For example, the use of cable bolt to hold back the walls.

4.1.4 Blasting Requirements

The rock domain distribution also aids in the blasting requirements as in the shear rock domain, where there is a potential for free digging the area than blasting; as it is the unstable zone and has the potential for instability causing delays in developments. While in a fresh rock domain, the area must be properly blasted to have the required fragmentation for transportation as well as achieving the cuts. The transitional rock domain can have a variable application, as the area closer to the fresh rock domain will appear competent than that close to the shear rock domain, as it will be broken.

4.1.5 Ground Support Requirements

Ground support based on the rock domain is determined by the development dimensions mentioned in subsection 4.1.3. Areas where the faults are close to or intercepted in the development drive, a separate application is issued with recommendation on extra cable bolts or grouting in ground conditions that pose potential fall of ground.

4.1.6 Waste Dump Design

Development of the waste dump incorporates a 13 weekly and a 6 monthly to 12 monthly plans. These plans identify the waster rock type that is going to be mined out as planned in the schedule. The waste dump design is in phases, in line with that is scheduled to be developed.

4.1.7 Waste Dump Developments

The waste dump development is the building of the waste dump in accordance to plan and the actual tonnage of the waste rock from the development. The fresh waste rocks are sent to areas as per the design to support dump stability along the toe and the crest of the dumps that holds to gather the transitional rock domains and the shear rock domains.

4.1.8 Waste Rock Management

This is the daily supervision of material coming out from the developments and drives by assigning their destination based on the rock domain. This will ease the waste rock management in dumps as the rock domains have different rock properties, which are critical to the dump overall stability. Regular supervision is required to ensure compliance to plan from time to time, while the reconciliation of the waste rock will assist in the tonnage mined.

4.2 Major Faults

Excavation is done perpendicular to the shear domain. This is for the ore bearing 1km vein to 700 metres below the surface. The small faults and fractures developed well with argillaceous gouge infilling and around the contact. The rock mass is easily broken in geological anomaly (fault) zones. The strength of the surrounding rock
is extremely low. The roof collapses can be easily attributed to the broken soft rock mass without stand-up time after excavation.

![Image](image.jpg)

**Fig 5.** The Mokane fault projection (red), a cross-cutting fault that intersect the major shear domain.

Information on major faults and the analysis made of the joint sets do assist in determining the general rock properties and characteristics for the area of interest. These include design review, kinematic analysis, joint combination analysis, ground support analysis, interaction analysis and the recommendation for the ground support. These are some tools utilised to determine the rock characteristics for the area of interest.

### 4.2.1 Design Review

In the design review with faults, the information is made available and placed in the common folder the “main data hub”. It is from this folder updated fault information in the form of 3D model are available. The design engineers use this information to draw designs that avoid potential wedge forming failures from the faults intersections. This information is assessed by competent geotechnical engineers sourced locally or abroad to verify.

### 4.2.2 Kinematic Analysis

In the kinematic analysis, the DIPS software is used to work out the mode of failures. The information is collected from the field mapping and the data is entered into the spread sheet and assessed as in stereo nets that identifies the mode of failures and the direction of failures. It also identifies the number of failures including the critical. This assessment is further assessed in Phase2 and Unwedge software.

### 4.2.3 Joint Combination Analysis

Joint combination analysis is carried out by the Unwedge software. The joint data entered in the DIPS software are imported into Unwedge Software and analysed including the development of the tunnel length in metres and its orientation in degrees. Joint combinations can be assessed including the factor of safety, the wedge volume, the apex height in relation to the tunnel orientation. The results are exported in an excel format for further assessment.

### 4.2.4 Interaction Analysis

In the interaction analysis Examine2D and Phase2 software are used to assess parameters based on generally the rock domains as in the fresh, transitional or shear rock domains for stability analysis. Scenarios as in estimating the crown pillar width are drawn to have a general understanding. Development next to the existing excavation on a side by side are also assessed to determine the minimum width required between the two developments. The same is applicable to a development next to the shear rock domain or a fault zone.
Fig 6. The DIPS software analysis of a wedge sliding failure.

Fig 7. The joint combination analysis in relation to the tunnel orientation.

Fig 8. The interaction analysis of the crown pillar between the two conceptual developments (A) and (B), the required distance width generated from a Surpac software.
4.2.5 Ground Support Recommendation

Because of the geo-hazards to be encountered and potential fault slip behaviour during underground excavation in the shear fault zone, providing adequate support or reinforcement to the rock mass with sufficient speed after excavation is almost impossible. Reinforcing the rock mass in advance of excavation should be practical and adopted. In addition, extra reinforcement should be provided as part of the normal cycle, in anticipation of higher stresses being imposed on the rock at a later stage during the service life of the opening.

4.3 Purple Rain

This is the water-bearing structure mapped in the underground and captured in 3-dimensional format that can be easily viewed by engineers. Decline and incline developments in the engineering design are made aware of the water-bearing structure that would be intercepted as during the excavation. Excessive groundwater inflow frequently associated with faults and fractures, often occurred. The excessive groundwater inflow and seepage not only threatens during excavation but also continues to deteriorate the strength and deformation characteristics of the rock mass over time and decreases the stability of the underground openings in argillaceous rock.

Fig 9. The ground support component of the Unwedge that has the factor of Safety (FS) value above 1, indicates that the section assessed is stable.

The influence of groundwater on the argillaceous rock contains two main aspects: the mechanical action of water on the surrounding rock, including the hydrostatic pressure of the effective force and the dynamic water scouring effect, and the physical and chemical action of water on the rock mass, including softening, argillization, dissolution, and swelling.

4.3.1 Decline Development

In the decline development the plans encompass the water-bearing structure and the projection depth at which it will be intercepted. Plans for the pumping and the piping of the water are put in place prior to development
including a development of a cuddy as a sump to store water that can be pumped. This is also to minimise the impact of water on the development face, so mining can continue.

### 4.3.2 Incline Development

In the incline development water-bearing structures are also projected at the depth of interception. This information is captured in the plan and is closely monitored and unlike the decline development, the water is flowing down the incline and diverted into a sump where it is piped away out from the main access.

### 4.3.3 Design

The design component looks at the possibility of avoiding the water-bearing structure. In this component, the engineer assesses the water-bearing structure and looks at designing ways it can be able to avoid the water-bearing structure where possible. However, if the design runs through the water-bearing structure, the engineer can come up with a workable plan to control water.

### 5. Software Applications

Mining software are used at the workplace for analysis, wireframing and section development, which are exported as DXF and imported by the other software. These include: Surpac, Unwedge, Phase2, Examine2D, Dips, and Slide.

Surpac is used for 3-dimensional modelling as in wireframing and block model, and the development of sections which are exported as drawing exchange format that can be easily used by other software. Unwedge is used for ground support analysis and for the joint combination analysis and Phase2 for slope stability analysis, interaction analysis and the ground support analysis. The Examine2D software is used for interaction analysis, while DIPS for the kinematic analysis, and Slide for the slope stability analysis.

### 6. Application

This section looks at the actual development based on the rock domains, the major fault structures, and the Purple Rain, which is the water-bearing structure.

#### 6.1 Fresh Rock Domain

**Fig 10.** The high voltage station and the refuge chambers built on the fresh rock domain. These are the longer term infrastructure that are developed and meant to last for the entire mine life, hence needs to be on a more competent and a stable ground.
6.2 Major Faults

Fig 11. The set up of the steel beam support and the use of W strap and Purlings are examples of approaches based on the fault extension and the likely impact. Recommendations are made to engineers, which are then achieved through a general consensus whereby a plan of attack is mapped out capturing the formal risk assessments and job safety and environment analysis.

6.3 Purple Rain

Fig 12. The presence of water for a decline development will have a pump set up with a piping system to keep the face development clear, while for an incline development water is diverted to a sump and it is piped.

6.4 Long Term Designs

Long term designs also do take into considerations the geotechnical challenges most likely to be encountered and factored them in the plan as in Rock Domains, Faults and the Purple Rain.
1. Introduction

This paper aims to present and discuss the petroleum exploration business in PNG. The main sections include: (1) life-cycle exploration and production (E and P) projects, (2) PNG legislation on oil and gas, (3) fiscal regime, and (4) challenges.

2. Life-cycle exploration and production

Stages in exploration and production – life cycle

Through time, oil and gas fields undergo five basic stages:
- Exploration
- Appraisal
- Development
- Production and enhanced oil recovery
- Abandonment

Objectives change as fields mature, effect on expenditure and production and development strategies.
Man Hours

![Man hours needed in petroleum exploration and development.](modified from Seiley, 1998)

**Fig 1.** Man hours needed in petroleum exploration and development.

**Expertise involved...**

- Exploration – geologists, structural geologists, seismologists, geophysicists
- Development and appraisal – field development geologists + operational geologists + petroleum/reservoir engineers + drilling engineers + petrophysicists + completion engineers; “Synergy or collaboration”

**Field Development Geologists**

- They play a pivoted role in the evaluation of a discovered field and main focal point for field development.
- Estimates oil and gas in place
- Understanding the petroleum resource management systems (PRMS)

**Resource ≠ Reserves**

- Resources are estimates that have degree of uncertainty.
- Reserves represent **part of resource** that is commercially recoverable.

![Classification of resources.](modified from Mavko, 2014)

**Fig 2.** Classification of resources.
PRMS Resource Classification System

- Technical definitions that have become standards
- Results of more than two years of collaboration by the SPE, WPC, AAPG and industry at large
- Guidelines that incorporate best practices and internationally recognised

PRMS Classification (Volumes and maturity)

![Fig 3. Resource categorisation and development phases.]

Examples of PRMS Classification

<table>
<thead>
<tr>
<th>Project</th>
<th>Category</th>
<th>Resource/Reserves Volumes</th>
</tr>
</thead>
<tbody>
<tr>
<td>PNG LNG Project</td>
<td>Commercial</td>
<td>2P – 10 tcf</td>
</tr>
<tr>
<td>P’nyang (PRL-3)</td>
<td>Sub-commercial</td>
<td>1C – 1.5 tcf / 2C – 4.36 tcf</td>
</tr>
<tr>
<td>Gulf LNG (PRL-15)</td>
<td>Sub-commercial</td>
<td>1C – 5.2 tcf / 2C – 6.5 tcf</td>
</tr>
<tr>
<td>Stanley (PDL-10)</td>
<td>Commercial</td>
<td>1P – 269 bcf / 2P- 355 bcf</td>
</tr>
</tbody>
</table>

Table 1. PNG examples of PRMS classification.

3. PNG Legislation on Oil and Gas

Legislation

- Oil and Gas Act (1998) and Oil and Gas Regulation (2002)
- Principal implementer is the Director of Oil and Gas Act (appointed by Minister for Petroleum)
- Governs issuance of Petroleum Licences, operations of all E and P activities, landowners and other stakeholders.

Petroleum Licence gathered for under the act...

- Petroleum Prospecting Licence (PPL)
- Petroleum Retention Licence (PRL)
- Petroleum Development Licence (PDL)
- Petroleum Pipeline Licence (PPL)
- Petroleum Processing Facility Licence (PPFL)

This is a “Progressive Licensing System” that exists in the oil and gas industry.

**PRMS Classification (Licensing)**

![PRMS classification and licencing](image1)

**Licence Map**

![Petroleum licence map](image2)

**Fig 4.** PRMS classification and licencing.

**Fig 5.** Petroleum licence map.
Application process of licensing

**Fig 6.** Application process in petroleum licensing.

Requirements

- Detailed proposal for work and expenditure in respect of block or blocks specified
- Technical qualifications of applicant
- Financial resources to meet work expenditure
- K10,000 non-refundable application fee
- Process covered in Sect 21 of OGA
- K100,000 security bond on acceptance of offer

**PPL Awarded, 2000 - 2016**

*Table 2.* PPLs granted 2000 – 2016. Tax incentives were introduced from 2003.
Example of Petroleum Prospecting Licence

**Fig 7. An example of Petroleum Prospecting Licence.**

4. Fiscal Regime

- Fiscal regime (FR) has very significant effect on field development economics and the decisions for project development.
- The effects of ‘taxation’ and the regime affects companies’ profitability.
- It also attracts investors if there is some stability and structure.
- There are various types and different countries have different FR that suits their legislation and their view on government take.
- Australia – levy/tax concession and petroleum resource rent tax (for offshore federal territorial projects).
- Indonesia – production sharing contract where both government and operator (referred as contractor) share oil/gas profits.
- Papua New Guinea – levy/tax/State participation and additional profit tax.

“White Paper on Natural Gas Policy of 1996” provides the foundation for the negotiations of the PNG LNG Project.

- Royalties – payable at rate of 2% wellhead value
  - Sales value at the point of export
- State participation – option to acquire ‘direct’ 22.5% carried interest (after PDL grant)
  - KPHL is the State nominee and State Negotiating Team
  - Liability to pay sunk costs plus interest from project income
- Income tax – 30% of oil/gas projects
- Additional profit tax – triggered after 15% rate of return (post tax) and charge at 30%
  - This have never been triggered.

5. Challenges

- Offshore Projects – there needs to be a new policy that provides guidance to offshore (continental and deep water projects).
- Landowner participation is still an ongoing issue and requires best approach
- P'nyang and Gulf LNG – underpin Third LNG Train (some fiscal and participation issues still exist)
- Western stranded gas fields (Stanley PDL 10, Kimu, Elevala) need development

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Paper PA09-ESD2018
TITLE: REVISITING THE SYSTEM Zn$_2$(Cu,Fe)S$_3$ OF THE LALOKI STRATABOUND SULFIDE DEPOSIT OF ASTROLABE MINERAL FIELD, CENTRAL PROVINCE, PAPUA NEW GUINEA. INVITATION TO RESEARCH

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Expanded Abstract

The mineral and system Zn$_2$(Fe,Cu)S$_3$ was approved as New Mineral by the Commission of New Minerals and Mineral Names (CNMMN) in 2003 (Jambor and Roberts, 2003). This Cu-Fe bearing zinc sulfide occurs in the Laloki massive sulfide deposit, Astrolabe Mineral Field (AMF), Papua New Guinea. The mineral is optically uniform in texture but is chemically variable and zoned even within a single grain. Copper contents vary from 0.1 up to 8.85 wt%. Iron reaches 18.31 wt% at maximum and decreases as Cu increases. It is remarkable, however, that the total Fe+Cu remains essentially unchanged between roughly 18 and 20 wt%. Zn and S are least variable, giving 45.85–47.84 wt% and 33.48–34.58 wt%, respectively. Other trace elements such as Cd and Mn are in general less than 0.2 wt%. It is strongly suggested that the mineral in question constitutes a unique Fe-Cu substitutional solid solution series belonging essentially to the Zn-Fe-Cu-S system.

The ideal chemical formula of the solid solution series can well be presented as Zn$_{10}$(Fe,Cu)$_3$S$_{15}$ or Zn$_2$(Fe,Cu)S$_3$, where Fe is always greater than Cu.

It is intriguing that chalcopyrite blebs are recognizable restrictively only in nearby portions of the Cu-rich end member with the ideal composition close to Zn$_{10}$Fe$_3$Cu$_2$S$_{15}$. It has been confirmed by vacuum-sealed heating experiments that this mineral is decomposed to produce chalcopyrite and Fe-bearing normal sphalerite at temperatures below 200°C. This would provide another evidence for the existence of such distinct phase as suggested here.

Electron Probe Micro Analysis Mole % plot onto the CuS-FeS-ZnS ternary plane of the Cu-Fe-Zn-S quaternary system after Kulange et al. (2002) (Fig. 1). It is intriguing that chalcopyrite blebs are recognizable restrictively only in nearby portions of the Cu-rich end member with the ideal composition close to Zn$_{10}$Fe$_3$Cu$_2$S$_{15}$.

Laloki and most of its associated mineral deposits show syngenetic mineralisation as the initial ore forming stage followed by epigenetic input. This syngenetic – epigenetic transition needs to be tested. The relationship of the Cu-Zn-Ag-Au mineralisation in the NW and the generally SE manganese/manganiferrous mineralisation of the AMF requires detail field work and exploration, e.g., Pandora manganese. Most of the known deposits within the AMF are relatively shallow and are speculated to have developed from graben developments of rift systems
followed by Sadowa Gabbro intrusion. Further work is emphasised within the low temperature mineralisation and their expressions within the known orebodies of the Astrolabe Mineral Field.

![Diagram](image.png)

**Fig 1.** The system Zn$_2$(Cu,Fe)S$_3$.

**References**


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**Paper PA10-ESD2018**
**TITLE: PICTORIAL SLIDE-SHOW OF ACTIVITIES OF THE GEOLOGY DEPARTMENT, PORGERA JOINT VENTURE**

**Norma Siki**
Senior Geologist, Porgera Joint Venture

**1. Introduction**

This presentation is a slide show of activities of the Geology Department of the Porgera gold mine, which is owned and operated by the Porgera Joint Venture (PJV). The first section is an overview of the Porgera gold mine.

**2. An overview of the Porgera gold mine**

The Porgera gold mine is a large gold and silver mining operation in Enga province, PNG, located at the head of the Porgera valley. The mine is situated in the rain forest covered highlands at an altitude of 2,200 to 2,700 m, in a region of high rainfall, landslides, and frequent earthquakes.

The Porgera operation comprises open-pit and underground mining operations.
Since the first gold pour in 1990, more than 143 million tonnes of ore has been mined in both the open-pit and the underground, producing over 20 million ounces in gold production to date. Crusher feed from the mining operations is based on blending the highest gold grades available to maximize the gold output, combined with an additional constraint of sulphur content as required by the process plant.

Electricity to the mine is supplied by the PJV Hides power station located in the neighbouring Hela Province. The gas-powered facility provides 75 megawatts of electricity across a 75 km electrical transmission line to the Porgera mine site.

A lime plant, 7km away from the mine site provides lime for neutralization. Water is supplied from a reservoir at Waile Creek containing 7 million cubic metres of water.

2.1 The Open Pit Mine

The open-pit mine is 500 metre deep, below the highest point of surface topography and approximately 30 million tonnes (t) of ore per year is excavated. The material mined is a combination of gold-bearing ore and barren waste.

Ore from the pit is delivered to the crusher either as direct feed or via adjacent run-of-mine pads depending on metallurgical blending and material handling requirements.

Lower grade ore material that is not fed directly to the mill is stockpiled depending on cut-off grade applied. If the gold grades available in the pit are lower than the stockpile grades, or if there is a shortage of direct feed ore, these stockpiles are recovered and fed to the mill.

Competent waste rock is disposed in stable dumps at Anawe and Kogai. Semi-competent and incompetent waste is disposed in two erodible dumps, Anawe and Anjolek.

Mining in the open pit is undertaken on 10 metre high benches. When the material is too hard to be free dug, the rock is drilled and blasted with a range of drill patterns to suit the litholog.

The open-pit is a conventional truck and shovel operation and is serviced by a large modern mining fleet of 175t and 90t haul trucks, loaded by 200t and 120t shovels and excavators. There are also smaller 40t and 35t excavators for ancillary work.

2.2 The Underground Mine

The Porgera underground mine is a modern, trackless mine, producing approximately 1.4 million tonnes of ore per year from three primary production areas: North Zone, East Zone and AHD.

The underground operation mines the lodes at depth currently up 330 metre beneath the current pit floor. The underground operation has a strike extent of approximately 1.6 km. The primary access is via a twin decline system from surface with secondary internal accesses connecting the various mining areas. Mining is done by convention long hole open stoping. Drives are developed along the strike of the lenses at 15m vertical intervals with long-hole stoping used to extract the ore between these levels.

The voids generated by mining are back-filled with a combination of paste and co-paste disposal to enhance ground stability and allow maximum extraction of ore.

The underground mine operates on a modern trackless mining fleet consisting of CAT 2,900 loaders, 45t and 55t capacity haul trucks and supporting drills and auxiliary equipment.
2.3 The Processing Plant

Ore is processed in a complex minerals processing plant. The open-pit and underground mines supply both course gold and refractory ore to a processing plant that includes crushing, grinding, gravity recovery, flotation, oxidation (autoclave) and carbon-in-pulp circuits to produce a gold dore product and a high grade pyrite concentrate for shipment to offsite refineries and smelters for final processing.

Run-of-mine ore is crushed and ground in semi-autogenous and ball mills, free gold is recovered in a gravity circuit and flotation is used to recover a sulphide concentrate. This is then oxidized using autoclaves, producing feed for conventional carbon-in-leach (CIL) cyanide leaching to recover the contained gold.

Since January 2016, the Porgera mine commenced exporting of pyrite concentrate. A recent modification to the flotation circuit had enabled the production of a gold rich sulphide concentrate that is shipped to an offsite smelter for further gold extraction. The concentrate export enables lower grade stockpiled concentrate to be reclaimed and processed in the autoclave and CIL circuits oxidized on site.

The autoclaves operate at 1,725 kPa pressure and 197°C to oxidize the pyrite (iron sulphide) into hematite (iron oxide) producing feed for the CIL circuits which recovers up to 95 per cent of the contained gold.

Lime used to neutralize the acid generated in the autoclaves is produced from limestone quarried from a quarry 15km from the mine. The limestone is burnt in two vertical kilns, which use waste oil or diesel as fuel before the lime is trucked to the autoclave plant for addition to tanks to neutralize the acid.

3. The Activities of the Geology Team

Photo (left). Core logging at core shed. Photo (right). Field work in one of PJV tenements.
Photo (left). Open pit work.  

Photo (right). Open pit sampling.

Photo (left). Ore block modelling for open pit.  

Photo (right). Equipment set-up for open pit work.

Photo (left). Discussion and teamwork.  

Photo (right). Industrial trainee at work.

Photo (left). Entering underground data into computer.  

Photo (right). Face mapping at underground.
Abstract

The Elk-Antelope gas-condensate fields, and Bobcat-1 and Raptor-1 wells are located in the NW eastern Papuan Basin (Figs 1 and 2). The discovered gas-condensate fields in the area are currently into development by InterOil and partners. Formation (mud) gas studies was one of the tools used to identify the presence of hydrocarbons in the interval of interest in the wells. This study aimed to show examples of how hydrocarbon types can be identified using formation (mud) gas data, and formation fluids affect hydrocarbon movement with examples using Bobcat-1. The lithostratigraphic correlation of wells to understand facies variation in the same area of study is given in an accompanying paper (expanded abstract in this volume).
triangular diagrams, were used to verify the type of hydrocarbon (gas-condensate) present, and determine whether or not the interval was productive.

Results from an interval in Bobcat-1 are given as examples below (Figs 3 and 4). Figure 3 is a \( C_1/(\sum C_n) \) Pixler ratio plot. It shows a substantial shift in the hydrocarbon density from a condensate phase towards dry gas phase at 2153m. Dry gas is predominant above 2153m. Gas-condensate or light oil is indicated below 2153m, suggesting that the carbonate reservoir hosting the main condensate may be present further down this depth. In this example, the \( C_1/(\sum C_n) \) and \( C_1/C_2 \) Pixler ratio plots identify the interval 2153m-2503m as potential productive zone, due to clustering of ratio plots within this interval.

The depth ranging from 2153m-2503m encompass the sweet spot/zone. Gas composition diagrams (Fig 4) were used to verify this interval for hydrocarbon presence. It shows that at 1603m and 1653m, the ratio trend (at point \( C_1/C_2 \)) indicates a non-productive dry gas zone. Between points \( C_1/C_3 \) and \( C_1/C_4 \) ratio trends display negative slopes, indicative of formation water. At \( C_1/C_4 \) and \( C_1/C_5 \) ratio trend shows varying positive slope inclination within the gas zone. It therefore suggests that the interval 1603m-1653m is a non-productive zone as presence of water-bearing formation has been revealed. The ratio plots and triangular diagrams suggest that at depths 2203m, 2253m, 2303m, 2353m, 2403m and 2453m to be hosting productive gas.

![Figure 3](image_url)

**Fig 3.** An example of a \( C_1/(\sum C_n) \) Pixler ratio plot from an interval in Bobcat-1, showing gas-condensate presence between 2153-2503m, and reservoir top at about 2153m.
Fig 4. An example of gas composition diagrams showing presence of formation fluid within the encompassed sweet spot/zone, 2153m-2503m, in Bobcat-1.

The overall results show strong presence of conventional hydrocarbons especially gas and gas-condensate across most of the wells. It also indicates that a dominant formation water system existed and has probably flushed most of the oil in a southeasterly direction.

Reference

To help solve this problem, Pacific Niugini Minerals and PNG Forestry Products, who jointly owned ML 457 Widubosh, have engaged the Geological Survey Division (GSD) of the Mineral Resource Authority, to conduct a seismic refraction survey over the tenement (Irarue, 2013). GSD shot 55m refraction surveys on fourteen sites, along four survey lines, with 12 detectors spaced at 5 metre intervals. All four survey lines were directed east-west, however, orientations in each survey site varied.

This study re-analysed and interpreted the data acquired by GSD. The primary objectives of the study have been to determine the depth to Otibanda formation, its lateral extent, and the thickness of gold-bearing gravels. Secondary objectives were to provide geological cross-sections and to estimate the resource for mining economics.

Interpretation of data involved techniques that considered different refractor geometries. These approaches were to interpret for planar (horizontal and dipping) and undulating refractors. The findings are grouped into three cases: one layer, two layer planar, and two layer non-planar (irregular). The delay time technique and wavefront reconstruction plus-minus method were utilised for interpretation of the seismic refraction data.

Results show that three survey sites consist of thick Quaternary sediments and show no refractions from subsurface layers. Two of these sites are unworked or undredged alluvial gold-bearing gravels while the other consists of reworked gravels. The lack of refraction, however, implies that the thickness and the nature of the interface cannot be determined precisely. The depth to refractors in these three sites are possibly greater than 11m and compared to other survey locations, it is approximated to be more than 15m.

Five survey sites indicated two layer cases with planar dipping interfaces. The second layer in these cases is the Otibanda formation. The top layer consists of poorly consolidated sand and clay while the lower layer of semi-consolidated sandstone and claystone. The other sites have gold-bearing gravels overlying the Otibanda formation. Three non-planar case sites out of the total six interpreted cases contained gold-bearing gravels. Two of three were overlain by residual gravels (Fig 3) while the other consisted of reworked gravels (Fig 4).
The Otibanda formation extends throughout Widubosh. The general inclination trends of the formation vary. The northern portions of the lease area appear to be slanting gently to the east. However, the other survey points do not appear to be following any trend in slanting orientations. This could be related to the nature of the deposited material and the environment of deposition. The gold-bearing gravel thickness varies as observed from the depths to refractors.

The results obtained from the study were primarily based on velocity differences, geological data and depth to refractor at each survey site. The delay time techniques and plus-minus method proved successful in separating Quaternary sediments from the Pliocene Otibanda formation. It shows that the P-wave seismic velocities can be used to infer subsurface geology at project level, in this case Widubosh; and the Otibanda formation and gold-bearing gravels have been precisely mapped.
References


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Paper PA13-ESD2018
TITLE: LITHOSTRATIGRAPHIC CORRELATION STUDY OF BOBCAT-1 AND ADJACENT WELLS: AN ATTEMPT TO UNDERSTAND FACIES VARIATION IN EASTERN PAPUAN BASIN

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Abstract

Miocene reefal and deep water carbonates host the Elk-Antelope gas-condensate fields, and Bobcat-1 and adjacent wells located in the NW eastern Papuan Basin (Fig 1). These gas-condensate fields and exploration wells are within the junction of the Papuan fold belt and the Aure deformation zone (thrust belt) (Fig 2), where the Papuan fold belt is a terrane dominated by successive folded and thrust-faulted marine sedimentary rocks. Aure deformation zone hosts marine sediments folded in an arched-like lineation. Local stratigraphic sequence previously identified had Quaternary sediments overlying the Aure beds, which overlies the Mendi Group and the Moogli Mudstone as the basal formation.

The subsurface geology at the lithofacies level, however, is poorly understood. This study aspires to provide an independent viewpoint in the understanding of the lithostratigraphic (facies) composition and variation. The formation (mud) gas to determine productive intervals in wells and the effect of formation water on hydrocarbons studies are given in an accompanying paper (expanded abstract in this volume).

Eight InterOil’s exploration and appraisal wells in the NW eastern Papuan Basin were utilised for the study, and includes Bobcat-1, Elk-1, -2 and -4, Raptor-1, Antelope-1, -2 and -3. The data comprised of drill cuttings brought to the surface by the circulating drilling mud. The method involved well correlations with picking of formation tops, identifying different lithotypes, unit thicknesses and stratigraphic interval.

Results of the study has revealed the following, from youngest to the oldest: - Era beds overlying the Orubadi formation, which overlies the Orbulina marl, and this in turn overlies the Kepau limestone. The Era Beds is absent in Bobcat-1 (Fig 3). Fault zones at depths of 6m and 321m were encountered at Elk-4 and Raptor-1, respectively. The total depths were not reached in Antelope-2 and -3 wells when drilling terminated. The older strata are reservoirs for the hydrocarbons and formation water. Correlation of these strata revealed highly deformed reservoirs.
Fig 1 (left). Locality map of the Eastern Papuan Basin, on the island of New Guinea. Fig 2 (right). Simplified structural map of the Papuan Basin showing approximate locations of the wells used in this study (after Wilson et al., 2013).

Era Beds consists mainly of sandstones with volcaniclasts, conglomerate, quartz sandstone, sandstone grading into very fine sandstone and claystone with traces of common forams and microfossils. The Orubadi formation has three sub-units: - upper Orubadi, intra Orubadi and lower Orubadi. The upper Orubadi is a homogeneous claystone with thin sandstone and siltstone beds. The intra Orubadi sandstone is about 100m thick and comprises equal amount of sands, clay and silt. The lower Orubadi has inter-bedded sub-units where sand, clay and silt inter-beds exist consistently with sandstone as the dominant lithology. Foraminifera including globigerina, orbulina and globorotalia and trace fossils dominate this unit.

The Orbulina marl is a transition unit that occurs between the lower Orubadi and the Kepau limestone. The marl is rich in orbulina, with minor globigerina and globorotalia, which grades into recrystallized limestone. The marl is argillaceous and grades into a silty and slightly arenaceous mudstone. The Kepau limestone is mainly composed of limestone and rare traces of orbulina. It has no pores and grades from fine-grained to coarse-grained limestone.

The various facies zones or belts observed reflect the transgression and regression episodes, causing sediments to be deposited in different environments. Facies variation is also affected by the subsiding tectonic activity apart from sea level fluctuations. Hence, the paleo-depositional setting is an open marine-sand shoal-slope environment (Fig 4).

The common case whereby marginal sand shoals interfingering with slope sediments consisting of bioclastic sand transported from the shoals to gentle slopes are at FZ 4 and FZ 7D (Fig 4). The lateral facies zones indicated in the model are defined based on the modified Wilson model (Wilson, 1975; Flügel, 2010) describing a rimmed tropical carbonate platform. This model can be used to interpret the facies belts observed in Bobcat-1 and adjacent wells.

This study also shows that the northwest eastern Papuan Basin most probably hosts highly deformed reservoirs, overlayed by a thick mudstone. Thus, facies variation depicts a paleo-depositional setting typical of platform interior to platform margin and down to the slope (Fig 4). Economical hydrocarbons are probably hosted in the slope facies zone.
Fig 3. Correlation of Bobcat-1 with the other wells to observe variation in formation thickness, lithologic (facies variation), and formation tops.

Fig 4. A paleo-depositional model (after Flugel, 2010) used to interpret the facies observed in Bobcat-1. FZ3 – toe-of slope apron (deep shelf marine), FZ4 – slope, FZ6 – platform edge and platform sand shoals, FZ7 – platform interior to normal marine (open marine). The lateral facies zones indicated in the model are defined based on the modified Wilson model (1975) describing a rimmed tropical carbonate platform.
Expanded Abstract

The Otibanda Formation has only been the subject of one detailed study which concentrated on the palaeontology of the formation. There have been different theories proposed to explain the origin of this formation. It has been suggested that the volcanic eruptions of the underlying Bulolo Volcanics deposited agglomerates which dammed the rivers, causing the formation of two lakes and subsequent deposition of sediments. On the other hand, it has been suggested that the Otibanda Formation was deposited within the Bulolo graben. The graben formed as an intra-arc rift along west-northwest trending extensional structures which is the Wandumi and Upper Watut Faults. Snake Transfer Structure and the Lakekamu Transfer Structure mark the edge of the graben to the northwest and the southeast.

Literature review was done on fluvial and lacustrine facies so as to get acquainted with the facies types. Field work conducted comprised a detailed study of total of 30 sections of the Otibanda Formation noting sedimentary structures, palaeocurrents, and way-up indicators to determine their facies patterns along sections in the Wau Basin. Thin sections were analysed from fine-grained rocks to determine the mineral contents and infer their provenance. The research attempted to identify the tectonic controls on the deposition of the Otibanda Formation.

The findings of this study indicate that the Otibanda Formation is fluvial in origin rather than lacustrine and the study also confirms that Otibanda Formation disconformably overlies the Bulolo Volcanics in many areas. The Otibanda Formation was deposited as a result of uplift of the Owen Stanley Range in the Pliocene.

Provenances of the clasts suggest it was derived from the uplift of the Owen Stanley Metamorphic Complex and magmatic and volcanic arc of the Wau-Bulolo area after volcanic activity waned. The sandstones are texturally and compositionally immature comprising of feldspathic and lithic wackes indicating transport was quick and deposition occurred hastily in channels and floodplains in a subsiding sedimentary basin in a tectonically active environment. The distribution of the grain-sizes and the thickness of the formation suggest thick floodplain deposits with fine-grained size sediments is dominant than coarse-grained conglomerate occurring as lenses in the Wau Basin and does not reveal graben type sedimentation. This suggests frequent avulsion indicating regions of tectonic activity, where frequent structural activity and related seismicity affect the river course, and in settings where overbank flooding is frequent, resulting in weaker banks that made it easier for the river to change course.
Fig 1. Map of the Papuan Peninsula SE PNG showing the study area.

Fig 2. Geology map of the area and sites visited.

References


1. Introduction

Behori Quarry area is located within the National Capital District of Papua New Guinea at latitude 9°24’13.69” S and longitude 147°15’20.03” E (Fig 1). It is directly northeast of the University of Papua New Guinea Waigani campus, and located a few metres away from the junction of main sealed Sogeri and Mount Eriama (Eda Ranu water treatment plant) roads.

Fig 1. Location map of Behori quarry.

This research project aims to identify the rock types and structures of the Behori quarry area. There were no previous detail geological investigation done for the geology of Behori quarry. The findings of this project will be used to create a detail geological map of Behori quarry and to briefly discuss the relationship of Behori quarry geology with Nebire quarry geology.

2. Geology of Behori Quarry

The main rock units as recognized in the study area are Olivine Gabbro, Hornfelsed Calcareous Siltstone, Hornfelsed Siltstone Breccia, Calcareous Siltstone and Wackestone. The Olivine Gabbro is a competent, dark greenish grey phaneritic intrusive igneous rock, which composed of altered fine grained crystals at the contact of intrusion with the country rock and coarser grains further away from the contact zone. The coarser grained olivine gabbro are highly weathered and oxidized. It is made up of ~67% plagioclase, ~10% pyroxene, ~10% olivine, ~7% chlorite, ~4% actinolite and ~2% opaque minerals.
The Hornfelsed Calcareous Siltstone is homogenous and massive (not bedded) with variable hardness. It is made up of granoblastic crystals with sizes ranging from ~ 0.0064mm – 0.048mm, which includes 70% of 0.0064mm, 20% of 0.096mm – 0.016mm and 10% of 0.016mm – 0.048mm in diameter and are not visible in unaided eye. It has predominate scattered visible spheroids of different size in diameter (5mm to 30mm) and colour (green, dark greyish brown). The grains are tightly packed in a decussate texture including angular quartz, feldspar, muscovite, wollastonite and reworked planktonic foraminifera.

Hornfelsed Siltstone Breccia is a consolidated greenish grey matrix supported sedimentary breccia, which is composed of monomictic elongated sub-rounded siltstone clasts and mud matrix. It constitutes of 60% matrix and 40% clasts. The general clast lengths are ranging from 0.5 to 3.0 centimetre and 0.3 to 1.5 centimetre wide. They are poorly sorted and heterogeneously distributed. Each clast’s length is directly proportional to its width and are tightly packed and cemented by calcium carbonate recrystallized from the organic rock clasts within the breccia with the mud matrix. It is dark green in colour in field observation, and at distance it can be confused as gabbro.

The Calcareous Siltstone is very fine grained siltstone and yellowish brown in colour in field observation with hard white surface coating on its exposed part. It is calcareous and made up of consolidated very fine silt to clay size grains (0.00312mm to 0.015625mm in diameter) with scattered calcite veins that are cross-cutting each other forming 30° angle. It is competent and highly resistant to weathering compared to overlaying wackestone.

The colour of wackestone in the field is dark red whilst it is fresh and pinkish when it is weathered or sheared. It is an organic sedimentary rock of moderately friable and sheared. It constitute of very fine silt to clay size carbonate grains, which are not visible with naked eye. It is predominately filled with micro cross-cutting white calcite veins. There are no grains or crystals visible in hand specimen. It constitutes of well-formed planktonic foraminifera and red – pink micritic mud. The size of the micrite mud ranges from 0.00312mm to 0.015625mm in diameter, and predominant of 0.00312mm to 0.00624mm.

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Fig 2. Stratigraphy column of Behori Quarry.
3. Structures of Behori Quarry

Behori Quarry is suggested to be deformed by at least two major structural events of low to moderate intensity. These structures are brittle structures including faults and joints. The faults at Behori Quarry area are presented as great circles and poles in the stereographic projection (Fig 4).

The structures at Behori Quarry are low to high angle normal faults, high angle reverse faults, near horizontal faults and joints. The normal faults are trending northeast-southwest and dipping 60°- 80° from horizontal towards northwest. Most fault planes are filled with 1 to 3 centimetres thick yellow clay (gouge) and some were oxidized into reddish orange colour by rain water seeping through the fault planes. The hanging wall block in normal fault structures are moving into the surface in relation to the foot wall block less than a metre. Reverse faults are distributed in almost the entire quarry area. It occurred early compared to the normal faulting and fractures the competent rock units including hornfels and weathered gabbroic body. Reverse faults are trending northwest-southeast and steeply dipping.

Fig 3. Geology map of Behori quarry.
Fig 4. Stereographic plot of the Behori structures. (a) Structures plotted as great circles, and (b) Point diagram of structures plotted as poles. Northeast/southwest structures are indicated by red colour and northwest/southeast structures by black colour.

There are two outcrops of fault breccia noted and are within hornfelsed calcareous siltstone. Both fault breccia are composed of unconsolidated rock fragments. One is matrix supported and the other is clast supported. Matrix supported fault breccia is consisted of unconsolidated yellowish brown mud, which acts as matrix and cone shaped angular hornfelsed calcareous siltstone clasts of boulder size. The mud materials are entirely friable and fractured. It is 2 metre thick on exposed surface and become thinner (10 cm) at depth. The clast supported fault breccia is made up of fractured angular boulder clasts of hornfelsed calcareous siltstone, which are slightly contorted and it is 4 metres thick.

The near horizontal structures are generally striking northwest to southeast and dipping in near horizontal. They occur on hornfels face where the rock is baked and competent. Few neat horizontal structures cut other high angle dip structures that strike at northwest and southeast but show no movement.

There are many visible joints observed on the face of the quarry benches and on surface outcrop. Some of these joints occur within the rock body and terminates. These joints are visible only on the quarry face. Others occur at a greater distance by cutting through more than one rock type and terminates.

Fluid escaping structures are also noted, particularly, at bench 2 and bench 5 within the hornfelsed calcareous siltstone. The tar black colour is generated by the hydrothermal fluids that seep through and mix with the hornfelsed calcareous siltstone. Some hornfelsed calcareous siltstone are found within the hydrothermal fluids in boulder size.

4. Discussion

The geology of Behori quarry and Nebire quarry including their structures are similar. Only few aspects are different. Nebire quarry is located about 4 km to the northwest of Behori quarry. The outcrop pattern and the style of topography setting for Nebire quarry is similar to the Behori quarry. Both areas have elongated ridge that are made of sedimentary and contact metamorphic rocks (Fig 5). These ridges are surrounded by intrusive complex specifically gabbro at the lower part of the ridge and extend upward creating a low relief undulating topography.
The Nebire quarry comprises of at least three rock units including the intrusive rocks of basalt and gabbro, the hornfels calcareous siltstone, and the red-brown calcareous siltstone. The gabbroic intrusion and hornfelsed calcareous siltstone were suggested to be deposited at the same time (Tevlone, 2015). These rock types are also noted at Behori quarry. There is also an evidence of fluid escaping structures noted during field work.

The bedded siltstone and wackestone rock unit observed at the top of Behori ridge are not noted at Nebire quarry. This suggest that the bedded sedimentary rock units of Nebire quarry had been weathered off, leaving only the bottom competent baked rock unit.

Behori quarry has two distinctive structural orientation including northeast and northwest trending structures and are steeply dipping. Few of the structures are near horizontal with shallow dips. These type of brittle deformation structures are also noted at Nebire quarry (Tevlone, 2015).

However, Nebire quarry is a fault bounded block, bounded by the Bogoro Shear Zone, apart from Behori quarry. The latter is a zone of contact metamorphism where the overlying sedimentary rocks are being baked by the gabbroic intrusion.

Reference

Tevlone, A., 2016. Investigation into the geology of Nebire quarry, a Paleocene phacoid within the Bogoro Shear Zone. The University of Papua New Guinea BSc Honours thesis.

Fig 5. Lithostratigraphy of Behori quarry and Nebire quarry. (a) Behori quarry stratigraphy and (b) Nebire quarry stratigraphy.
THE 2018 EVENT IN PICTURES

The 2018 Convention banner

Photo (left). Emeritus Professor Hugh Davies (ESD) giving his talk. Photo (right). Dr Harrison Gedikile (ESD) making his presentation.

Photo (left). Mr Trotsky Benjamin, (K92 Mining Inc) giving his talk. Photo (right). Mr Jesse Pakalu (Consultant), making his presentation.