Geological Society of South Africa

geobulletin

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VOLUME 60 NO. 4

news

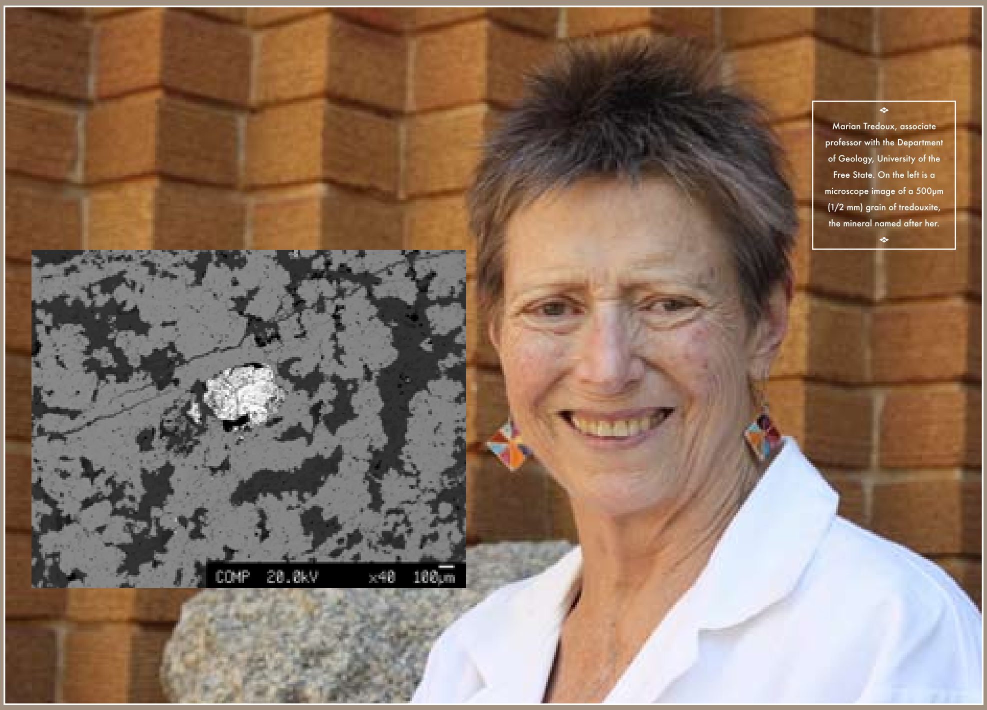
Marine mining

Women in Geology

Geoheritage: Fish River Canyon

COVER PHOTO:

Halite blisters. The dark square cubes represent inverted pyramids or cornets of dissolved halite crystals. The lighter coloured, rough textured surfaces around the dark squires represent "blisters" around the halite crystals. Note the polygonal outline and the fine crystalline "cubic" derived texture of the blisters.



CENTREFOLD

Marian Tredoux, associate professor with the Department of Geology, University of the Free State. On the left is a microscope image of a 500μm (1/2 mm) grain of tredouxite, the mineral named after her.

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Geological Society of South Africa

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from the editor's desk

Chris Hatton

What lies beneath? Geologists make observations at the surface to infer the inner workings of the earth. In the early days of seismology Inge Lehmann inferred that a solid inner core must lie within the liquid iron core. For this achievement she was awarded the Bowie medal and the inner-outer core boundary thus became 'officially' known as the Lehmann discontinuity, at least among the community of seismologists studying the core. But this boundary was not the only fundamental boundary that this prolific seismologist recognised; among seismologists interested in the mantle, the Lehmann discontinuity refers to an entirely different boundary, the lithosphere-asthenosphere boundary which lies near 220 km below the continents. An obvious possible way out of the confusion of having two fundamental boundaries named after the same person is to name one of them after somebody else. The lithosphere-asthenosphere boundary below the oceans is known as the Gutenberg discontinuity, but because this boundary typically lies near 80 km it is not obvious that the oceanic lithosphere-asthenosphere boundary is the same as the continental lithosphere-asthenosphere boundary. For the time being the Lehmann discontinuity will continue to refer to either of two major boundaries in the earth.

Another way an individual is recognised within the broad geological community is by having a mineral named after them. On p. 30 of this issue Freddie Roelofse report on thethe naming of the mineral tredouxite after Marian Tredoux of the University of the Free State.

Marian Tredoux has long campaigned for recognition of woman as equal members of the geological community and is wary of especial treatment being given to women so it is conceivable that she might object to the section on Woman in Geology on pp. 31-35 of this issue. To forestall this objection I am tempted to reiterate the defence advanced by TW Gevers some three decades ago. His somewhat reverential approach was to refer to women as the Better Half, often symbolising Learning

and Wisdom, but also seen as formidable defenders of what they had nurtured. The reality is that South Africa is an incredibly diverse society, and sex is only one of the labels that can be used to divide us. In the past divisions within this diversity have been used to weaken the whole society. Hopefully the future will see our diversity as a source of strength.

And speaking of women in geology, Mother Earth has been on her best behaviour for the last five and a half thousand years, providing the unusually favourable and stable climate which has allowed civilisations to grow and flourish. Although Geobulletin of three decades ago records the same concern about the drought, one cannot help but wonder that the current drought is something more brutal. Perhaps Mother Earth is withdrawing her favour and we are at the beginnings of a megadrought. Perhaps the severe drought in the Western Cape will spread to the Highveld and the 87 litres a day that our Executive Manager is using to frighten the visitors will become the new normal. Who knows? Whatever the case turning your back on Mother Earth is not the answer. As the first woman President of the Geological Society of South Africa says "It is only by understanding earth processes that we can learn to adapt to the inevitable changes in earth conditions."

Chris Hatton

executive managers corner

Craig Smith

SOCIETY NEWS

As we head into the year end, the earth science community in South Africa is facing uncertainty and challenges largely due to political and economic factors outside its control. Geologists, and particularly new graduates, are facing uncertain employment prospects as well as suffering research funding cuts in the academic sector. The industry sector is facing a fall in investment because the rest of the world – which is the source of capital – is seeing too much risk in South Africa. The risk now seems to outweigh the opportunity as far as the investment community is concerned.

In my opinion, South Africa has once again arrived at a high road – low road fork in the road ahead, and there are three key events to watch carefully in the coming few months. First is the ANC Congress in December. The outcome of this event will give some indication as to whether the country continues on the current path, or turns in a different direction. Second is whether the ratings agencies downgrade South African debt to junk status or not, which will impact investment capital flight or inflows) and the exchange rates against other currencies (which affects inflation). We may have the answer to this question by the time of publication, but as of the time of writing the signals are not positive. Third, and more specific to the resource sector, is the outcome of the legal challenge by the Chamber of Mines to the revised Mining Charter. Be assured that the rest of the world is watching carefully, and jobs and research funding in the resources sector are on the line.

South Africa has the right 'geological address', with opportunities in both brownfields and greenfields exploration, and mining. Yes, the country is a mature exploration destination, and the difficulties in obtaining permits and rights are well documented. But there are also current success stories for those who persevere despite the high investment risk. Increased efficiency in permitting and adherence to the 'use it or lose it' principle is needed because that will revitalize junior activity in particular, creating jobs at all levels. I do not agree with those who claim South Africa has no exploration potential. Given that South Africa's rich storehouse of minerals might be unique, maybe it's time to stop differentiating between greenfields and brownfields projects, and rather focus on what might be appropriate for different levels of investment or accessible information.

In the last two months I have been privileged to represent the GSSA at a number of conferences, starting with the 11th International Kimberlite Conference in Botswana in September, attended by over 300 delegates from across the world. As is normally the case for the IKC's, the technical content was excellent (with a couple of 'Aha' contributions); you can access the program and abstracts on the 11 IKC website.

In October, three key events took place in the Cape. First up, was the South African Geophysical Association Conference (SAGA) in Somerset West, which was an excellent conference. Second was the GSSA Groundwater Division Biennial Conference at Spier Wine Estate, in which the drought in the Western Cape featured prominently. A couple of take away messages from the conference are that South Africans should get used to the 'New Normal' in water access, that groundwater is going to be a key component in mitigating water shortages in Cape Town, and that despite 50 years of experience the management of the Ogallala aquifer in the USA (which occurs across nine states) is still shambolic. We can do better than that. Third, thanks to the American Association of Petroleum Geologists (AAPG) I was also able to attend this year's Africa Oil Week (AOW) in late October in Cape Town. This is an annual investment meeting of the oil and gas sector akin to Mining Indaba, and the key message was that oil and gas companies are experiencing regulatory uncertainty and unfavourability in much of Africa (South Africa included) – with a 50 percent drop in the oil price since 2014 adding to their woes. Oil and gas are voting with their feet – particularly in South Africa.

The 2017 meetings agenda was completed in early November with the Fellows Dinner in which the Gamsberg project owned by Vedanta was featured, and with Exploration Technology and Exploration Projects days in Johannesburg. Without exception presentations were excellent; what struck me was the array of new digital tools available to assist geologists – from drones to logging technologies. There is concern that our students are not getting enough exposure to these tools, and possibly there needs to be some modifications to curricula. I'll leave that debate to department heads!

October also saw the formal establishment of the Geoheritage Division of the GSSA under Genevieve Pearson, and the re-launch of the Egoli Branch of the Society under the guidance of several members of Council. Watch for announcements in the monthly newsletter.

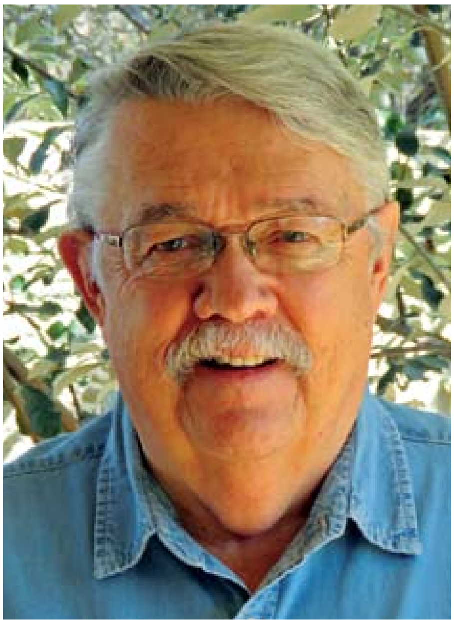
As we head into the year-end holidays, please drive carefully, stay safe and have a relaxing break. For those migrating to the Western Cape for a couple of weeks, spare a thought for us poor locals enduring the drought. Don't use all our water! (You will be allowed 87 litres per day per person…)

Craig Smith

GSSA Geological Society of South Africa

president's column

Ed Swindell



I am sure that many of you have been watching the evolution of the geoscience workspace in recent years as closely as I have, and will have become increasingly concerned about the future of the exploration and mining industry in South Africa. In the last few months there has been an ever increasing number of negative events and tendencies, including, for example the publication of the latest version of the Mining Charter, the reaction to it by industry, the many court cases with the DMR that industry have found necessary to become embroiled in, the many announcements by companies cutting back and even abandoning exploration activities and the closure of shafts and retrenchment of miners. At the GSSA we have become increasingly aware of the fact that an ever increasing number of new Geoscience graduates, our student members, are finding it impossible to find employment. Some of them have even taken to resorting to previously unheard of tactics, like standing on street corners with placards trying to bring light upon their plight. Clearly there is a major disconnect between the numbers of graduates being churned out by the Geoscience departments and the demand in the market place for those graduates. A simplistic review by myself notes that in the mid-1970's when I graduated, the country was producing just under 1000 tonnes of gold per year, while in 2016, a mere 141 tonnes of gold were produced. The geology departments of the time typically had Honours classes of between 5 and 10 and that produced sufficient graduates to staff an industry capable of producing so much gold. Of course there was also the coal, platinum, chrome, iron and other commodities, many of which continued to grow and need geoscientists. And of course there was the possible top-up made with off-shore recruiting if and when necessary. But it still does provide some perspective to the problem that, the current typical honours classes of up to anything between 20 and 30 students at some of the universities neglects the fact the supply has massively outstripped demand for graduates. Furthermore, this is said against the background of the fact that the heyday of greenfields exploration in South Africa was from the 1960's through the 1970's and to the end of the 1980's when a great many of the graduates of the time also found employment. Since that period not only has exploration declined but it has become almost entirely brownfields in nature, in that known resources are being largely drilled out for extensions and resource development purposes. Some excellent finds such as the Northern Bushveld Waterberg limb Pt deposits were uncovered but by and large no new greenfields discoveries have been made in decades.

There is an urgent need for a conversation within our fraternity as to how to cope with this situation. At the very least better guidance for undergraduates, as to realistic career prospects, needs to be provided. But there is also a clear need for better data as to the employment prospects for the graduating geoscientist. We at the GSSA hope to explore this question in more depth and some plans are under review. We have made our African Exploration Showcase an annual event in order to give the exploration projects that are in play some air. We will also continue to offer the basic skills courses so as to ensure that that new graduates are better able to improve their marketability and we will continue to try and keep the cost of our events as low as possible so as to encourage attendance. We also continue an active advocacy role and provide comment to every Government paper every time such opportunity arises.

In trying to become more responsive to the environment we have undertaken and implemented some changes at MANCO in that we have now merged responsibility for the SAJG with the "Academic Affairs" portfolio. In doing so we hope that this will provide a more customer – centric structure and that the relationship between our academic community and the SAJG editors will be further enhanced. In addition, we have moved responsibility for the Branches to the previous "Communication Portfolio" and have renamed the portfolio the "Networking" Portfolio. This portfolio will hopefully bring all the networking activities together including the social media platforms, the Geobulletin and the branches. All these portfolios are manned by volunteers who give much of themselves and we hope that each portfolio will over time form into more cohesive supportive structures with shared goals. We are also very pleased to announce the reinvigoration of the Egoli Branch. At the last meeting of the Council we challenged the Johannesburg based Council members to stand up and reform the branch. There was overwhelming response and all the youngest members of Council agreed to take on all the Branch positions. Over to them now but watch this space. I look forward to regular meetings of the Egoli Branch in the New Year at the GSSA office at the Carlow Road CSIR Mining Precinct. We can also announce the formation of a new division, namely the Geoheritage Division. This division is now formally constituted and the various positions filled with volunteers. We wish Genevieve and her Committee a lot of luck as they progress the division over the next few years.

About 3 years ago I was asked by the European Federation of Geologists to join a Panel of Experts sitting to enhance an EU/ EFG project called INTRAW. (The International Raw Material Observatory (https://youtu.be/NGXVqTBnfEA). I attended the final meeting of that Panel recently and can report that the EU now has their Observatory and that it is a Not For

Profit International Association created to support worldwide cooperation on raw mineral materials' Research & Innovation, Education & Outreach, Industry & Trade and Recycling, Management & Substitution of Strategic Raw Materials. South African interests in this project were ably represented by the CSIR Mining Innovation team at the Mining Precinct where the GSSA now resides. The purpose of this observatory is to provide useful information to agents directly and indirectly engaged in the value chain of raw materials. This initiative will hopefully enhance our industry and the opportunities that arise from it. One particular point I learnt was that the European view of the mineral industry is not confined to that of the primary mineral sector but is multi-faceted, value chain focussed and in particular includes a great deal of attention on recycling and substitution. From the European point of view it is focussed on security of supply and sustainability. It was apparent to me that the concept of the Urban Mine is real in the EU concept and we need to take it into account.

Of some considerable note I learnt that the EU have a methodology for the identification of Critical Raw Materials. This determines consequent trade and industrial practice treatment. The list of 27 Critical Raw Materials (http://ec.europa.eu/growth/sectors/raw-materials/specific-interest/critical_en) includes; Antimony, Fluorspar, LREEs, Phosphorus, Baryte, Gallium, Magnesium, Scandium, Beryllium, Germanium, Natural graphite, Silicon metal, Bismuth, Hafnium, Natural rubber, Tantalum, Borate, Helium, Niobium, Tungsten, Cobalt, HREEs, PGMs, Vanadium, Coking coal, Indium, Phosphate rock. This list includes nine materials that have just been added to the list which is regularly revised and updated. Explorers need to take this list into account and while it is immediately evident that South Africa is well positioned to supply some of these materials it is clear that many exploration concepts remain to be developed as well. Some food for thought for our strategic thinkers.

Ed Swindell

all the news fit to print

University of Johannesburg

Department of Geology (Including CIMERA and PPM)

In recent months the department has been active on several fronts, including research, student excursions, scientific meetings and other related matters. This report is compiled from individual contributions as noted.

Coal and CCS

The IEA Greenhouse Gas R&D Program (IEAGHG) is an international collaborative research program established in 1991 as an Implementing Agreement under the International Energy Agency (IEA). Recently, the IEAGHG committee selected 40 students from around the world with diverse academic backgrounds to attend the 10th annual IEAGHG International CCS Summer School. Rowan Abraham, an MSc student of Nikki Wagner, was the only student selected from Africa. The summer school was hosted at the University of Regina, Canada, and all costs regarding accommodation and meals were covered by the IEA. Travel costs were covered by research funds provided by Prof Wagner.

The aim of the summer school was to encourage active participation on issues surrounding CCS. The school was a weeklong exercise comprising numerous lectures regarding both the capture and

Delegates at the IEAGHG-CCS Summer School in Canada. UJ MSc student Rowan Abraham is second from the right, back row.

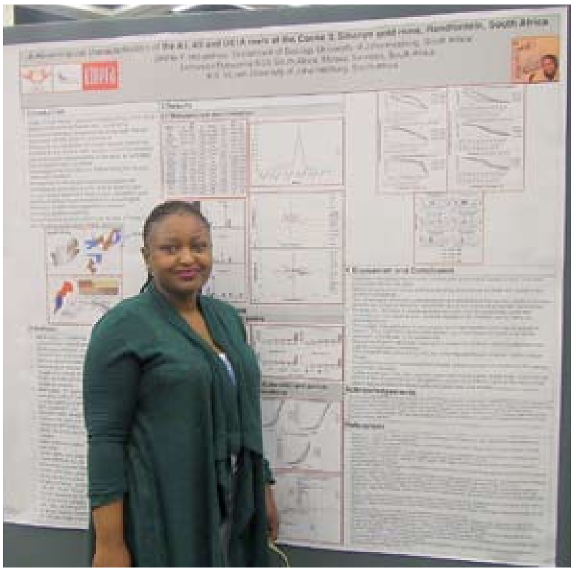
storage aspects of CCS as well as social impacts and stakeholder engagement. In addition to the lectures and discussions, students were broken into groups and undertook short research activities of issues of importance to CCS. At the end of the intensive week, a presentation of these issues was held where facts and opinions were shared with peers. Informal discussions tackling critical issues regarding CCS were held during the time set aside for networking with professionals, mentors and peers for. A specific focus was on the progression of CCS in the corresponding student's country of origin to get a better idea of the status of CCS globally.

The most interesting part of the course was the visit to a fully operating commercial CCS plant, Boundary Dam. A guided tour of the plant was enlightening with regards to the operational procedure and technical difficulties the plant faces. By the end of the week, a good network of contacts was made, as well as a broad overview of the issues surrounding technology development and implementation in CCS.
Nikki Wagner

Geometallurgy

Staying in Canada, the 14th Biennial meeting of the Society for Geology Applied to Mineral Deposits, was held in Québec City, Canada, on 20-23 August 2017, and was attended by UJ PhD Geology student Sindile Mkhatshwa, supervised by Fanus Viljoen, and co-supervised by Bradley Guy and Bertus Smith. Sindile presented a poster entitled 'A mineralogical characterisation of the A1, A5 and UE1A reefs at the Cooke 3, Sibanye gold mine, Randfontein, South Africa'. This particular conference was held in North America for the first time and more specifically in the oldest city on the continent, where French explorers established their first settlement in 1608. The conference was jointly organized by the Université Laval, Natural Resources Canada (Geological Survey of Canada), the Ministère de l'Énergie et des Resources naturelles du Québec, and the Institut national de la Recherche scientifique, Centre Eau Terre Environment.

Fanus Viljoen



Sindile Mkhatshwa seen at her poster presentation at the SGA meeting in Canada.

Namibia Research Excursion July 2017

From July 1st to 16th 2017, some of the staff of the Department of Geology, University of Johannesburg, undertook an excursion to Namibia (via Botswana) during the mid-year research break of the university. The geological aspects of the trip were arranged by

Jeremie Lehmann, Bruce Cairncross, George Henry and Trishya Owen-Smith, with Hennie Jonker in charge of the logistics. Apart from the academic staff, the group was complemented by some of the department's support staff, so they could gain first-hand experience of what geology entails. Circa 6,500 km distance was covered, taking in a wide variety of geological stops, ranging in age from 2.05 Ga granites to modern dune systems.

A unique aspect of this trip was the diversity of expertise brought together at one outcrop. It was great to hear the various different perspectives on issues and to be introduced to some of the debates and developments in other fields. We rarely have such opportunities for interaction across disciplines in our day-to-day work, yet it is so often at this transition between worlds that scientific breakthroughs are made. So the trip enabled all staff members to widen their geological outlook, but certain outcrops were of particular interest to specific participants.

The visit to the Aris Phonolite quarry south of Windhoek was of special interest to Bruce Cairncross and Marlina Elburg; for the former, the main interest was the occurrence of rare minerals, while Marlina was focused on these minerals as a reflection of the geochemistry of so-called 'agpaitic' rocks. She is currently working on similar rocks in South Africa, of the Pilanesberg Alkaline Province, and the (much younger) Aris Phonolite gives an insight in a different evolutionary path for such highly alkaline rocks.

Apart from Aris, Bruce was able to extend his mineral research to include some of the other interesting mineralogical localities visited during the excursion. Samples, information and photographs were obtained from the Okorusu fluorite mine, the defunct Berg Aukas V-Pb mine and Tsumeb mine, the type-locality of tsumebite and tsumcorite. In addition Khorixas, Karibib and Arandis were visited to supplement data collection for articles on khorixasite, karibibite and arandisite, and the Namib Desert in general, the type-locality name used for namibite. In addition, the experiences and photographs from the trip were used for Community Engagement, in the shape of a public lecture to the Witwatersrand Gem & Mineral Club (delivered on 30th August 2017) detailing the Namibia excursion and presenting on the geology, mines and minerals of Namibia.

Gemstones were also of interest to Tebogo Makhubela who focused on phenakite and beryl crystals from the Erongo region which can be studied for the purpose of making 9Be and 27Al carriers. This will be part of a plan to set-up a laboratory for cosmogenic nuclide studies in collaboration with the NRF iThemba LABS here in Johannesburg.

Henriette Ueckermann will be starting a PhD study on isotopic ratios in semi-precious minerals from Southern Africa by laser ablation MC-ICPMS, and the trip gave her the opportunity to obtain several specimens of tourmaline. Tourmaline contains the element boron at sufficient concentrations for isotopic characterization by laser ablation. Black tourmaline (schorl), green and blue tourmaline were obtained mainly from the mineral market on the road to Henties Bay, and from a mineral stall at the entrance to the White Lady visitor site at the Brandberg. Although these tourmalines probably all originate from the Erongo area, this is not certain. Therefore they will only be used for the development

Gross Spitzkoppe in Namibia, viewed from Klein Spitzkoppe, one of the several localities visited during the July Namibia field trip.

phase of the investigation, to set up a procedure for sample preparation and measurement, and potentially as in-house reference materials.

For Jeremie Lehmann, who worked on Namibia geology during his post-doc, the field excursion provided an opportunity to discuss the various tectonic interpretations related to the formation of the Namibian continental crust. The questions debated during the field trip were:

- What are the potential heat sources that promoted long-lived thermal anomaly in the upper plate of the Damara orogen?
- Is the copper mineralisation at Tsumeb similar to the one of the Zambian Copperbelt?
- What are the lateral continuities of well-known Namibian sedimentary units in Botswana, where the exposure is very scarce?

This also interested Marlina Elburg, so we pushed (also literally, as one of the vehicles got stuck) to get to the beautifully cross-bedded sandstone outcrops of the Okwa Group in Botswana in order to take samples. (This was en route to Namibia). This poorly known sandstone unit may be a correlative of the Nama Group further to the west in Namibia and South Africa. Since the origin of the Nama Group has been part of a study Marlina is conducting with Prof Tom Andersen (University of Oslo) and fellow Namibia traveler Herman Van Niekerk, these samples made a welcome addition to the data set.

What are the origin(s) of the banded iron formation capping and interleaved with the glacial Chuos diamictite, interpreted to mark a Snowball Earth glaciation event, and what is the effect of granulite metamorphism and partial melting on mobility of iron in this banded iron formation? These are some of the questions that grabbed the attention of Bertus Smith, who sampled an iron formation-like unit from the Chuos Formation east of Swakopmund in an area where the iron formations have not been documented previously. These samples will be used for an Honours project to test whether this unit is in fact an iron formation, and where it fits in structurally and stratigraphically in the region. For Clarisa Vorster, the diamictite units of the Nama Group were of interest too, as she is planning to conduct some detrital zircon studies on the clasts found in these units. She was also keen to see the units of the Damara and Gariep Belt, which have been put forward as source areas to the Cape Supergroup, the topic of her PhD thesis, which she is still following up with more research. Are the numerous veins observed in the Numees diamictite of the Gariep Belt contemporaneous to the thrusting event of the Port Nolloth Zone over the Kalahari basement? The veins display beautiful fibrous textures, which can be used as strain markers.

Visits of new key field exposures allowed gathering of samples that will help in answering the above questions in collaboration and teamwork with colleagues at the department. The output will bring new knowledge on the structural and tectonic evolution of the Pan-African Orogen in Namibia and Botswana as well as new understanding on the origin of its mineral (copper, iron) endowment.

For Herman Van Niekerk, Namibian geology was previously something that was "just on maps" prior to the field trip. He now has a much clearer appreciation for the regional geological picture which will aid a lot in further efforts to understand the assembly of the geological terranes that occupy the space on the western side of the Kaapvaal-Limpopo-Rehoboth cratonic terranes. Herman and co-workers recently finished a new study on the Koras Group in South Africa and the trip enabled him to understand the results obtained in a better regional picture; this helped to identify new possible areas in Namibia where this research could be extended.

Marvin Moroeng noted that Namibian coal deposits are found mostly in the Aranos Coalfield as well as in the Ovamboland, Waterberg and Toscanini areas. However, there are currently no coal mines operating in the country and very little is known about the deposits; unfortunately, the aforementioned could not be visited during the excursion in part because of inaccessibility. As South African coal deposits continue to be exploited and may be exhausted, perhaps not in the immediate future, Namibian deposits may become increasingly relevant. It would be desirable in the future to examine the petrographic composition and geochemistry of the coal deposits to aid not only potential applications, but also to understand the origin and, the coalification pathways of the different organic components of the deposits.

For Mike Knoper, the excursion was a good opportunity to ascertain the quantity and quality of exposure of Mesozoic-age igneous rocks. Such rocks are of interest to him in the context of Gondwana breakup, particularly with respect to Mesozoic reconstructions of Africa, South America, Antarctica, and the development of the Indian and South Atlantic ocean basins. The Mesozoic igneous rocks were also the excursion highlight for Trishya Owen-Smith, who has now worked for several years on the Cretaceous-age magmatic products in Namibia; however, a large portion of this has been a desktop study. It was highly beneficial to be able to visit some of the components of the Damaraland Suite that were so familiar from the literature (Messum, Brandberg, Spitzkoppe, Cape Cross) and the sample material collected at these sites will be used to extend her research here. A future plan is to develop a more complete isotopic database for the intrusive suite, comparable to that which currently exists for the extrusive components, to provide insight into pre- and syn-breakup mantle processes.

Some staff used the opportunity to undertake field work in Namibia in the aftermath of the trip. Axel Hofmann and postdoctoral researcher Pierre Dietrich, who joined the excursion half-way of his own accord, investigated glacial sedimentary rocks of the Karoo Supergroup near Great Brukkaros volcano. Beautiful exposures along the Fish River and the presence of a hot spring near the camp site made the field work a very memorable experience. So from the aforementioned, it can be seen that the multidisciplinary nature of the Namibia excursion benefited all participants and provided information, data and samples for several ongoing and new, future projects.

Marlina Elburg

Medical Geology

Hassina Mouri was invited to give a plenary lecture at the 7th International Medical Geology Conference held in Moscow during late-August / early-September 2017. In addition, sponsorship has been raised from the NRF for 12 MSc students to work on projects in Medical Geology under a large collaboration program involving National and International institutions. The students who registered under this program are from South Africa and other African countries including Nigeria, Kenya, Namibia and Ghana. Finally, Hassina is leading the organisation of a Medical Geology Session to be held at EGU-Vienna – 2018, the first time in the history of EGU to host a session in this field. The theme is: "Medical Geology: an interdisciplinary field of science for the benefit of the society" with convener: Hassina Mouri and co-conveners: Prosun Bhattacharya, Brenda Buck, Olle Selinus, Iosif Volfson, Sesan Odukoya.

Hassina Mouri

Hassina Mouri at the International Medical Geology Conference held in Moscow.

Sebastian Tappe of UJ Geology (centre) discussing kimberlite rock textures with international experts from 5 continents at Orapa Mine, Botswana. This mine visit was part of the 11th International Kimberlite Conference held in Gaborone during September 2017.

Two UJ staff members, Bertus Smith and Sebastian Tappe, were "upgraded" to Fellows of the GSSA. Sebastian also attended the 11th International Kimberlite Conference in Botswana in September where he delivered a talk addressing the distribution of global kimberlites through time. He also attended Goldschmidt Conference in Paris in August. A Keynote Talk was delivered there detailing the usage of rare nitrogen isotope evidence from the oldest confirmed diamonds for the operation of plate tectonics prior to 3 Ga.

Sebastian Tappe

Moodies drilling workshop 5-10 Oct 2017, Barberton

A new scientific drilling initiative to explore the 3.2 billion years-old Moodies Group of the Barberton Greenstone Belt is being planned and an application for funds is close to being submitted to the ICDP (International Continental Scientific Drilling Project). The main target is identifying and studying evidence of early life forms in continental to shallow marine environments. A planning workshop to discuss the project and select the best drilling sites was held between the 5th and 10th October in Barberton under

The "Moodies Group" seen here at Barberton, the site of the ICDP drilling program.

the guidance of Christoph Heubeck, who is leading the effort. The workshop was attended by approximately 55 researchers from different parts of the world, including South Africa (UJ and UP were the only two invited universities from Africa), United States, Japan and Europe. From UJ CIMERA, Nic Beukes, Michiel de Kock, Clarisa Vorster, Bertus Smith, Herve Wabo and Andrea Agangi attended. The five days of workshop were divided between field observations, scientific presentations and proposal writing. At the end of the workshop, a cohesive and enthusiastic team of researchers with a wide array of scientific interests had been built, which will surely result in a strong scientific plan.

Andrea Agangi

Honours Students

On Wednesday 11th October, the UJ Honours class visited Anglo Coal's Isibonelo colliery in the Kriel district. Nikki Wagner organized the trip to coincide with the Honours coal course that she and Bruce Cairncross present to the class as part of their Economic Geology module. The mine personnel were very accommodating to the group and spared no effort with regards the days visit. The geology of the No. 4 seam sequence is excellently exposed in the open cast mine operation and the students got to view an operating coal mine first hand, a valuable addition to the theory component of their course.

Nikki Wagner and Bruce Cairncross

Northern Cape Field School 2017: A transect through ~3 billion years of South African geological history

The sixteen students from the UJ Honours class went on their 'Advanced Geological Mapping' trip, also known as the Northern Cape Field School, from 22-9 until 7-10-2017, under the leadership of Dr. Herman van Niekerk, assisted by Prof. Marlina Elburg, and Drs. Jeremie Lehmann and Trishya Owen-Smith. During the trip, the students do a traverse of South Africa from Johannesburg to the west coast, looking at geological events that range in age from 2.9 Ga (deposition of the Witwatersrand Supergroup) down to the development of the African land surface and active migrating dunes. An important focus of the trip is the large-scale structure of the western part of South Africa, which is an area the students hear little about during their undergraduate studies, but which gives fascinating insights into the processes of Proterozoic crustal accretion. An economic focus is provided by the iron- and manganese deposits of Sishen and Hotazel, as well as the diamond mining around Kimberley and Kleinsee (including the post-mining rehabilitation), and the by now abandoned copper mines around Springbok. Although the zinc deposits of Gamsberg can only be appreciated from a distance, the students do a three-day individual structural mapping exercise at the nearby 'Big Syncline' area, which is another base metal target for Vedanta Resources. This is a true 'authentic learning' exercise, as understanding the structure of the area has direct implications for the exploitation of any ore deposit. Although structural geology, and its relation with sedimentation, magmatism and metamorphism, is the main focus of the trip, a myriad of other topics is also addressed, among which feature the Great Oxidation Event, the development of life (in the Palaeoproterozoic and Ediacaran), the Dwyka glaciation, the formation of less usual igneous rocks such as charnockite, orbicular diorite and kimberlite, and the interpretation of detrital zircon studies. In total, the excursion covered more than 4000 km in sixteen days, during which the students did seven marked exercises – and all of them passed.

Marlina Elburg

DST-NRF CIMERA Annual Colloquium 24th October 2017

This year the DST-NRF CIMERA Annual Colloquium was hosted by UJ and held in the Chinua Achebe Auditorium in the UJ Library. The event was held at the School of Geosciences at the University of the Witwatersrand last year. The day's programme was filled with 24 talks, all but two presented by post graduate students supported by our Centre of

Excellence. The talks were mostly of a high quality, and thanks must be extended to the students and their supervisors for their time and trouble in making the event a success. The eight research focus areas of DST-NRF CIMERA were covered, with most of the talks being on early Earth processes, the Witwatersrand Basin, the Bushveld Complex and other layered intrusions, diamonds and kimberlites, base, ferrous and rare earth metals, and energy resources. The invitation was open to the South African geoscience community, and 96 delegates registered. The after-colloquium drinks and snacks took place in the UJ Department of Geology, and enjoyed by all. We received positive feedback from both industry and academic attendees with regards the colloquium, and hope to maintain the standard in the future. A word of thanks must be extended to the UJ support staff, especially Ms Viwe Koti, for ensuring that the event ran smoothly.

A getting-to-know-you event was organized for all DST-NTR CIMERA collaborators and students and staff and students of the UJ Paleoproterozoic Mineralization (PPM) research group. A manageable group of 18 people, who fitted neatly into two Quantums, left UJ for the Walter Sisulu Botanical Garden at 9:30 am. On arrival, Prof Nic Beukes gave a potted talk on South African geology during a walk through the Rock Garden, set up a decade or so ago by the Geological Society of South Africa. It was most interesting and informative although some of the explanatory plaques have badly faded over the years. We proceeded to the Maropeng Museum after a short lunch where the highlight was undoubtedly the Homo naledi display. It was truly awesome to see the much-publicized fossil hominid bones in the flesh, so to speak! The good weather ensured that the excursion was enjoyed by all, and a good team spirit was fostered.

George Henry

Compiled by Bruce Cairncross

Tebogo Vincent Makhubela and Mike Knoper attended the 2017 Annual Fall Meeting of the Geological Society of America, held at the Washington State Convention Centre in Seattle from the 22nd to the 25th October. At the meeting, Tebogo gave a talk titled *Cosmogenic 10-Be and 26-Al studies of the Rising Star site, Cradle of Humankind, South Africa: Mystery of the denudation rates*, based on his PhD work. Tebogo and Mike also visited The Grand Canyon National Park, and looked at the geology along the South Rim and down the famous Hermit's trail.

Mike Knoper and Tebogo Vincent Makhubela at the GSA meeting in Seattle.

Wits

An exciting 2017 at Wits Geosciences has seen the opening of the new isotope dilution laboratory (WIGL). The WIGL is an ultra-clean lab facility that will allow preparation for a range of analytical techniques for traditional radiogenic isotope analysis (e.g. Sr, Nd, Hf, Pb, U-Th), together with non-traditional stable isotope techniques (Fe, Mg etc). Potential sample material is not limited to geological samples, but includes fossils, archaeological artefacts, water samples and biological samples. Dr Linda Iacherri arrived in October and will oversee quality control in the WIGL, alongside Dr Grant Bybee. The WIGL will operate in collaboration with the UJ MC-ICPMS facility. In addition to the WIGL, at the end of 2017, a new laser ablation system was installed in the EARTH LAB, overseen by Associate Professor Robert Bolhar. Combined, these new lab capabilities at Wits Geosciences will ensure the production of high-quality research for years to come.

Professor Lew Ashwal became a celebrity early in 2017 following publication of his article documenting the discovery of Archaean zircons in Mauritian Miocene lavas in Nature Geoscience. The media were quick to pounce on the release and Lew conducted many TV and radio interviews both in South Africa and globally. Lew was not the only one making TV appearances, as Professor Sue Webb and MSc students Lebogang Sehoole and Tamara Makhateng appeared on YoTV. Lebogang and Dr Steph Enslin also appeared on SABC2 to discuss the importance of near surface geophysics.

Lew Ashwal following publication of his work in Nature Geoscience

Celebrations were due for both Rais Latypov and Musa Manzi. Rais celebrated his promotion to Professor with his inaugural lecture entitled "Restless Life of Magma Chambers is Key to Generating Giant Ore Deposits". Musa received the inaugural AGU Africa Award for research excellence in Earth Science at December's AGU conference in San Francisco. The award honours an early-career scientist from the African continent for "completing significant work that shows that focus and promise of making outstanding contributions to research in Earth and space sciences".

A healthy contingent of Wits geophysicists, led by Professor Sue Webb, attended the 2017 SAGA meeting in Cape Town where MSc student Michael Westgate was awarded best student talk and Nkimo Moleleki was awarded best student poster. Some of the geophysicists also attended the 24th Africa Oil Week, also held in Cape Town. Also, Dr Muza Manzi led

The Wits geophysics team visiting Cango caves en route to SAGA 2017.

SABC2 on campus outside the Wits Geosciences building

Musa Manzi celebrating his award with Wits Geoscience colleagues at AGU 2016.

students Siyanda Mngadi and Zama Nkosi to Japan for IAG-IASPEI.

Wits Geosciences MSc students launched a mentorship program titled "Bridge the Gap". The program is designed so that postgraduates in the school can create a support network for undergraduate students to help them transition into the tertiary landscape and help motivate them to develop a passion for geology. The program began with great success as 54 postgraduates registered as mentors and 111 undergraduates registered as mentees. After this success, Bridge the Gap will continue in 2018.

The Wits geophysics group, led by Musa Manzi, at the 24th Africa Oil Week.

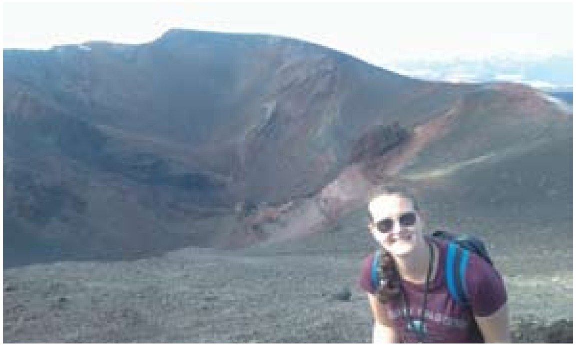
Professor Ray Durrheim visited Cairo in October to attend a meeting convened by the Africa Union Scientific, Technical & Research Commission, UNESCO, and the Egyptian National Research Institute for Astronomy and Geophysics (NRIAG). The focus was on earthquakes and climate change. The meeting was held to commemorate the 25th anniversary of the 1992 Cairo earthquake, which claimed hundreds of victims in Old Cairo. As part of the meeting, the group was guided through Old Cairo by a historian and a geotechnical engineer. It was a true meeting of the sciences and the humanities.

The launch of the Bridge the Gap program, with Professor Gill Drennan and postgraduates Vuvu Mahlalela, Itumeleng Tshwane, Mandy-Jane Sebola and Bavisha Koovarjee.

Sara Burness presented part of her PhD research at the 2017 Goldschmidt conference in Paris. Sara's poster, titled "S-bearing Metasomatism of Mantle Eclogite: Constraints from the Kaapvaal Craton" provided insights into the nature of COHS-fluids and their influence on eclogite in the lithospheric mantle. Sara also attended a post-conference workshop that took place on the flanks of Mt Etna in Italy.

Ray Durrheim in Cairo.

AfricaArray group outside the Great Hall.



PhD student Sara Burness on Mt Etna.

In June-July, Wits Geosciences hosted the annual AfricaArray and REU program with attendees from across the African continent and the USA. The REU program also included field trips to Vredefort, Bushveld and Pilanesberg led by Profs Sue Webb, Lewis Ashwal and Dr Ben Hayes.

MSc students Pulane Seholo and Kofi Acheampong were selected for the Anglo American BLAST program. Anglo's BLAST graduate program targets high achieving postgraduate students. Both Pulane and Kofi will work in three positions on two continents over a four-year period. Previous awardees include Obone Sepato and Sello Mashabela who both completed an MSc with Wits Geosciences. Sello graduated from the programme last year and has now been posted to Peru to work on one of their projects.

Congratulations also go to Profs Tamiru Abiye and Gill Drennan whom graduated from the "Fast Track to Leadership Development" short course organised by the Wits Business School. Gill was awarded second

Ben Hayes (centre) with the REU students at Dwars Rivier in the Eastern Bushveld.

place overall while her syndicate research group was awarded first place for producing the best research project.

Elsewhere, the joint SAS-SEG collaboration between Wits and UJ organized a field trip to Bakerville diamond & lead mine. SAS-SEG also organized the annual Geoquiz with quizmasters Judith Kinnaird and Paul Nex. The Geoquiz was its usual success!

Compiled by Ben Hayes

Gill Drennan celebrating her award.

UCT

Meteorite hits furniture store in Paarl

A chance phone call to the Department on Monday morning turned out to be the beginning of a story that made the evening news. Mr Faghri Allie, a furniture store owner from Paarl, was closing up his shop when he heard a loud crash and, expecting that he was being burgled, decided to investigate. After he did not find an intruder and was happy that his store was still intact, he noticed a puff of dust coming from a small hole in the ceiling. He climbed up into the roof cavity and noticed a similar small hole in his newly-installed roof. Back in the office, he looked for what might have made the hole and found a number of tiny black rock fragments. This is when he contacted UCT's Geology Department, still very sceptical that what he had witnessed was actually a meteorite fall.

Mr Faghri Allie shows off the meteorite fragments found in his shop.
Photo by Tandy-Lee Marinus, courtesy of Paarl Post.

Phil Janney and Johann Diener examined photographs of the fragments, and concluded that they were consistent with being from a meteorite. The next day Mr Allie brought the fragments to the Department, with a crew of journalists in tow. An examination of the fragments under the microscope revealed that they were indeed small pieces of a chondrite meteorite, and confirmed that Mr Allie's experience was a one-in-four billion chance event!

TV news coverage of the story can be viewed at:
www.youtube.com/watch?v=5SDaWE8BM3w

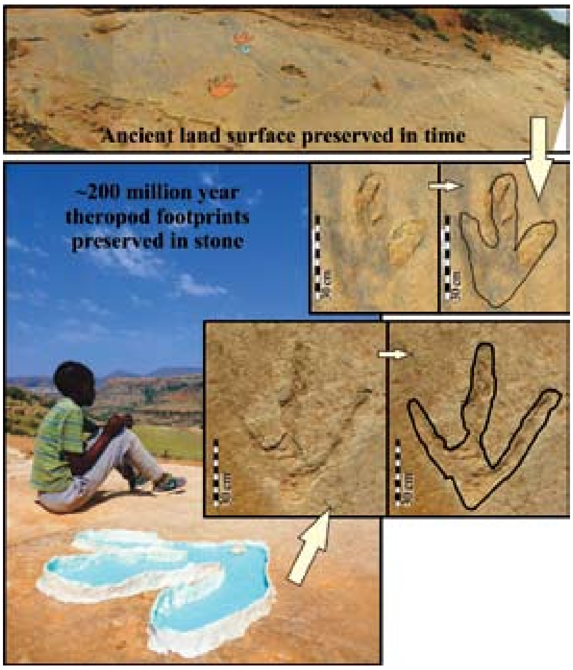
Close-up of the fragments under the microscope.

UCT researchers discover mega-carnivore tracks in Lesotho

A team of scientists from the University of Cape Town, University of Manchester, Fundación Conjunto Paleontológico de Teruel-Dinópolis and Universidade de São Paulo, have discovered the first evidence to show that extremely large carnivorous dinosaurs roamed southern Africa 200 million year ago. This evidence comes from impressions left by its three-toed, 57 cm long and 50 cm wide feet. This extremely large animal roamed a landscape otherwise dominated by a variety of herbivorous and omnivorous dinosaurs and much smaller carnivorous dinosaurs.

The study, which involved UCT researchers Dr Emese Bordy, Dr Lara Sciscio and PhD student Miengah Abrahams, found that the tracks were made a very large carnivorous dinosaur, estimated to have been between 8 and 9 meters long. The discovery was made just 2 km from the National University of Lesotho at Roma in western Lesotho. The footprints occur on a palaeosurface within the Elliot Formation that is covered in ripple marks and desiccation cracks, indicative of an environment such as a river bank where water flowed and pools of water dried up. Along with the prints of the new mega-carnivore, many tracks of other, much smaller theropod dinosaurs were also found.

UCT PhD student, Miengah Abrahams, lying next to the megatheropod tracks found in western Lesotho. Miengah is 1.6m tall.



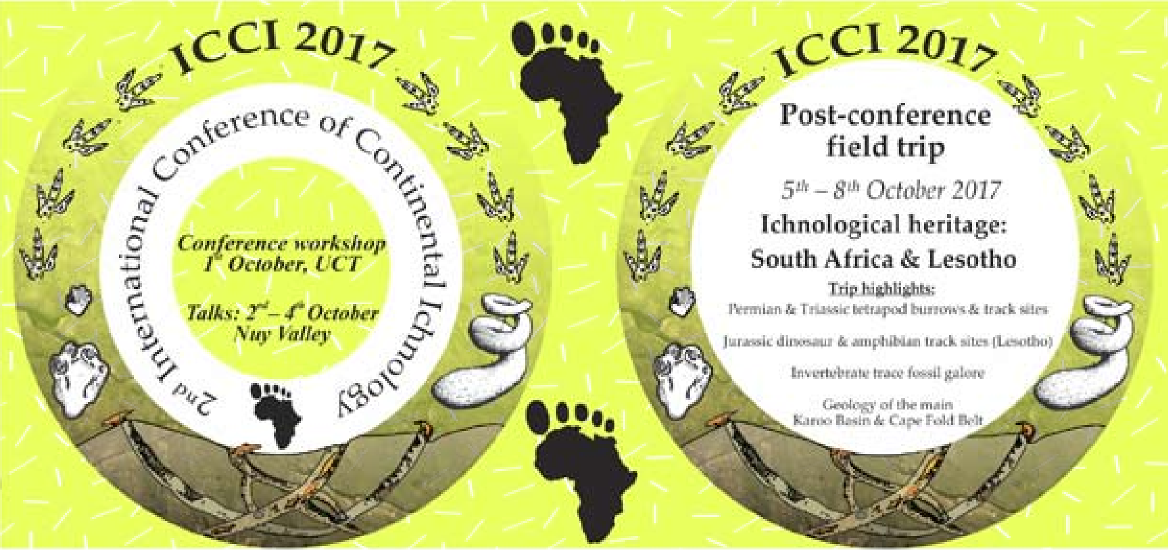
Photograph showing an overview of the Lesotho palaeosurface which contains the footprints of theropod dinosaurs and the 57 cm long megatheropod footprints. Inserts are of typical theropod footprints on the ancient surface in comparison to the megatheropod tracks. The Basotho boy is sitting next to a megatheropod footprint which was being cast in blue silicon rubber.

The giant megatheropod has been assigned a new species name, ambrokholohali. This name is derived in honour of Professor David Ambrose for his detailed recording of the trace fossil heritage within Roma. In fact, the footprints were discovered when the research team were looking for another surface that was previously described by Prof. Ambrose. The latter part of the name - kholohali - is derived from the South Sesotho 'kholo', meaning 'big/large/great'; and 'hali', meaning "much/very" after their unexpectedly large size. To date, these footprints are the only evidence of this new dinosaur, but the team hopes that body fossil material that matches the footprints could be preserved somewhere in western Lesotho.

Full details of the discovery is published in the journal PloSONE: Sciscio L, Bordy EM, Abrahams M, Knoll F, McPhee BW (2017) The first megatheropod tracks from the Lower Jurassic upper Elliot Formation, Karoo Basin, Lesotho. PLoS ONE12(10): e0185941.

https://doi.org/10.1371/journal.pone.0185941

Johann Diener



UCT Sedimentology–Palaeontology Group hosts successful ICCI conference

The 2nd International Conference of Continental Ichnology (ICCI 2017) was held in Nuy Valley (Western Cape Winelands) and followed by a field trip across South Africa to Lesotho from 1st to 8th of October 2017. The conference was organised by Dr Emese Bordy and post-graduate students of the Sedimentology–Palaeontology Group at UCT, and was attended by 50 international delegates from Canada, USA, Uruguay, Argentina, France, Germany, Sweden, Switzerland, Russia, Spain, UK, Italy, Poland, South Africa and Lesotho. One third of the delegates were postgraduate students, and about of quarter of them were international students.

The conference was dedicated to the study of continental trace fossils, and delegates presented research that focused on investigating various ichnofossils such as burrows, nests, tracks and trails. These are important not only for detailed characterization of past depositional environments, recognition of unconformities, prospecting for hydrocarbon resources, and biostratigraphic subdivisions, but also for the direct link they provide to ancient animal behaviour. All of which are geared towards the better interpretation of the geological record.

In the recent decades, this mostly field-based geoscience research theme, which bridges palaeontology and sedimentology, has been neglected in southern Africa, in spite the rich trace fossils heritage of the region.

Delegates at the ICCI 2017 during the conference dinner in Nuy Valley.

Gansfontein palaeosurface at Fraserburg, South Africa.

This conference therefore was a wonderful opportunity to promote and further develop ichnological research in southern Africa, most of all for the benefit of our postgraduate students and early (and not so early) career geoscientists.

The ICCI kicked off on 1st October with a full day photogrammetry workshop that was led by Dr Matteo Belvedere (Office de la culture, Paléontologie A16 Porrentruy, Switzerland) in the Department of Geological Sciences at UCT. The conference was officially opened by Prof Bruce Rubidge (Director at South African Centre of Excellence in Palaeosciences) in Nuy Valley and was followed by a string of scientific events during the week. These included keynote talks by Profs Daniel Hembree (Ohio, USA), Alfred Uchman (Krakow, Poland), and Andrew Rindsberg (Alabama, USA), a multitude of oral and poster presentations. The conference was concluded by an ichnological and geological field trip across the main Karoo Basin, which showcased some of the best ichnological outcrops in South Africa and Lesotho. All in all, these events provided several invaluable opportunities for learning, networking, and exploring current ideas of continental ichnology.

Lower Moyeni palaeosurface, Quthing, Lesotho.

Based on a democratic vote, the best student presentation award was given to Mr Martin Qvarnström, a PhD Student from Uppsala University and the second prize went to Ms Miengah Abrahams, a PhD Student from University of Cape Town. The best presentation prize in the researcher category was awarded to Dr Charles Helm, who is affiliated with the Peace Region Palaeontology Research Centre (Canada) and is an associate in Centre for Coastal Palaeoscience (NMMU of South Africa).

Based on the feedback received so far, the event was an enjoyable experience and an exciting break from the usual academic routine for all colleagues, senior and junior alike. The ICCI 2017 program allowed plenty of time for socializing, meeting potential collaborators and networking among peers, but good science, above all else, defined the event.

Emese Bordy

The ICCI 2017 was made possible by the sponsorship received from the following organizations:

Stellenbosch

Stellenbosch students rack up core-logging experience

Earth Sciences at Stellenbosch has invested in two new core-display racks that enable students to gain essential and fundamental core-logging skills. During the first practical session to use the facility, our students thoroughly enjoyed their first exposure to core, and ably identified structures and rock types at the centimetre to decimetre scale. The Department gratefully acknowledges Kolomela Mine for the iron-ore core and Exxaro Resources for core segments from the coal-bearing Karoo stratigraphy. Should any other mines have mineralised or interesting core that could be donated toward student training needs, the Department would be a welcoming recipient.

Creative teaching interventions in the Earth Sciences

The Department of Earth Sciences had a strong showing

Core

at the recent 2017 Stellenbosch University Scholarship of Teaching and Learning (SOTL) conference. This even aims to foster a culture of innovation and reflection in teaching and learning at the Stellenbosch. Dr Susanne Fietz (senior lecturer in our Environmental Geochemistry stream) presented her initiative, which focuses on collating undergraduate field work data collected from the Rooiels estuary. This multi-year (and publishable) data set is then used in subsequent, interactive, classroom discussions, to promote further learning in the fields of applied geochemistry and environmental change.

Dr Bjorn von der Heyden (lecturer in economic geology) submitted two abstracts and one of his presentations was awarded the overall runner-up prize (covering all expenses to present at a 2018 South African Teaching and Learning conference). In his first project, he investigated different peer- and near-peer learning interventions with his third-year economic geology students as the study group. The project was designed encourage students to take more ownership of learning, to test whether this learning is effective, and whether it is, in any sense, 'de-colonised'.

His second project looked at industry-based geologists as a valuable resource from whom students could acquire additional knowledge of the applied aspects of their degree. Students were required to conduct telephonic interviews with geologists employed in the South African minerals industry, to gain insights into the roles and responsibilities of a professional geologist. Students were urged not to neglect the interpersonal elements in the telephonic interviews, since a secondary outcome was that they should learn to develop professional networks in what is actually quite a small industry. Dr von der Heyden is deeply grateful to all industry geologists who took the time and energy to interact with our students, and the students were exceedingly positive about their learning experiences, as well as the interactions with and mentorship from the industry partners.

Bjorn von der Heyden (center) poses merrily with the other four candidates who were short-listed for consideration at the Stellenbosch University Teaching and Learning conference awards ceremony.

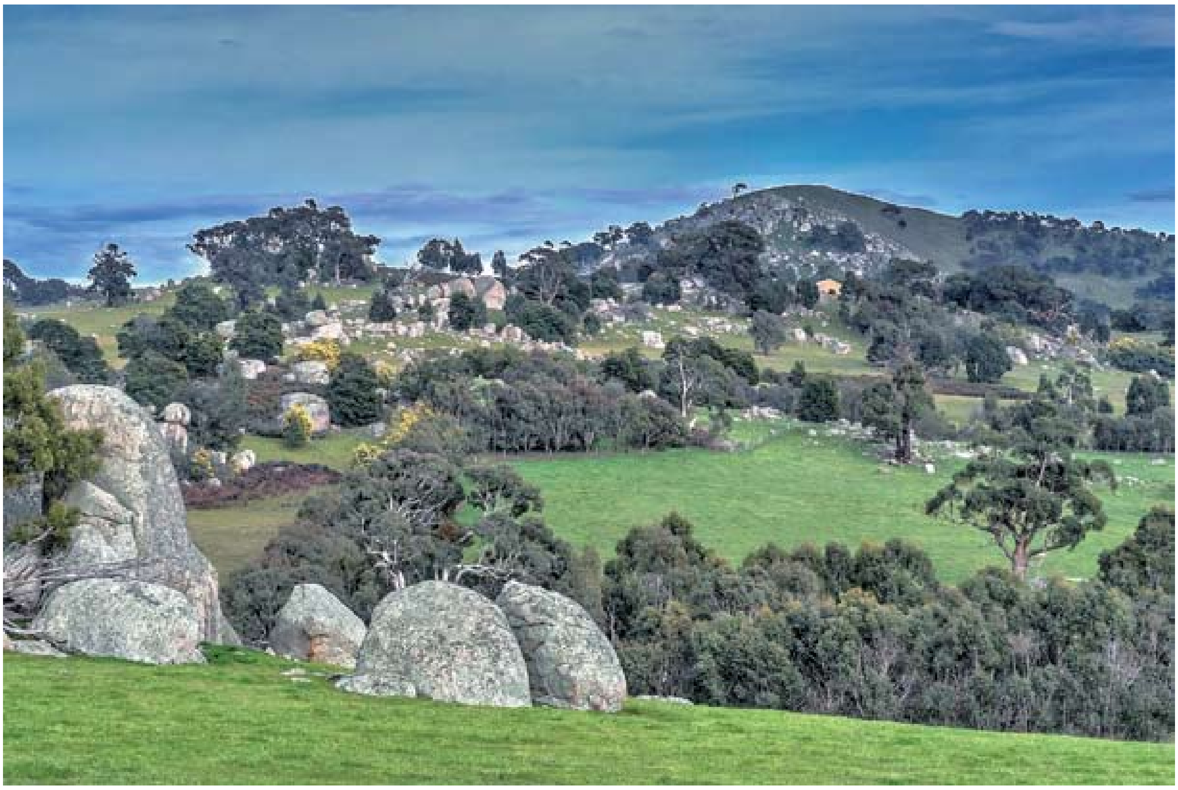
Stellenbosch features prominently in international meeting in Australia

On 25th to 28th September this year, The Australian Institute of Geoscientists, The Australasian Institute of Mining and Metallurgy and The Geological Society of Australia sponsored an international field symposium on 'Granites: Crustal Evolution and Mineralisation' (granites2017@benalla). Prof. Clemens of Stellenbosch was part of the organising team that planned the event (starting in 2015), in association with geosymposia.com.au and SJS Resource Management. This was an unusual event because it brought together not only academic and industry geologists from many countries, but also included an opening outreach session designed for, and extremely well-attended by the members of the local community from the rural city of Benalla and its surrounding pastoral district. Prof. Clemens provided the opening lecture (Granites 101), which proved very popular with the general audience and, perhaps surprisingly, much appreciated by even the student and academic audience. He also made a presentation on 'The Giant Donkerhuk Batholith of Namibia: World's Most Heterogeneous Granite?'. It is, by the way. He also led one of the field trips (to visit classic S- and I-type granitic batholiths ... and a winery) and assisted in the production of a very detailed guide for the other trip that he co-led with Prof. Neil Phillips, published as: Phillips, N., Clemens, J., 2017. *Geology of the Tallarook Plateau. Outdoor Recreation in Australia, Central Park, Melbourne, Australia*, 58 pp, ISBN: 978-0-9593329-3-3.

The photograph below shows one of the remarkable views across the northern part of the Late Devonian Cobaw batholith in the Central Victoria, which was visited on one of the field trips. It shows the younger I-type Baynton pluton (in the foreground) rimmed by the older, foliated, S-type Pyalong pluton, and the roof contact between the Pyalong pluton and the hornfelsed Late Ordovician slate country rocks, clearly visible on Hayes Hill, in the background.

That's about it from Stellenbosch Earth Sciences for 2017. Our Staff and current students wish all the readers of Geobulletin a very relaxed and refreshing holiday season and a happy and prosperous 2018.

John Clemens



diamond short course

24 -27 October 2017

The sixth annual Diamond Short Course was held at the University of Pretoria from the 24th to 27th October. The course provides an insight in exploration, evaluation, mining of primary and secondary diamond deposits, and the valuation and marketing of diamonds over the first three days. On the fourth day of the course the students and delegates are hosted by Petra Diamonds and get treated to an underground trip at Cullinan Mine. The organisers of the course have however tried to retain the general structure of the course over the last 6 years.

It was attended by the 16 honours students from the Department of Geology at the University and 18 outside delegates which this year all came from South Africa. The delegates represented the Council of Geoscience, De Beers, Ekapa Mining, Mintek, Petra Diamonds and Qinisele Resources.

The structure of the course is designed in such a way that the participants get exposed to lectures by some of the world leading authorities in their field of expertise in diamond geology and valuation. The history of diamonds, world diamond markets, origin of diamonds, kimberlites and lamproites, cratons, geophysics and exploration (*John Bristow, Fanus Viljoen, Johan Stiefenhofer, Hielke Jelsma, Gavin Selfe and Mike de Wit*) are covered on the first day. Mantle mineralogy, indicator minerals, alluvial diamond deposits in Africa, and the offshore marine deposits (*Sarah Burness, Hilde Cronwright, John Ward, Lyndon DeMeillon and Mike de Wit*) are discussed on the second day. The third day is dedicated to mining methods and diamond recovery, rough diamond valuation and pricing, the evaluation of alluvial deposits, and the introduction and importance of the Samrec code (*Alex Holder, Derek Lahee, Grant Ziegler, John Bristow and Tania Marshall*). On the fourth and final day of the short course, like all previous years, the 34 participants were taken underground at Cullinan Mine which is made possible by **Petra**

Participants of the 2017 Diamond short course going underground at Cullinan Mine near Pretoria

Diamonds Ltd. This underground trip makes the course so unique as it provides the students and delegates first-hand opportunity to see a Tier-1 diamond mine in operation, and exposes the delegates to the practical side of the diamond business.

Each expert who presented their materials at this Short Course ensured that their presentations included the latest technology and ideas in geology and mining. Examples such as the new X-ray technology to recover large diamonds before these may be broken in the metallurgical processes, waste sorting from kimberlite before treatment in a processing plant, new crushing techniques, new models in geophysics and major and trace element geochemistry updates of mantle minerals and diamond inclusions, are but a few that are presented. Interaction between presenters, delegates and students is encouraged and this year this proved to be extremely lively.

Since the start of this program in 2012 the revenues generated from the Diamond Short Course have been used to cover the registration expenses for the honours students of the University of Pretoria and to fund some of the University's post-graduate students for part of their field and laboratory expenses. The presenters of this Short Course all provide their services on a voluntary basis and their efforts are gratefully acknowledged by the course organizers, **John Bristow** and **Mike de Wit**, and the HOD **Prof Wlady Altermann**.

Mike de Wit

marine mining

Marine Mining around the Southern African Coast

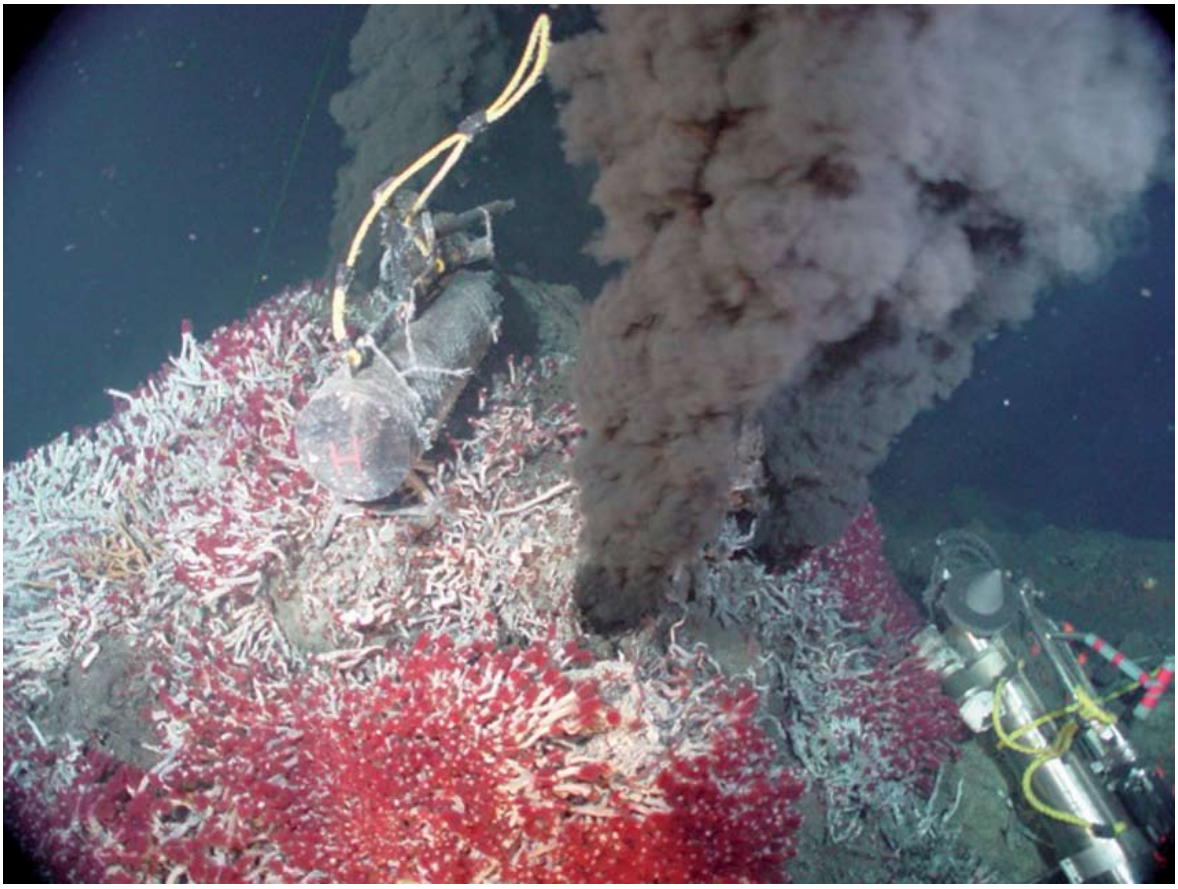
Marine mineral mining in the Southern African region is not a new development, but with expansion of initially exploration operations followed by mining, it is bound to become more controversial in the near future. Marine diamonds and heavy mineral sand deposits are actively mined and exploration for oil and gas continue along the coast of Southern Africa. The approval of phosphate exploration licences along the South-western coast of South Africa has caused a public outcry due to the potential negative environmental impact. Apart from placer deposits and phosphates, a range of other marine minerals are found along the coast and off-shore.

Marine Mineral Deposits

Unconsolidated deposits include construction materials such as sand, gravel, and shells. Heavy mineral placers contain materials such as titanium, tin, and gold; metalliferous muds and nodules and oozes of silica and calcium carbonate. Consolidated deposits include bedded deposits, such as coal and iron ore; crusts, such as the cobalt-rich manganese oxides; massive sulphide deposits in the form of mounds and stacks occurring at spreading centres; and essentially tabular veins or mineralized channels in consolidated host rocks associated with active or extinct hydrothermal vents or so-called "black smokers" (Photo 1). A summary of the main marine minerals and their average occurrence depths are shown in Table 1.

Table 1: **Marine Mineralisation Occurrences and Depths**

Type of mineral deposit	Average Depth	Resources
Polymetallic nodules	4,000 - 6,000 m	Nickel, copper, cobalt, and manganese
Manganese Crusts	800 - 2,400 m	Mainly cobalt, some vanadium, molybdenum and platinum
Sulfide deposits	1,400 - 3,700 m	Copper, lead and zinc some gold and silver



Hydrothermal vents or so-called "black smokers".

Marine phosphorite deposits occur on continental shelves and slopes, primarily off the west coast of continents where easterly trade winds blow offshore thereby inducing upwelling. These deposits formed beneath zones of coastal upwelling from early diagenetic processes very near the seawater-sediment interface in an organic matter-rich environment. Mineralisation usually takes the form of nodules.

Placer diamond deposits encompasses beaches and the adjacent continental shelf from 100 m above to at least 200 m below sea level and extends between 450 km south and 300 km north of the present Orange River mouth on the West-coast. De Beers has been mining diamonds from shallow waters off southwest Africa since the 1960's

Mineralisation usually takes the form of nodules

Marine metallic heavy minerals are derived by mechanical erosion of terrestrial rocks and transported, sorted, and concentrated by flowing water as placer deposits in beach and offshore sediments of continental margins as a consequence of their higher density. In South Africa, Titanium and Zirconium is recovered from the Richard's Bay area up to a depth of 30 meters below sea level. Placer deposits containing titanium, thorium, rare earth elements and zirconium have been mined at a location on the southeast coast of Madagascar. The Corridor Sands and the Moma disseminated beach deposits is developed onshore near the coast of Mozambique.

Precious metals placer deposits such as gold, silver, and copper are also attractive targets, but have not been developed to the same extent as the afore mentioned minerals.

ARTICLES

Mining diamonds from shallow waters off southwest Africa.

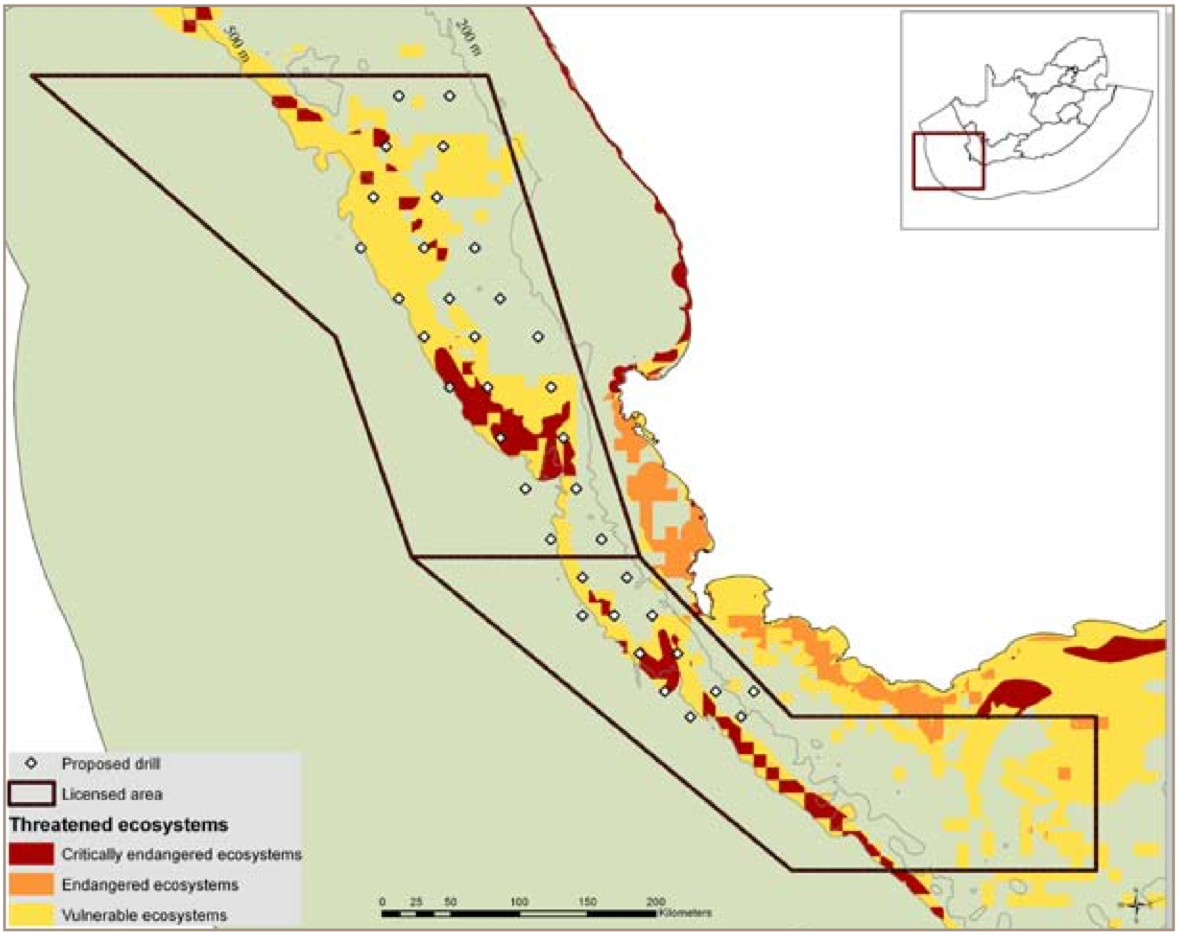
Operation Phakisa

The South African Government's Operation Phakisa: Ocean Economy plans to utilise the economic potential of the country's marine environment through the rapid promotion of marine petroleum and minerals extraction. At the moment in South Africa's Exclusive Economic Zone (EEZ), 98% has been leased for offshore oil and gas exploration. As part of the program, it aims to fast-track the drilling of 30 wells in the next ten years and develop infrastructure such as a phased gas pipeline network. It also includes offshore mineral sands mining and unconventional gas exploration and exploration of ferromanganese crust between South Africa and Madagascar. Operation Phakisa also relates to the establishment of marine transport and manufacture, offshore oil and gas, aquaculture and marine protection services.

Southern African Marine Phosphate Exploration Applications

Mining operations off the coast of South Africa has to date been very limited and mainly constrained to the marine diamond and oil-and-gas exploration work. The issuing of three exploration licences off the coast of the Western Cape for phosphate was almost unnoticed for years. Concerns are now being raised that these

The Corridor Sands and the Moma disseminated beach deposits is developed onshore near the coast of Mozambique



Location of Phosphate Exploration Lease Areas off the South-western Cape Coast - Image Heather Dugmore

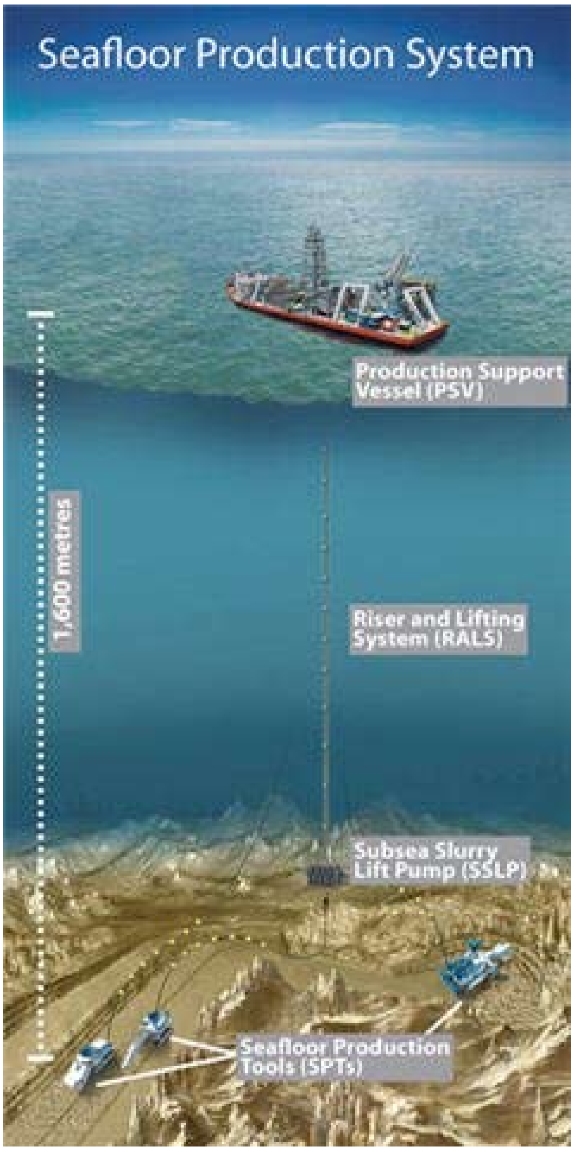
exploration rights are close to expiring and that it may be extended and eventually converted to mining rights. The three mining rights were granted, in 2012 and 2014, by the Department of Mineral Resources to Green Flash Trading 251, Green Flash Trading 257 and a Canadian company Diamond Fields International to prospect for marine phosphates, on claims covering more than 150 000 km² or 10% of the country's marine environment. The prospecting rights extend from the northern reaches of the West Coast, down the West Coast to Cape Town, then around the peninsular and all the way to offshore Mossel Bay. The prospecting areas are located mostly in depth contours of between 200 meters and 2,000 meters, with the shallowest depth being five meters.

The Sandpiper phosphate operation is located off the coast close to the harbour town of Walvis Bay. Sandpiper mine have estimated reserves of 1.82 billion tons of ore grading 19.5% P2O5. The other company that has applied for an offshore mining licence is LL Namibia Phosphate. Phosphate mining is also controversial in Namibia due of its potential impact on the fishing industry. Following civil objections, the Namibian government has temporarily suspended clearance given by the ministry of environment, for a period of 18 months, to start marine phosphate mining, in order for an environmental impact study to be completed.

Marine Mining Methods

Deep sea mining is done using a remotely operated vehicle (ROV) to scrape up nodules or mineral-rich crust. ROV's comprises of three components 1) drive body, 2) ore crusher and 3) ore lifter. The main limitation with this method is that mining is done on a trip-by-trip basis and the weight of material lifted will be limited by the capacity of the ROV.

A more efficient method is locating a ship or floating platform above the mining site. A conveyor belt could bring material up to the surface, where it could be sorted and separated or an alternative option is to



ROV's comprises of three components:
1) drive body, 2) ore crusher and 3) ore lifter

use a hydraulic suction system. Once the valuable materials are separated from the surrounding rock, the spent tailings are dumped over the side.

Environmental Concerns

Currently only 0,4% of South Africa's EEZ area is officially protected. Preliminary studies by the World Wildlife Fund (WWF) suggested that marine organisms on the seafloor would not survive marine mining operations, owing to the generation of a continuous sediment plume. It is also suggested that the disturbed continental sediments will cause a change in the chemical characteristics of the water column, due to the release of potentially toxic elements, such as radioactive materials, methane, hydrogen sulphide and heavy metals locked in the sediments. The release of heavy metals from seabed sediments could also lead to these elements being absorbed in the food chain and ultimately impacting fisheries products. It may also impact on surface photosynthesis and could lead to low oxygen levels in the affected ocean water. Preliminary assessments, undertaken internationally, outline considerable and irreversible consequences for marine ecosystems and fishery resources. It is suggested that the destruction and permanent alteration of marine habitats would be inevitable with direct destruction of spawning, breeding and feeding habitats for fish species.

The three prospecting rights for marine phosphate mining in South Africa's EEZ directly overlap with critically endangered ecosystems, ecologically and biologically significant areas and habitats earmarked for protection under another Operation Phakisa initiative designed to establish a network of marine protected areas. The benthic habitat types that coincide with the prospecting areas also do not exist anywhere else in the world. The benthic zone is the ecological region at the seabed or sediment level, together with the subsurface layers.

Internationally Approved Marine Mining Operations

To date Papa New Guinea have signed-off on commercial seafloor mining in its waters. It has leased an off-shore site called Solwara 1 to Nautilus Minerals and the company plans to begin copper production at the site in the first quarter of 2018. According to the company's website, the Solwara 1 deposit contains a copper grade of approximately 7%. In addition, gold grades of well over 20 g/tonne have been recorded in some intercepts, with an average grade of approximately 6 g/tons. New Zealand's Environmental Protection Authority also approved Trans-Tasman Resources' application to mine iron sands from the seabed of South Taranaki Bight, located 22 kilometres to 36 kilometres offshore from Patea.

Dr Nicolaas C. Steenkamp

ARTICLES

a new mineral

Tredouxite – A new mineral from the Barberton Greenstone Belt

(See Centrefold)

The International Mineralogical Association Commission on New Minerals, Nomenclature and Classification in September announced the acceptance of a new mineral, named "tredouxite", that was discovered and described by Luca Bindi (University of Florence), husband-and-wife team Federica Zaccarini and Giorgio Garuti (University of Leoben), and Ducan Miller (University of the Free State). The tetragonal mineral with the formula $NiSb_2O_6$, is the Ni analogue of the mineral bystromite ($MgSb_2O_6$), and was discovered in the enigmatic Bon Accord Ni-oxide deposit of the Barberton greenstone belt that has been the source of six new minerals prior to the discovery of tredouxite.

The Bon Accord body was originally proposed to be an oxidized remnant of an iron meteorite, but this hypothesis has been largely discarded in favour of models suggesting a terrestrial origin for the deposit. The Bon Accord body was extracted during the 1920s due to its high nickel content, but the material proved too refractory for smelting and the ore was abandoned on a pile approximately 3 km away from where it was extracted. This pile, and an abandoned sample shed near the original location of the body was pointed out to Marian Tredoux by Maarten de Wit in the 1980s. The samples in which tredouxite was discovered were collected from the shed by Marian who, after the prolific activities of Sybrand de Waal in the 1960s and 70s on the mineralogy, became the prime researcher into the geochemistry and origin of this remarkable deposit. The new mineral was named "tredouxite" in her honour, for her lifelong contributions (see below) to our understanding of the geochemistry of ultramafic rocks in general and more specifically, that of the Bon Accord body.

Tredouxite occurs as grains ranging from 10 to 500 μm in size and is associated with trevorite ($NiFe_2O_4$) and bottinoite ($Ni[Sb(OH)_6]_2{\cdot}6H_2O$), within a matrix mostly composed of willemseite ($(Ni,Mg)_3Si_4O_{10}(OH)_2$). For any non-scientist reading this, tredouxite is therefore unlikely to significantly influence the gross domestic product of South Africa, nor will its discovery alleviate the problem commonly encountered when trying to find the end of a roll of Sellotape. However, its discovery shows that the secrets of Bon Accord have not been finally revealed and as scientists we look forward to further discoveries from this perplexing body of rocks that may prove pivotal in furthering our understanding of geological processes in and on the early Earth.

Marian Tredoux's contributions to our understanding of the Bon Accord Ni-oxide deposit:

- Tredoux, M., De Wit, M.J., Hart, R.J., Armstrong, R.A., Lindsay, N.M. and Sellschop, J.P.F. (1989) Platinum group elements in a 3.5 Ga nickel-iron occurrence, possible evidence of a deep mantle origin. Journal of *Geophysical Research*, 94(B1), 795–813.
- Tredoux, M., Roelofse, F. and Shukolyukov, A. (2013) Isotope characteristics of the Bon Accord oxide body, Barberton greenstone belt, South Africa. *Mineralogical Magazine*, *77*, 2371–2385.
- Tredoux, M., Roelofse, F. and Shukolyukov, A. (2014) A Cr isotopic study of the Bon Accord NiO body in the Barberton greenstone belt, South Africa. *Chemical Geology*, 390, 182–190.
- Tredoux, M., Zaccarini, F., Garuti, G. and Miller, D. E. (2016) An investigation of phases in the Ni-Sb-As system, and associated platinum-group minerals, which occur in the Bon Accord oxide body, Barberton greenstone belt, South Africa. *Mineralogical Magazine*, 80, 187–198.
- Zaccarini, F., Tredoux, M., Miller, D. E., Garuti, G., Aiglsperger, T. and Proenza, J. (2014) The occurrence of platinum-group element and gold minerals in the Bon Accord Ni-oxide body, South Africa. *American mineralogist*, 99, 1774–1782.

Freddie Roelofse

women in geology

The numbers of women in prominent positions in South African geology are gradually increasing. Below are brief profiles of the first female President of the Geological Society of South Africa, **Lesley Turner** and the past President, **Jeannette McGill**. Representing the next generation of leaders are four in transitional leadership positions at the Council for Geoscience; **Refilwe Shelembe**, Acting Executive Manager for Geological Resources; **Hayley Cawthra**, Acting Manager of the Western Cape and Northern Cape offices; **Joyce T Leshomo** Acting Manager of the Water and Environmental Unit; and **Valerie Nxumalo**, Acting Manager of the Strategic Management Unit of the CGS.

LESLEY TURNER (nee OWEN) Pr. Sci. Nat., FGSSA

My initial curiosity in matters geological was sparked by the collection of rocks and maps in my grandfather's study. He was a mine surveyor and self-taught geologist (and GSSA Member) who worked on several diamond and gold mines during the 1920's and 1930's, culminating in his part in the discovery of the East Champ D'Or Mine in 1936.

That curiosity became a life-long fascination with geology, minerals and earth processes where every rock and landscape tells its own story.

With a B. Sc (Geology, Chemistry) UND, now UKZN, in 1967 and with legislation preventing women from working in a mine, the next 18 years were spent as research assistant to Professor E. P. Saggerson with the compilation of The Metamorphic Map of Africa (1979) for the UNESCO Commission for the Geological Map of the World, as co-author of The Metamorphic Map of South Africa (1991) for the Council of Geoscience and as co-editor for the International Atomic Energy Agency publication on the "Correlation of Uranium Geology between South America and Africa". (1986).

Lesley Turner

A major change in career occurred in 1987 when I joined the MINTEK (Council for Mineral Technology) Research Group in the Dept of Chemical Engineering at UND as a minerals research technician. It was a very steep but enjoyable learning curve as I was introduced to the world of engineering and problem solving. In 1992 I was invited to join Minemet Technologies (Pty) Ltd, a consulting group in mineral processing and metallurgy as a director, a position I still hold. Here I must acknowledge that my career in geology would not have been possible without the support and encouragement of my dear husband, our two sons, family and friends.

Joining the Geological Society of South Africa in 1969 was one of the best decisions I ever made. Becoming part of a unique global fellowship at a time when the pieces of the Plate Tectonics puzzle as a viable theory were falling into place was a wonderful experience. I will be forever grateful for the many opportunities to network with other geologists from local institutions and all over the world at GSSA conferences and meetings. As a GSSA member I found that the best way to meet the other members was to actively participate in Society affairs. In 1980 I was a founding member of the KZN Branch and served on the Main Council for more than 10 years. In 2001 it was a great honour and a major highlight of my career to be elected President of the GSSA.

My hope is that the GSSA will evolve, grow and continue to provide a solid professional and scientific platform from which new generations of African geologists may flourish. It is only by understanding earth processes that we can learn to adapt to the inevitable changes in earth conditions.

Jeannette McGill – Head of Telstra Mining Services

I spent much of my youth in the mountains of the Eastern Cape and this immersion into the outdoors fuelled the choice to study geology and zoology at UPE. However a classmate and I made the rather unconventional request to also complete credits in the B.Comm faculty, including Business Economics as well. I spent holidays working for the National Parks Board at Tsitsikamma National Park but on receiving a scholarship from Anglovaal to complete honours at Rhodes University and after a summer vacation spent measuring pebble imbrications at Beeshoek Iron-ore mine my mining industry fate was sealed.

Jeannette McGill

I am the global Head of Telstra Mining Services with a solid career in the global mining sector beginning as the 2nd woman to be issued an underground blasting certificate, being technical advisor to a Minister of Mines, managing technology development of the mining sector and most recently being identified as one of the 100 most inspirational women in mining globally, as recognized by women in management, UK (WIMUK). My other passion in life is mountaineering. I have climbed mountains in Peru, Bolivia, USA, Iran, Tanzania, Tibet and Nepal. My dream is to summit an 8000m mountain.

Refilwe Shelembe
Council for Geoscience, South Africa

With 11 years' experience as a field geologist and a master's degree in geology from the University of Witwatersrand, I have mapped six 1:50 000 scale geological maps in and outside (Ghana) South Africa. My focus was on the metamorphism of the upper Pretoria Group of the Transvaal Supergroup as affected by the far western Bushveld Complex. I have also worked on various research and commercial projects which range from 3D geological, Geological Mapping in the Keimoes area, Thyspunt and Duynefontein Nuclear Siting Projects, Strategic Nuclear Reserves, alluvial diamond gravel mapping, to name a few. I have a keen interest on the impact of geology on the health of the surrounding communities and the environment (medical geology). I am closely involved in CGS groups on international collaboration.

I have served as a committee member in the Young Science Forum, Young Geoscientists Network and the

Refilwe Shelembe

Job-grading committees in South Africa. Added to transformation, I have a passion for talent and career development for early-career scientists.

I am currently Acting Executive Manager for Geological Resources at the Council for Geoscience. Previously I was the Technical Assistant in the Office of the CEO and an Acting Manager for Geoscience Mapping.

Dr Hayley Cawthra

I have always had an insatiable curiosity about how the earth works and collected rocks, stones and information about dinosaurs as a young child. My inspiration to pursue marine geoscience comes from my father and my family. We lived on the coast just south of Durban where we free-dived, surfed and fished. To be able to map the seabed excites me massively and the ocean space remains a last frontier in many ways, which we are yet to deeply understand. Highlights in my career have been the opportunity to spend extended periods of time at sea on research vessels working in depths of up to 5000 m, having Antarctic Intermediate Water pour out onto on my hand from a core catcher (sample

Dr Hayley Cawthra

from ~1800 m), and diving on numerous previously unchartered reefs around the South African coast.

I currently hold the position of Acting Regional Manager of the Western Cape and Northern Cape offices of the Council for Geoscience (CGS). Outside of this I am employed as a Senior Geologist in the Marine Geoscience Unit, where I lead the newly initiated continental shelf mapping programme, and am a Research Associate at Nelson Mandela University in the Centre for Coastal Palaeoscience.

In 2006 I graduated with an Honours degree in Geological Science at the University of Natal (now the University of KwaZulu-Natal) and have since worked at the CGS for eleven years. During this time I completed a part-time M.Sc. from the University of KwaZulu-Natal (2010) which was awarded Cum

Laude, a Ph.D. from the University of Cape Town (2014), and I conducted a post-doctoral research fellowship at the University of Bremen Centre for Marine Environmental Sciences (MARUM) in 2016. My Ph.D. research was co-funded by the CGS and National Geographic Society and has led to further collaboration with partners from various disciplines within a broad context of understanding global change. My research interests include various aspects of Quaternary geology and glacio-eustatic sea level change, with particular reference to submerged deposits on the continental shelf and sequence stratigraphy. Submerged landscapes, human origins and human use of ancient coastlines were the focus of my Ph.D. work offshore of Mossel Bay.

I have 28 authored and co-authored peer-reviewed journal articles and scholarly book chapters on sea-level change, marine sediments, carbonate petrology, continental shelf geology, integrated archaeological studies, and coastal vulnerability in South Africa.

I am involved in numerous ongoing multi-disciplinary research projects in South Africa with local and international collaborators from various disciplines including the fields of Palaeoanthropology, Archaeology, Palaeobotany and Marine Biology.

Joyce T Leshomo (nee Shongwe) Pr. Sci. Nat.

Joyce T Leshomo

I was always fascinated by nature especially rocks and landscapes, but didn't know that this could be a career. Growing up in deep rural areas of Mpumalanga where the only career that you know is the one you see (teaching, nursing, police, soldier, clerk, etc.), I grew up determined to be a nurse, thus I applied for a BCur nursing degree with BSc as my second choice. The University accepted me for a BSc. I chose natural science (geology & geography), life science and chemistry courses in first year. It was then that I was introduced to geology and I knew this is what I wanted to do for the rest of my life. I continued with geology at the University of the Western Cape and graduated with an Honours degree in 2002. I joined the Council for Geoscience in January 2003. I continued studying part time at the University of the Witwatersrand while employed by the CGS and graduated with an MSc in Hydrogeology in 2012. I am currently enrolled for PhD in hydrogeology with the University of the Witwatersrand (part time).

I started working at the Council for Geoscience in 2003 as a junior scientist in the Mapping Unit, working on the Randfontein Mapping project and the Meyerton Engineering project. In 2004 I joined the Water and Environmental Unit (then the Water Unit). I am employed as a senior scientist (Hydrogeologist) working on different projects. My interests are in the occurrence of metals and radioactive elements in groundwater and medical geology projects. Among other projects I worked in the Stampriet Transboundary Aquifer Systems, a UNESCO project on the aquifer shared by Botswana, Namibia and South Africa. In addition to this, I am currently Acting Manager of the Water and Environmental Unit in the CGS.

Valerie Nxumalo

From my side the initial interest was when my sister who is currently a metallurgist, told me about Geology and after speaking to my dad about it, he brought an article from a Sowetan Newspaper published in 2001. It was about SA government encouraging women to do Mining courses and that included Geology. So, knowing where SA was before 1994 I decided to contribute and to make a difference in the field of Geoscience.

Iam a registered Professional Natural Scientist who graduated from the University of the Witwatersrand

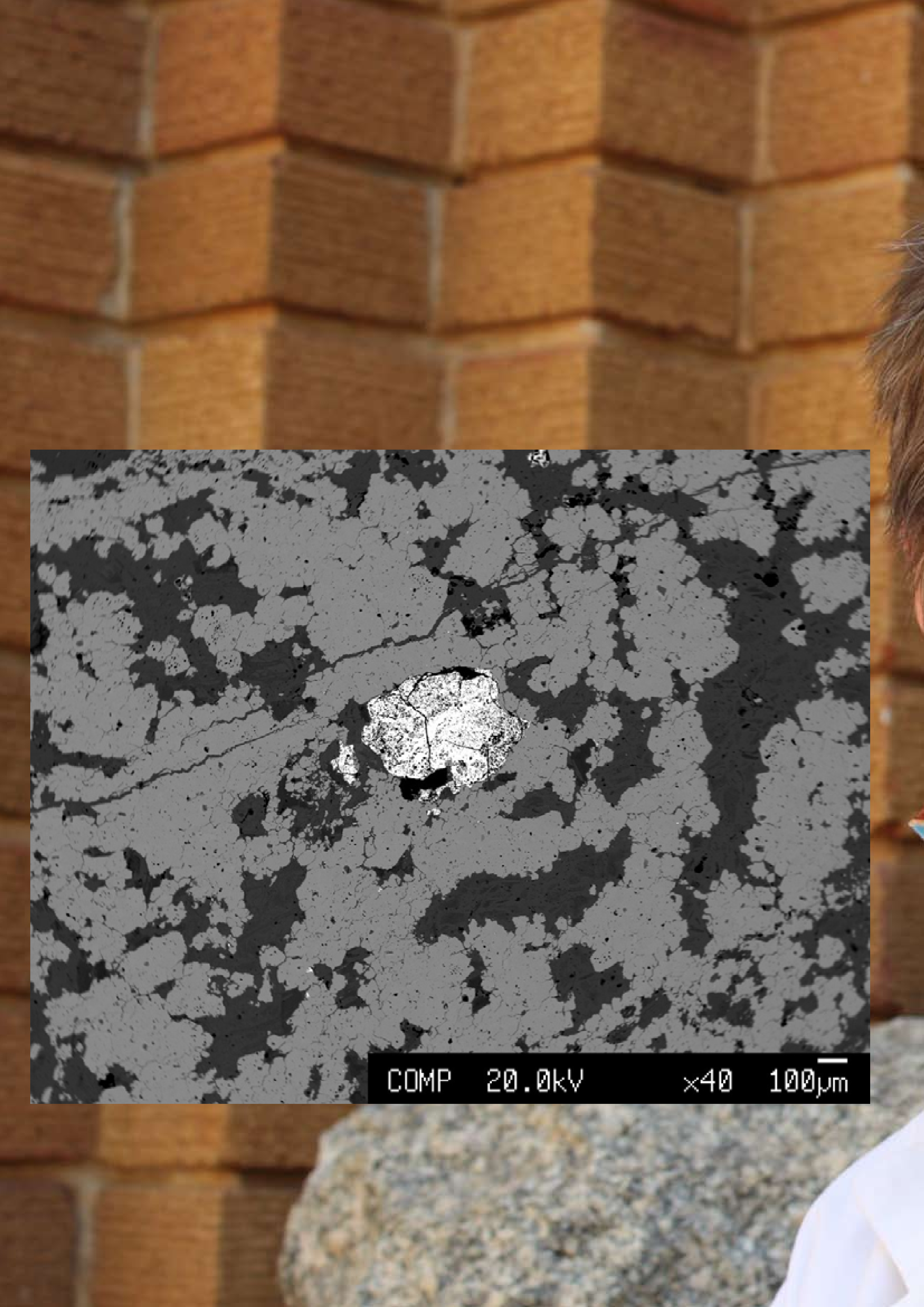
Valerie Nxumalo

with a BSc Honours [2006] and MSc [2011] in Geology. I started my career in 2007 as a junior exploration geologist at SRK Consulting. The main project I worked on at SRK involved exploration for uranium in Beaufort West. This involved logging of sedimentary rocks of the Beaufort Group in search of channel-hosted uranium mineralisation, sampling, positioning of new exploration boreholes, and field mapping.

I joined the Council for Geoscience (CGS) in November 2007 to continue investigation of Karoo rocks. My first project at the CGS investigated the stratigraphy and sedimentology of Karoo Supergroup rocks in the Kalahari Karoo Basin (Botswana and Namibia). The purpose of this project was to develop a correlative framework for the various stratigraphic units in the Kalahari Karoo Basin and to understand the distribution of mineral resources; especially coal. I contributed to multidisciplinary projects that investigated the proposed nuclear sites in South Africa; the geology and mineral potential of the Rosendal area in the Free State Province with the main focus on uranium and molybdenum; and I also contributed in several small commercial projects on classification of rock samples for road aggregate material and 3D geological modelling of quarries.

I am currently working on research projects on the nature and the distribution of uranium in the Springbok Flats Basin, and on the collaborative project between the Canadian Geological Survey and the CGS, which involves exchange of scientific ideas and concepts, knowledge and skills transfer on ore geology and mineralisation system, mineral exploration and mineral development. I am a registered PhD student at the University of Johannesburg. Most recently, I assumed the role of Acting Manager for the Strategic Management Unit of the CGS.

Compiled by Chris Hatton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Marian Tredoux, associate professor with the Department of Geology, University of the Free State. On the left is a microscope image of a 500μm (1/2 mm) grain of tredouxite, the mineral named after her.

halite

Rare preserved efflorescent halite crust with halite casts, and salt blisters from a sub-aerially exposed supratidal mudflat in a marginal marine sabkha from the early Eoproterozoic Rooihoogte Formation, Transvaal Supergroup, South Africa.

Sedimentary structures are the "DNA" of Geologists forensic investigation into the environmental conditions in which the "crime" of sedimentary deposition took place. Because it can be compared with modern processes, careful detective work on sedimentary beds and surfaces can reveal many clues to explain the physical, chemical and biological condition of the "deceased". The subject of the investigation may be very large; from tens of meters of cross-beds of aeolian sand dunes and delta-fronts to remnants of microscopic sized traces of algae and mineral particles.

To the untrained eye many small features on bedding planes might go unnoticed or simply interpreted as the result of weathering or simple diageneses related concretions or minerals like Pyrite. Due to time constraints, scale of mapping and focus on economic deposits these features might simply not be noticed or overlooked. The preservation potential of many small structures in sedimentary rocks is also low as they may easily be destroyed by physical and chemical processes soon after their formation or by subsequent diagenesis or metamorphism. Consequently, the older the rocks, the smaller is the chance that these features may survive.

It was therefore not a surprise that halite casts were only recognized in early 1992 in South Africa by Dr. George Henry and the author on in-situ bedding surfaces of the Paleoproterozoic upper Black Reef and lower Oaktree Formations, Transvaal Supergroup near Bourke's Luck - these were first noticed on slabs of rocks on buildings and the paved paths at the visitors center leading to the well-known potholes! These halite casts and their implication for palaeoceanic chemistry are described in a paper by K.A. Eriksson et. al. (2005). In 2001 during a period of intense 1:10 000 scale mapping in the Alberton area, south of Johannesburg, the author discovered a small, approximately 1 m by 60 cm, partially covered bedding surface on mudrock of the Eoproterozoic Rooihoogte Formation. This contained various sedimentary features, including those associated with thin crusts of efflorescent halite, halite casts, halite blisters, desiccation cracks and a low amplitude tepee structure. While the Black Reef and Oaktree Formations occur at the base of the Chuniespoort Group, the Rooihoogte Formation lies above the Chuniespoort Group, at the base of the Pretoria Group. The halite casts of the Rooihoogte Formation are also different in crystal shape and form.

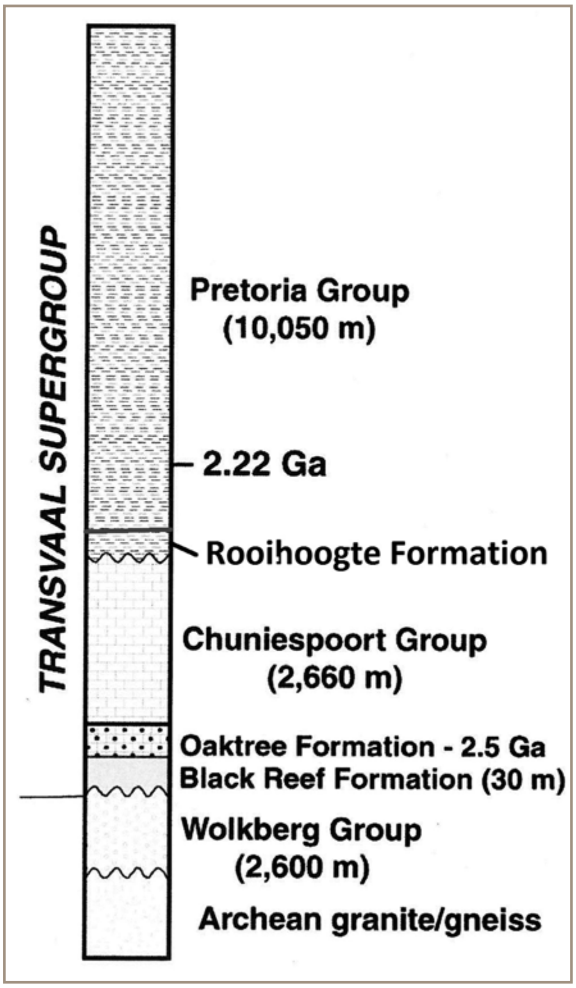

FIGURE 1: Stratigraphic column for the Transvaal Supergroup (modified from Catuneanu & Eriksson, 1999).

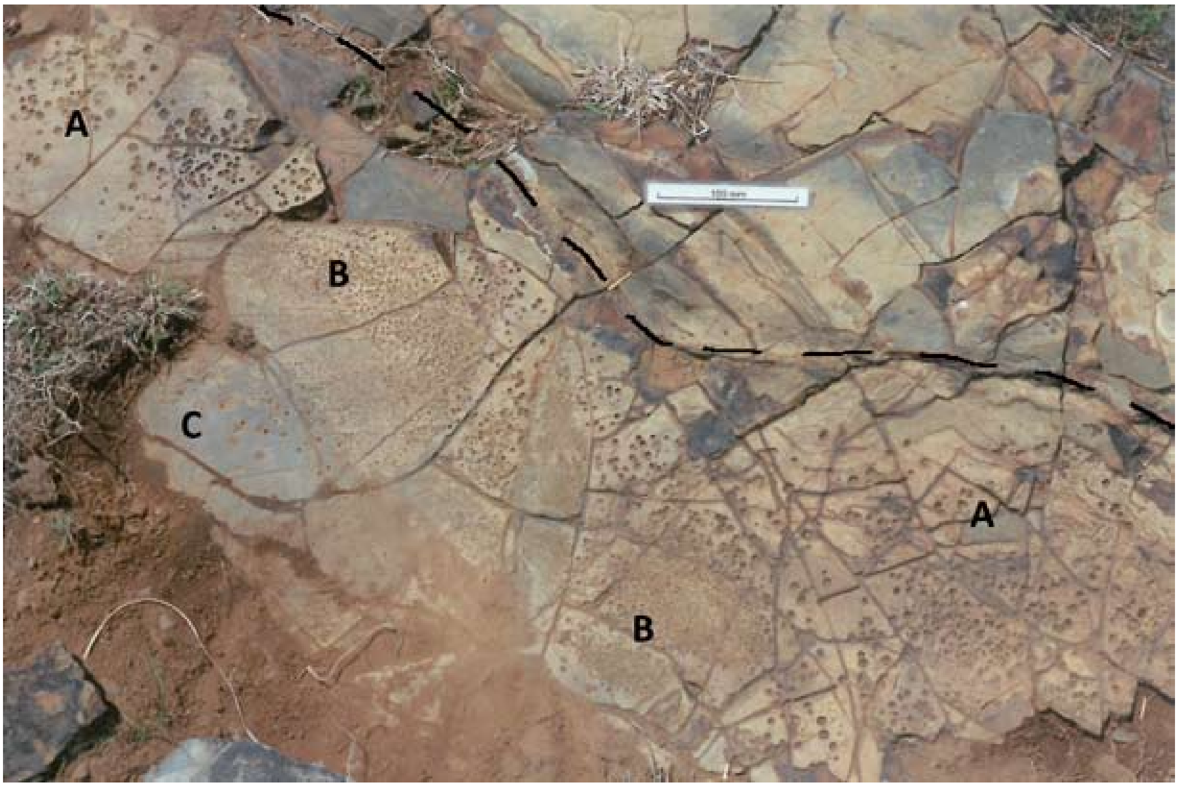

*FIGURE 2:
Bedding surface of the Rooihoogte Formation south of Johannesburg showing axis of Tepee Structure(broken line), halite cast marks Zones A, efflorescent halite crust Zone B and single salt blisters of Zone C and desiccation cracks. Scale is 100 mm.*

In 2011, after an extensive search Chris Hatton and the author relocated the bedding surface which was at the time almost completely buried below debris.

The exposed surface shows a low amplitude fold, possibly a tepee structure related to desiccation, with the axis of the fold manifested by a large crack running from the right to the top left of the photograph (figure 2.). It is worth noting that the evaporate related structures and desiccation cracks are only present on the lower flank of the tepee in the bottom side of the photo, suggesting that the formation of the tepee and the evaporate structures are related. Three different evaporate related zones, grouped together (figure2), may be seen on the bedding surface namely (A) areas with isolated, large halite cast marks with in a smooth mudrock surface, (B) zones with higher concentrated, relatively smaller cast marks with a pitted, coarse "sandblasted" surface and (C) halite blisters with smooth mudrock surface between them. Although it may not be clear in the figure, it appears that the smaller casts (B) might be located at the crests of ripples while the larger casts (A) might be along the flanks or troughs of ripples. Zone C might be in the trough of a ripple. It may therefore be deduced that the various zones are related to the depth of the water or to the variable speed of desiccation of the mudrock on an uneven floor.

The isolated, large casts of zone A are found at the surface of the bedrock and are up to 6 mm deep, varying between a few to 12 mm in diameter. They are negative imprints of mostly upright four-sided, inverted pyramidal hoppers and cornet-shaped halite crystals as described by C. Robertson Handford, 1991. The mostly upright orientation of these halite cast marks, their concentration on or near bedding surfaces and their position within the uppermost part of the mudrock or siltstone suggests that they grew by displacing sediment at or near the sediment- water or sediment-atmosphere interface. This is in contrast to the halite cast marks of the Black Reef and Oaktree Formations which show randomly oriented cubic, dumbbell, triangular as well as hopper-like cubic hollows or faces which, according to Eriksson, K. *et. al.*, (2005) formed due to displacive growth *within* the sediment

*FIGURE 3:
Close-up view of inverted pyramid (above scale bar) and/or cornets in Zone A. Note the hopper-shaped (cube within cube) halite casts at the top left of the image.*

from supersaturated residual brines after mudstone deposition. However, halite crystals might also form, drift and sink in supersaturated water which might be rich in sediment (C. Robertson Handford, 1991).

Zones B possibly represent a thin crust of efflorescent halite (figure 2). It contains a high concentration of relatively small halite casts representing inverted pyramids or cornets in very close proximity and the surface around these are smooth to coarse or "sand blasted" (figure 5). This zone may be explained by the crystallization of halite into very fine crystals in the upper few millimeters of the mudrock bed or at the mud-atmosphere interface during surface evaporation of groundwater and desiccation (C. Robertson Handford, 1991). It is also possible that the halite crystal pyramids and cornets were partially or completely dissolved and the halite was recrystallized in the mudrock along the upper surface. The presence of inferred halite blisters that seem to coalesce at the margin of this zone supports this hypothesis (figure 5). Subsequent exposure and weathering resulted in the etched upper surface of the mudrock on the bedding plane. Zone A and C may grade into Zone B (figure 5). Halite crust may also have collected and concentrated near the top of ripples due to wind blowing fine crystals of halite (C. Robertson Handford, 1991).

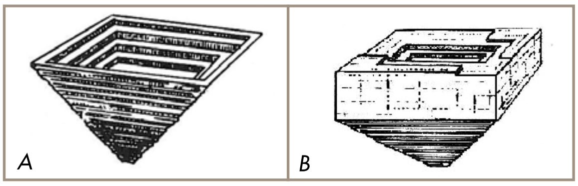

FIGURE 4: Four-sided inverted pyramidal hopper crystal (A) and Cornet crystal with depressed cube-face on inverted pyramid. After C. Robertson Handford, 1991.

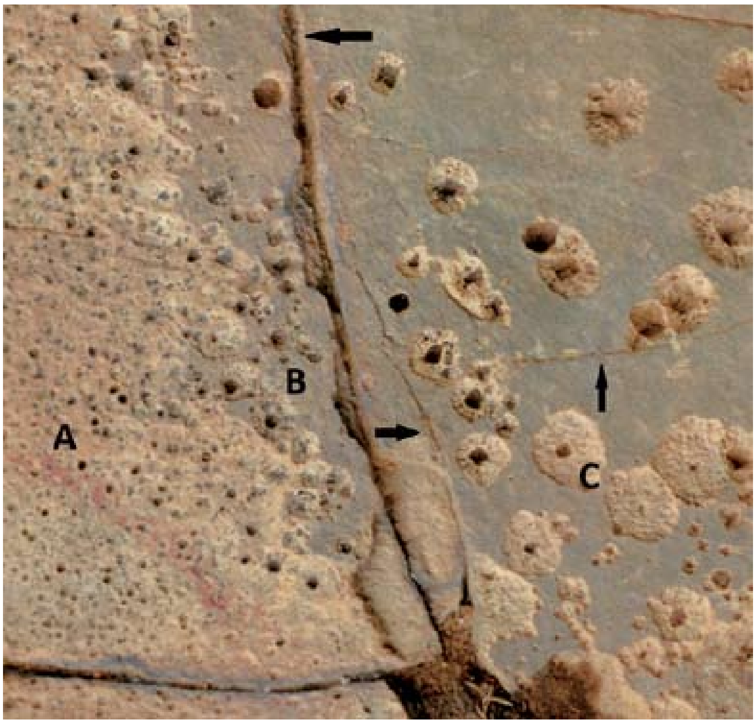

Figure 5: Efflorescent halite crust (A), coalescing halite blisters (B) and halite blister (C). The top arrow shows a desiccation crack while the lower arrows show wedge-shaped cracks.

Zone C consists of "isolated halite blisters. These are cast marks of halite in the form of inverted pyramids or cornets that are on surface surrounded by "sand blasted" or mudrock surface which are relatively coarse and lighter coloured. The area between the sand blisters is relatively smooth and darker coloured. Close inspection of the coarse surface around the casts show a texture related to very small rectangular or cubic imprints of crystals and a polygon-shaped outline (figure 6A). The polygonal blisters might be explained by partial solution of the larger halite crystals, with the brine solution cohesively spreading outwards while redepositing the salt as finer crystals or crust. This corresponds to a modern example of salt blisters that was found on muddy sediments of the lake of the saline Tswaing Impact Crater north of Pretoria (figure 6B).

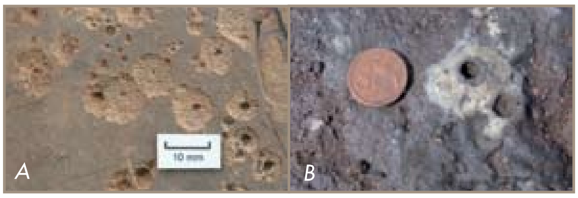

Figure 6A: Halite blisters. The dark square cubes represent inverted pyramids or cornets of dissolved halite crystals. The lighter coloured, rough textured surfaces around the dark squires represent "blisters" around the halite crystals. Note the polygonal outline and the fine crystalline "cubic" derived texture of the blisters. Figure 6B: Modern halite blister in muddy sediments of the Tswaing Crater north of Pretoria. Note the eroded salt casts which are surrounded by a polygon-shaped white crust of salt

The presence of these efflorescent halite structures in the Rooihoogte Formation is unique because they are rarely, if ever, preserved in the geologic record (C. Robertson Handford, 1991). Efflorescent halite crust may easily be destroyed by a moist atmosphere, when water vapor in the atmosphere condenses when it reaches dew point, rain or if the surface of the casts are covered with another flood, tide, sheet-wash or strong winds (C. Robertson Handford, 1991).

The presence of the halite crust, halite casts and halite blisters might be explained by precipitation from salty pore waters drawn to the surface by capillary action from the phreatic zone and/or evaporated salty water. The halite blisters might suggest partial solution of the halite by slight changes in the atmosphere, possibly followed by cooling down. The lance-shaped cracks in figure 5 might represent ice-cracks when a surface is frosted. Frosting of the surface with the sensitive halite structures might provide a clue how and why the structures were preserved. The presence of diamictite, interpreted to have a tillite origin by Coetzee, L.L (2002) suggests that a cold climate existed during deposition of the Rooihoogte Formation.

The efflorescent halite crust, halite cast marks and halite blisters may therefore have been formed in sub-aerially exposed mudflats in a marginal marine sabkha environment during a glacial period. Salt in the mudrock was probably drawn to the surface due to capillary action and some of the crystals was partly or completely re-dissolved and precipitated at or near the surface around halite crystals. An efflorescent crust formed where the growth of the salt was concentrated and very fine-crystalline or where the blisters coalesced due to re-solution and crystallization of fine crystalline salt at the mudstone surface.

These rare structures probably formed and were preserved due to special climatic conditions. Coetzee, L.L. (2002) discussed the presence of possible glacial diamictite near the base of the Rooihoogte Formation. Eriksson, (1988); Eriksson *et. al.* (1991) referred to varve structures of the lower shales of the Rooihoogte Formation and Eriksson and Reczko (1995) also referred to shale deposited in a periglacial, lacustrine environment in the western part of the Transvaal Basin. Evidence for an open ocean deltaic system for the Rooihoogte and Timeball Hill Formations rather than a restricted basin is presented by Hannah, J.L., *et. al.* (2004) based on the lack of mass independent fractionation (MIF) of sulfur isotopes and the presence of highly negative sulfate isotope concentrations. The minimum age of 2316±7 Ma obtained for the Rooihoogte to Timeball Hill synsedimentary to early diagenetic pyrites by Hannah, J.L. *et. al.* (2004) also brackets the age of the first and second global "Snowbal Earth "glacial events at low latitude between 2.45 and 2.32 Ga. It is probably only circumstantial that the rise in global atmospheric oxygen started around 2.31 Ga Hannah, J.L., *et. al.* (2004).

It appears that the halite in the Rooihoogte Formation and Blackreef and Oaktree Formations both may have formed due to subaerial exposure as shown by the presence of mudrock and or siltstone, ripple marks, desiccation cracks and a tepee structures. The presence of isolated halite casts and hopper-shaped textures within the sediment suggest that they both grew due to sediment displacement after deposition in similar environments. However the presence of salt blisters and possibly efflorescent crust at the top or within a few millimeters of the surface suggests that halite might have been dissolved and re-precipitated from existing halite crystals at the surface and might even have been concentrated by wind or as salty brine on some sedimentary premonitions in the area. It is also important to note that the occurrence of halite casts in the Black Reef and Oaktree formations near Bourke's Luck appears to be much more extensive and appears in and on several different bedding surfaces whereas the occurrence on the Rooihoogte Formation appears to be very limited. The halite casts in the upper Black Reef and lower Oaktree Formations occurs in an alternating succession of mudrock, siltstone, dolomite and chert associated with supratidal flat or sabkha deposits in the vicinity of a carbonate platform. The mudrock, siltstone, diamictite and conglomerate of the Rooihoogte Formation possibly formed in a lacustrine and fan-delta or alluvial fan environment (Eriksson *et.*

ARTICLES

al. 1995) with some deposits probably of a glacial origin (Coetzee, L.L., 2002). According to Eriksson *et. al.* (2005) the absence of gypsum and anhydrite, which is normally associated with modern halite deposits, suggests that the waters of the Neoarchaean Black Reef and Oaktree Formations was deficient in sulphate or contained a high bicarbonate to calcium ratio. Therefore with progressive evaporation most calcium was consumed before the gypsum stability field was reached. No evidence of gypsum or anhydrite was also found in the beds of the Rooihoogte formation and it is therefore also possible that the ocean or lake during deposition of the Rooihoogte Formation was deficient in sulphate. The association of halite and carbonate in the upper Black Reef and basal Oaktree formations constrains, according to Eriksson *et. al.* (2005), the palaeolatitude of the Transvaal Basin during deposition of the late Black Reef and early Oaktree Formations to subequatorial (10 – 30°).

From the above it is apparent that the sedimentary environment and palaeoceanic chemistry of the water may have been very similar during the formation of the halite casts in the early Transvaal basin and during the deposition of the Rooihoogte Formation. However there might have been a big difference with regards to the temperature and climate as suggested by the warm humid conditions suggested by the subequatoral latitude of the early Transvaal basin and the cold, possibly dryer, periglacial to glacial conditions of much lower latitude suggested by the Rooihoogte Formation deposits.

Given the circumstantial evidence it may therefore be inferred that these halite structures formed and was preserved due to a short period of seasonal desiccation, possibly in a kettle (a subglacial lake), sabkha, or small marginal marine lake, followed by frosting in a glacial or sub-glacial environment.

Pieter Bosch

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book review

Geological Wonders of Namibia
by Anne-Marie & Michel Detay.

Format: 250 x 210mm
Extent: 160 pages
Text: ± 40,000 words
Photographs: ± 100 full-colour images
Language: English
Binding: Softcover
Imprint: Struik Nature
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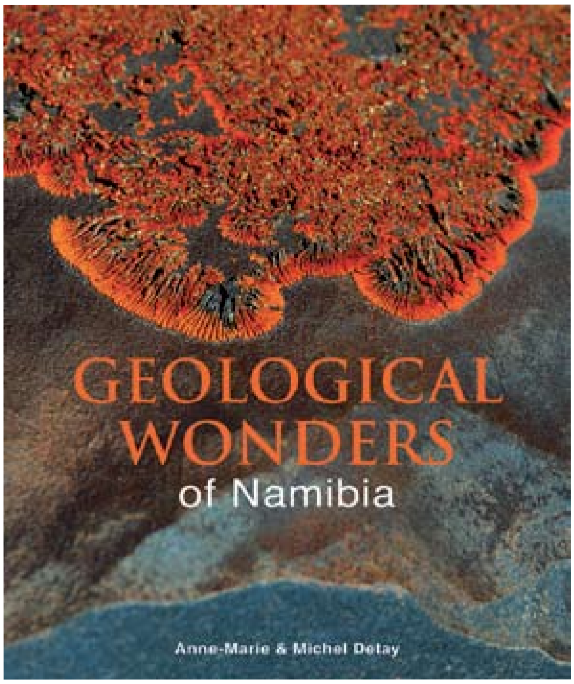
Recommended Retail Price: R 200.00



For the past decade and more, Struik Nature have been producing colour illustrated, informative books dealing with southern Africa geology and this latest addition to their natural science catalogue continues in the same vein. Regarding the authors, Struik Nature's publicity release states that French couple Michel and Anne-Marie Detay live partly in the south of France, partly in Hong Kong and spend much time on the road as travel and nature photographers and writers. Both were involved in corporate careers for many years before finally deciding to get out into the wild to capture the vanishing wonders of today's natural world. Both individually and jointly they have published a range of books, papers and articles on travel, geology and the natural wonders of many regions, including Asia, Iceland, Ethiopia and now their latest endeavor on Namibia. (Out of interest I Googled Michel Detay and see from his Researchgate site that he has written 11 books, has had work published in magazines such as Elle, Photo and Le Scienze, and describes himself as a hydrogeologist and hydrovolcanologist and is currently working in the field of volcanology. More information can be found at http://detayphoto.com/home)

This book should appeal to geologists, landscape photographers and tourists who are interested in the geology and scenery of Namibia. Michel Detay has a PhD in geology and the chapters are structured based on the ages of rock formations in Namibia from oldest to youngest, with the first two chapters briefly outlining the origin of the solar system and planet Earth. The text is geologically accurate and written in understandable simple language without diluting the geological information into meaningless layman's prose. There are 15 chapters in the book, inter alia:

- A relief map of Namibia
- Introduction: milestones of Namibian geology
- How it began (13.8 billion years ago)
- Meteorites (4.567 billion years ago)
- The oldest rocks in Namibia (2.645 billion years ago)
- Africa's largest canyon (1.4 billion years ago)
- Caves and senotes (750 million years ago)
- Fossils and footprints (750-190 million years ago)
- Snowball Earth (630 million years ago)
- Volcanoes at work (580-550 and 139-128 million years ago)
- Wutenquell's granite domes (550 million years ago)
- Bornhardts (137-124 million years ago)

- Bull's Party granites (130-110 million years ago)
- Deserts and how they formed (60 million years ago)
- Natural arena for art (35,000 years ago)
- A wealth of gems and minerals (20th Century)
- Flowing groundwater (today)
- Bibliography, picture credits and index

Not all text is purely about Namibia. For example there is general summary text at the beginning of some chapters such as "The oldest rocks in Namibia" that explains radiometric age dating of rocks; the chapter on caves provides general information on karsts and how caves form in carbonate rocks and the Snowball Earth chapter gives some insight into this phenomenon. The main text in each chapter does, however, describe Namibian geology. Each chapter is also subdivided into sections and to cite two examples "Volcanoes at Work" features the Etendeka LIP, giant dyke swarms, the Messum crater, and the Brukkaros Complex while "Fossils and footprints" details stromatolites, mesosaurus, Khorixas petrified forest, and dinosaur footprints of Otjihaenamaparero.

The text is well written throughout but it is perhaps the accompanying photographs that will appeal to a wider audience, not only to Earth scientists. Except for four images the magnificent photographs were all taken by the authors; images of the Milky Way taken under cloudless and moonless nights, cave scenery from the Dragon's Breath cave, and bizarre weathered granite, to name a few. The photos are all large format, often full page or bleeding across pages and some are half page, all doing justice to many panoramic views of Namibia and in particular, its geological terrain. Many photos feature scenes of geological interest but some also show Namibian wildlife. The photos range from micro – the book cover close-up photo of the lichen growing on pebbles at Cape Cross– to sweeping landscapes across the desert and mountainous plains. Perhaps my only criticism, and it is somewhat biased, is that the chapter titled "A wealth of gems and minerals" mainly features diamonds and does not describe any minerals as such. It has one paragraph dedicated to the Tsumeb mine, but no photographs of any of the mineral specimens which have made Namibia mineralogically world-famous, but this is a minor quibble.

In summary, the book is very well illustrated, with competent text, laid out in a logical fashion and at a recommended retail price of only R200 is well worth the money.

Bruce Cairncross

mineral scene

Stilbite from Butha-Buthe district, Lesotho

Bruce Cairncross

Department of Geology, University of Johannesburg

The Drakensburg Group basalts are known to host a variety of secondary minerals in vugs and amygdales, especially in the Eastern Cape district surrounding Barkly East (König, 1993) and at Sani Pass (Dunlevey et al, 1993). Typically, agates, chalcedony and quartz are the most common species. Less common are stilbite and other zeolites, although local mineral collectors have found these in some parts of the Drakensburg in northern KwaZulu-Natal and the aforementioned Eastern Cape district.

During the past few years, some of the finest examples of stilbite from South Africa and southern Africa in general have been collected in the Butha-Buthe district of Lesotho. Most of Lesotho comprises Jurassic basalt, with Permo-Triassic sedimentary strata forming the northwest, west and southwest fringes of the country as well as parts of the southeastern regions. It is the basalt formations in the Butha-Buthe district that have in recent times, from

2012 onwards, yielded stilbite and associated species including laumontite, apophyllite, calcite and quartz.

$NaCa_4(Si_{27}Al9)O_{72}{\cdot}28H_2O$ - stilbite-Ca,
and $Na_9(Si_{27}Al_9)O_{72}{\cdot}28H_2O$ - stilbite-Na

now form the two end members with the Ca variety being far more common. The exact species of the Lesotho stilbite has not yet been determined but is presumed to be the calcium-rich end member. The monoclinic crystals have a bright luster and most are remarkably clean and unaltered, considering that they have been exposed in outcrop. The luster is related to the degree of weathering and exposure that the crystals might have been exposed to in the basalt outcrop. The color varies from white, off-white to an attractive salmon pink on some fresh specimens, although this color is relatively rare.

Individual crystal size varies from less than 1 cm, up to 7 cm. The smaller crystals can be partially transparent while larger crystals are opaque. Specimens vary from individual crystals that are floaters as they are doubly terminated with no apparent point of contact with the matrix; interlocking crystals forming stand-alone groups without matrix; and matrix specimens where the density of stilbite crystals present varies from a few scattered crystals to surfaces virtually covered with stilbite and few associated species. Classic twinned bowtie forms are relatively common. Some of the most attractive specimens are not necessarily the large cabinet sized samples; small stilbite crystals that are separately and randomly attached to the elongate drusy quartz 'fingers' form very attractive miniature and thumbnail-sized specimens. However, cabinet-sized matrix specimens consisting of cascading stilbite crystals, many doubly terminated and openly stacked, also constitute aesthetic specimens.

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*Figure 1. Salmon-pink "bowtie" stilbite on drusy quartz from Butha-Buthe district, Lesotho, 9.4 cm.
Bruce Cairncross specimen and photo.*

*Figure 2. Lustrous, pale cream stilbite from the Butha-Buthe district, Lesotho, 9.2 cm.
Bruce Cairncross specimen and photo.*

fossilised raindrops

First find of fossilized raindrop imprints in the Moodies Group (3.2 Ga), Barberton Greenstone Belt, South Africa

During a geological excursion following a recent International Continental Drilling Project (ICDP) field workshop near Barberton, the world's oldest raindrop imprints were discovered. While attending the field trip led by Dr. Martin Homann to the so-called "Laura's Delta" of the Moodies Group on Oct. 10th, Tyler Robinson, a local geologist, came across a particular sandstone slab. Mudcracked shale topping that slab revealed upon closer examination several circular and elongate depressions 2-3 mm in diameter which were identified by Wlady Altermann as fossilized raindrop imprints, to which all field trip participants agreed.

Altermann's interpretation was strengthened by Dr. Stefan Lalonde, finding nearby another shale-coated sandstone slab with desiccation cracks developed in mud pools between symmetrical ripple troughs, but without raindrop imprints. These two loose slabs and the sedimentary structures in the over- and underlying sandstones support the overall facies interpretation of a prograding delta sequence from this unit, described by Laura Stutenbecker in her 2014 Master thesis at the Freie Universität Berlin. An interbedded tuff has been dated at 3229 ± 15 Ma (Stutenbecker, 2014). These fossil raindrop imprints are thus to-date the world's oldest evidence of atmospheric precipitation and make yet another superlative from the geology of the Barberton-Makhonjwa Mountains.

To fossilize raindrop imprints requires special conditions. A brief shower on fine-grained volcanic ash, rapidly covered by subsequent ash and quick lithification is ideal, otherwise the subtle craters will desiccate and disintegrate. Raindrop imprints are known from terrestrial deposits throughout Earth history. South Africa probably has the best geological record of very old raindrop imprints in the world. Aside from the well-known raindrop imprints first described by van der Westhuizen et al. (1989), Altermann and Lenhardt (2012) and Som et al. (2012), from

Photographs of the sandstone slab with mudcracks and some of the raindrop imprints found in the Moodies Group, Barberton Greenstone Belt (taken by Tyler Robinson)

the ca. 2.78 Ga T'Kuip section of the Ventersdorp Supergroup, raindrop imprints were also documented by Altermann and Robinson in former lacustrine strata of the Hekpoort Formation (about 2.22 Ga) during BSc Hons mapping (unpublished). In the strata of the Pongola Supergroup, ca. 2.9 billion years old, some raindrop imprints are also preserved (N. Hicks and A. Green, pers. communication).

Why are fossil raindrop imprints important? To begin with, they document the existence of an atmosphere and of a hydrological cycle, that is, of evaporation, transport of water vapor in the atmosphere and subsequent precipitation as water droplets over land, followed by runoff in streams back into the oceans. Although calculations to reconstruct the Archean atmospheric density using crater size by Som et al. (2012) appear unreliable (Kavanagh and Goldblatt, 2015), the terminal fall velocity of the largest raindrops is a function of air density and gravity. In the present-day atmosphere, the largest raindrops measure c. 7 to 10 mm in diameter and their fall velocity is ca. 9.3 m per second. Raindrops cannot fall faster or grow larger because they would break up into smaller droplets; however, they can be significantly accelerated by downward-oriented storm gusts etc. Thus, a large data set of raindrop imprints from different depositional settings over the immense Precambrian time span could conceivably contribute to a better understanding of atmospheric evolution (Cassata and Renne, 2012; van Kranendonk et al., 2015).

Photographs of the sandstone slab with mudcracks and some of the raindrop imprints found in the Moodies Group, Barberton Greenstone Belt (taken by Tyler Robinson)

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GEOHERITAGE

fish river canyon

A new hiking and geological map of the Fish River Canyon, Namibia

1. Introduction

The Council for Geoscience (CGS) and Geological Survey of Namibia (GSN) recently teamed up with legendary cartographer and author Peter Slingsby of Slingsby Maps to produce the first hiking and geology map of the Fish River Canyon. The 1:40 000 scale map is printed on both sides with the front side representing the hiking map showing the recommended route, short-cuts and escape routes, travel distances, suggested overnight camp sites, the usually-perennial pools and points of interest on a hill-shaded topographic background with 10m contours. The geological map on the reverse side matches the area of the hiking map exactly and is a by-product of a much larger 1:50 000 scale mapping program that the Council for Geoscience has been carrying out under contract for the Geological Survey of Namibia/Ministry of Mines Namibia since March 2013. The geological map is accompanied by a legend, cross-section, type photographs and a simplified geological history. The waterproof map is available at outdoor retailers or directly from Slingsby Maps (https://slingsby-maps.myshopify.com/products/ah05-fish-river-canyon).

FIGURE 1: Paul Macey, Peter Slingsby, Leslee Salzmann (CGS) and Moses Angombe (GSN) at the launch of the Fish River Canyon map at the Cape Town section of the Mountain Club of South Africa. Peter presented on the making of the hiking map and Paul presented a talk entitled "The 2 billion year Geological History exposed by the Fish River Canyon".

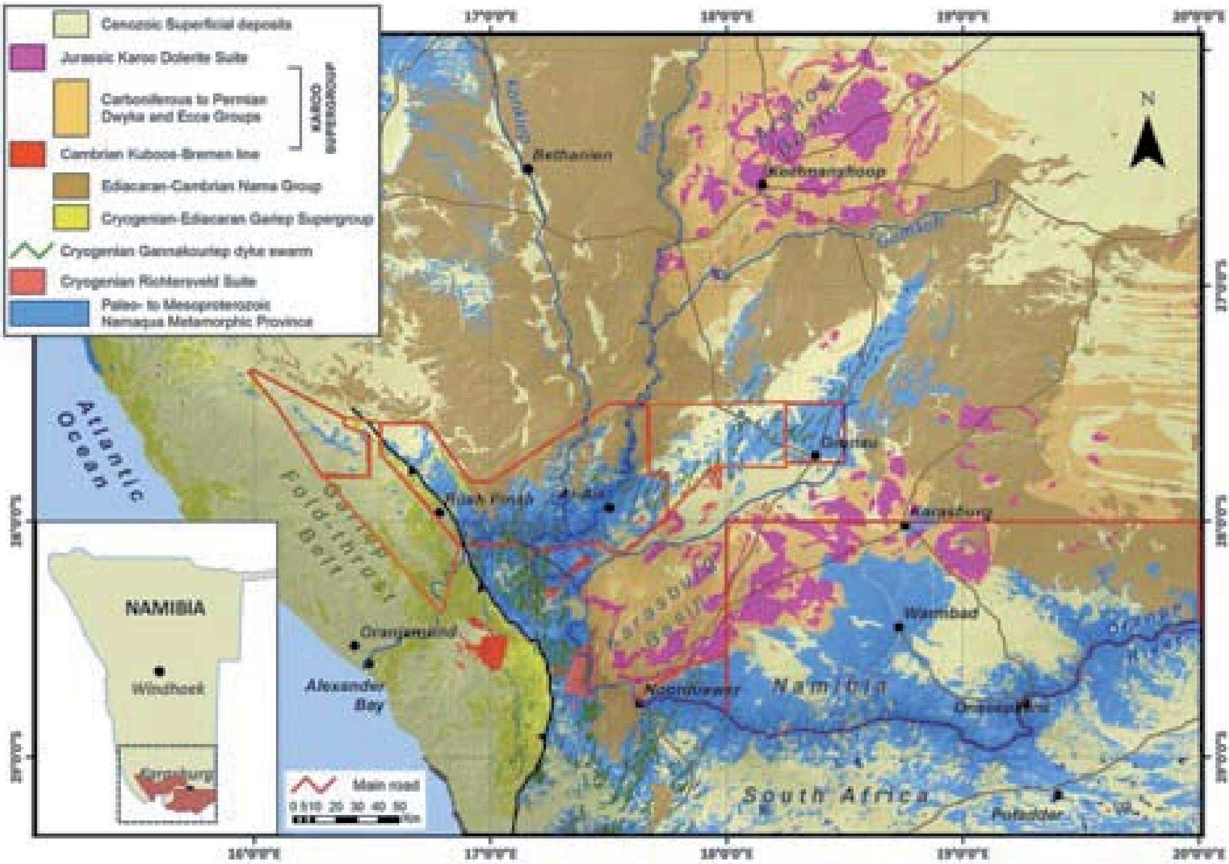


FIGURE 2: Location of the geological mapping (red blocks) overlain on a simplified geological map of southern Namibia.

2. The Southern Namibia Mapping Program

The Southern Namibia Mapping Program (SNMP) has produced new 1:50 000 geological maps covering an area of almost 30 000 km2 along the Orange River border with South Africa (Fig. 2). The program has mainly focused on producing a unified cross-border tectonostratigraphy and lithostratigraphy for the Proterozoic Namaqua-Natal and Gariep basement rocks. The mapping has been accompanied by significant amounts of research supported by 180 new U-Pb zircon, monazite and titanite ages; ~170 Sm-Nd, Rb-Sr and Lu-Hf isotope determinations, ~30 000 structural measurements, pseudo-section PT studies and over 750 whole rock major, trace and REE analyses. The results and interpretations of the mapping and research data have been written up in several geological explanations and journal articles with the final explanation due in 2018. The project also produced new 1:250 000 scale geological maps of the 2818 Warmbad sheet.

In addition to the scientific work, the program has allocated significant resources to the transfer of mapping and research skills to the GSN and CGS geologists. The training has progressed from office-based short course modules and basic field skills modules to joint CGS-GSN field mapping campaigns and geological mapping under supervision. The project has collaborated with several other research institutions (UCT, University of Stellenbosch; McGill University, Curtin University) which have resulted in the completion of 1 PhD, 3 MSc's and 8 honours projects, with 2 MSc projects in progress. This is probably the most intensive geological survey training program anywhere in Africa and has seen significant mapping skills development in the CGS and GSN geologists.

3. The Geology of the Fish River Canyon

(text from map)

Overview: The Fish River Canyon hiking trail provides a spectacular 90km-long transect through rocks formed over more than 2 billion years and several major global-scale tectonic cycles. The granites and strongly deformed metamorphic gneisses at the bottom of canyon form part of the Namaqua-Natal Metamorphic Province (NNMP) consisting of rocks

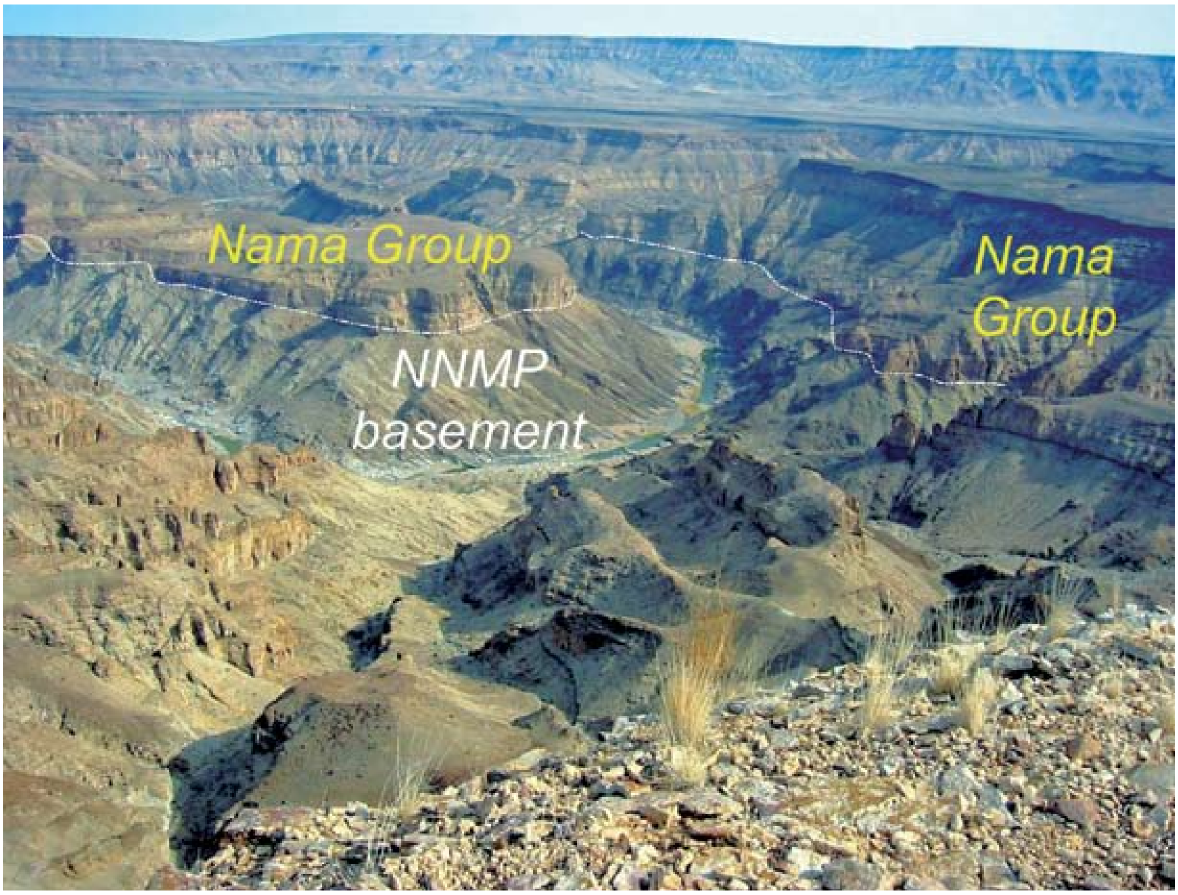


FIGURE 3: The geology of the Fish River canyon is dominated by granites and gneisses of the Namaqua-Natal Metamorphic Province (NNMP) that are unconformably overlain by the Nama Group.

formed in two main cycles (Fig. 3): the first between about 2050 and 1850 million years (Ma) ago and a later overprinting episode between about 1300 and 950 Ma ago. The younger, flat-lying sedimentary strata of the Nama Group at the top of the canyon are easily distinguishable from the NNMP basement rocks onto which they were deposited towards the end of the Gariep cycle (~850-480 Ma). Rocks formed during the subsequent Karoo cycle (~300-180 Ma) dominate the geology to the southeast of the canyon towards Noordoewer. All these rocks and structures representing two billion years of earth history played a role in the development of the canyon we see today.

Namaqua-Natal cycle:

The NNMP rocks exposed in the Fish River Canyon represent just a small part of a much larger, ~400 km wide, tectonic belt that extends across southern Africa from Kwazulu-Natal, into southern Namibia. In Namibia, the NNMP consists of ~1900 Ma old rocks that were variably deformed, metamorphosed, reworked and intruded by granitic and, to a lesser degree, gabbroic magmas during a prolonged, multiphase tectonic episode between ~1300 and 1000 Ma ago called the Namaqua Orogeny. During this period, the NNMP crust was transformed into a stack of thin but laterally extensive sub-horizontal tectonic 'slices', each tens of kilometres wide and hundreds of kilometres long, thrust on top of each other. In the Fish River Canyon area, the NW-trending Kakamas 'tectonic slice' or 'domain' was thrust south-westwards over the Richtersveld Domain. The wide zone of strongly deformed rocks sandwiched between the two domains has been called the Lower Fish River-Onseepkans Thrust Zone (LFROTZ). Most of the Fish River Canyon hike is within the LFROTZ.

The Richtersveld Domain (Fig. 4) occurs southwest of Ai-Ais and formed between ~1905 and 1865 Ma in a volcanic setting similar to the Andes Mountains of today with rafts of volcanic rocks (Orange River Group) intruded by large volumes of similarly-aged granites (Vioolsdrif Suite). Small inclusions of older (~2000 to ~2800 Ma) rocks within the sea of Richtersveld

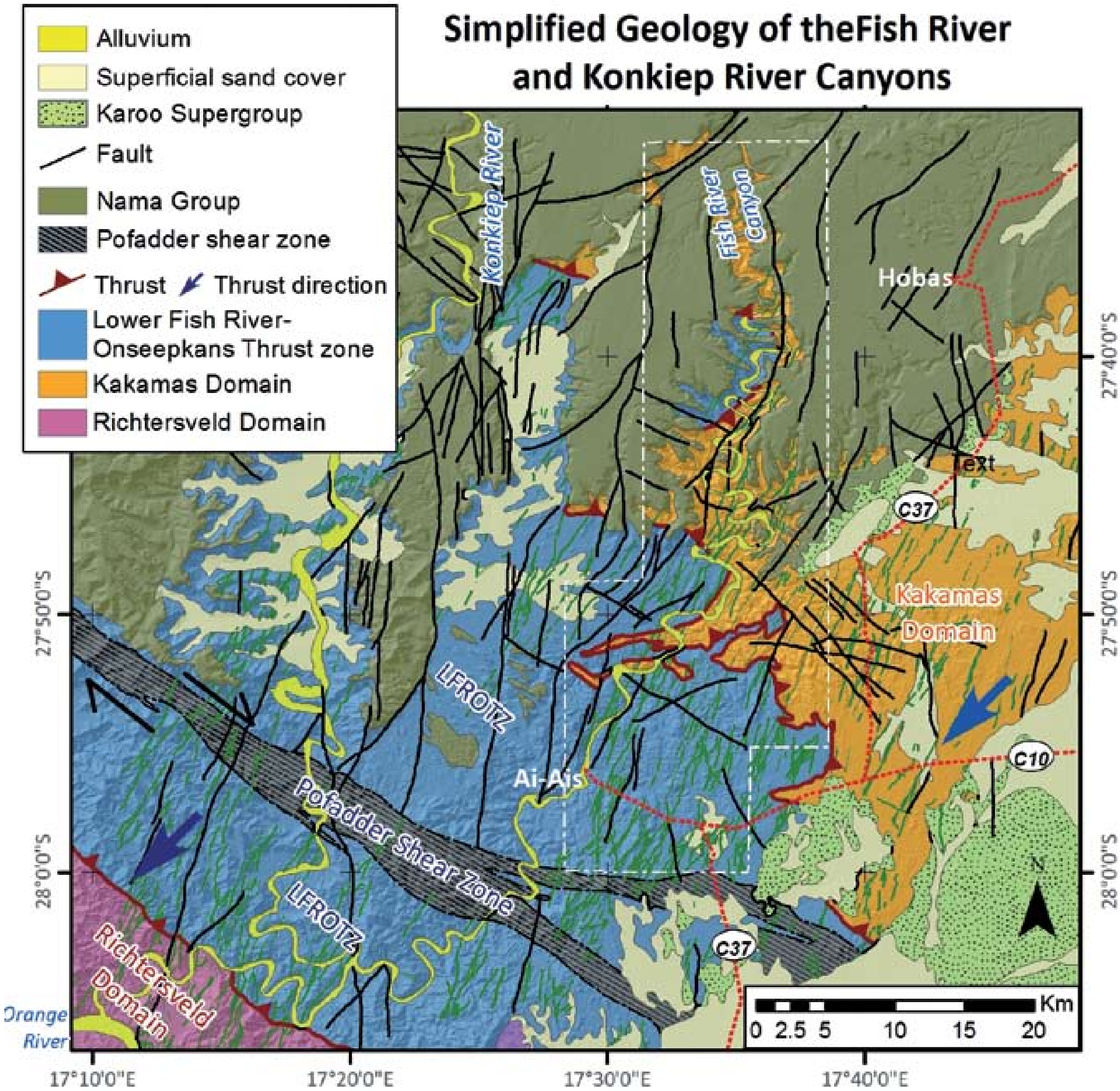


FIGURE 4: The simplified tectonostratigraphy and geology in the Fish River canyon region. The outline of the published canyon map is shown with white dashed line.

granites point to an even more ancient, now obscured, geological history in the area. During the Namaqua Orogeny, the Richtersveld Domain rocks were variably deformed and metamorphosed with the NW parts strongly reworked into gneisses at temperatures of about 660°C and pressures of 4kbar (equivalent to ~12km depth).

The Kakamas Domain consists of very different rocks that experienced a different tectono-metamorphic history. Narries Group pelitic granulites (shales metamorphosed under high grade conditions, Fig. 5) were deposited at ~1215 Ma and then intruded by granite gneisses (Eendoorn Suite) and gabbros (Jerusalem Metabasites) between 1220 and 1195 Ma. The high grade metamorphism (~780°C / 5.5 kbar) occurred at ~1140 Ma and was hot enough to melt the Narries pelites and form voluminous garnet-leucogranites (Witwater Gneiss, Fig. 5). This was followed by the intrusion of late-tectonic granites (Komsberg Suite) at ~1115 Ma.

The sub-horizontal LFROTZ comprises interleaved sheets of highly sheared gneisses from both the Richtersveld

Figure 5. Granulitic meta-pelites and leucogranites that dominate the Kakamas Domain in the Fish River Canyon

and Kakamas Domains but, importantly, also slices of other rocks not found in either domain. In the Fish River Canyon area, the thrust zone contains slices of ~1900-1830 Ma gneisses derived from the Richtersveld Domain as well as ~1320-1270 Ma gneisses (Kochas Gneiss, Attie se kop Complex, Spieelberg Meta-gabbro) and late-tectonic ~1115 Ma granites of the Komsberg Suite (Kakamas Domain). Thrusting occurred during at least two major episodes at ~1200 and ~1100 Ma at temperatures of ~640°C and pressures of ~6 kbar. Following the thrusting, the NNMP was further deformed by dome-shaped mega-folds several kilometres wide. To complicate things further, all of the rocks and structures were reworked along several major, NW-trending shear zones, synchronous with the intrusion of granite (Warmbad Granite) and pegmatite dykes at ~980 Ma.

Gariep Cycle:

A period of stabilisation, uplift and erosion followed the end of the Namaqua Orogeny but at around 800 Ma the crust began to extend and fracture. A dense swarm of black, N- to NE-striking Gannakouriep dolerite dykes intruded into the fractures cross-cutting the rocks of the NNMP (Fig. 7). These dykes form prominent features all along the Fish River Canyon. Extension continued in the region west of the Fish River Canyon where the thick sedimentary succession of the Gariep Supergroup was deposited into a series of deepening rift basins and onto the eroded NNMP basement between 750 and 600 Ma. The sense of tectonic movement changed again from extensional to compressional during the assembly of the Gondwana supercontinent (550 to 500 Ma ago) causing the closure of the Gariep basin.

The subsequent continental collision between the South American and African plates resulted in the development of the Himalayan-style Gariep fold-and-thrust belt along the southwestern coast of Africa. This major collision caused flexure of the crust in the region east of the Gariep Orogen forming several basins in southern Namibia and the Northern Cape of South

Figure 6. Subhorizontal thrust imbrication typical of the Lower Fish River Onseepkans Thrust Zone along the Fish River near Ai-Ais.

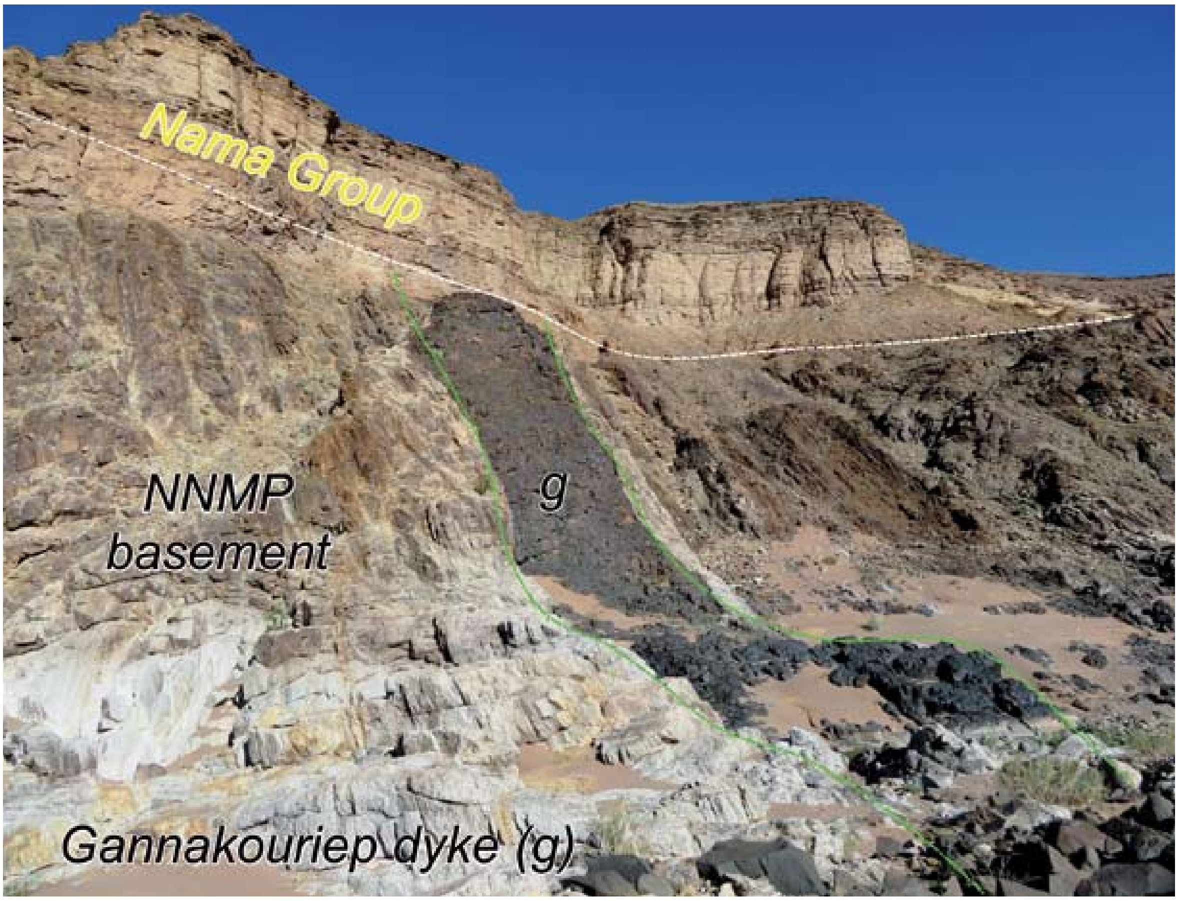


Figure 7. A Gannakouriep dolerite dyke (g) cross-cutting the NNMP gneisses and unconformably overlain by the Nama Group

Africa into which the conglomerates, sandstones, shales and limestones of the Nama Group were deposited unconformably onto the NNMP basement and Gariep rocks. The Nama Group spans the very important Cambrian – Precambrian boundary (~541 Ma) and contains the Earth's oldest recognised fossils marking the era of 'the explosion of life' on earth. Of these, the shelly fossil Cloudina, a calcified metazoan, is probably the oldest and is accompanied and succeeded by a range of spectacular soft-bodied fossils such as Ernietta, Namalia, Rangea and many others in the lower Nama succession (the Kuibis and lower Schwarzrand Subgroups). Having passed the Cambrian-Precambrian boundary, an even wider range of new life forms appears in the upper Nama Group (upper Schwarzrand & Fish River Subgroups) including Skolithos, Bergaueria, Nereites, Phycodes Pedum and many others.

Karoo cycle:

The southern supercontinent of Gondwana (comprising South America, Africa, India, Australia and Antarctica) remained tectonically stable until about 300 Ma when rift basins developed in the area of southern Namibia immediately southeast of the Fish River canyon. These rift basins formed along the periphery of the main Karoo Basin developing in central South Africa and were filled by glacial diamictites (Dwyka Group) and shales (Ecca Group) of the lower Karoo Supergroup. The NW-SE trending faults forming the margins of the rift basin were controlled by older fault structures that developed during the opening and closure of the Gariep basin. Continued extension led to the break-up of Gondwana and the separation of Africa from South America. This was associated with extensive magmatism and intrusion of dolerite sills into the Karoo sedimentary succession at around 190 Ma. The Karoo sedimentary rocks and dolerite sills dominate the moon-like landscape between Noordoewer, Aussenkehr and Ai-Ais.

Fish River Canyon:

The Fish River Canyon is the result of a combination of faulting (Fig. 8) and erosion. First, a set of sub-parallel,

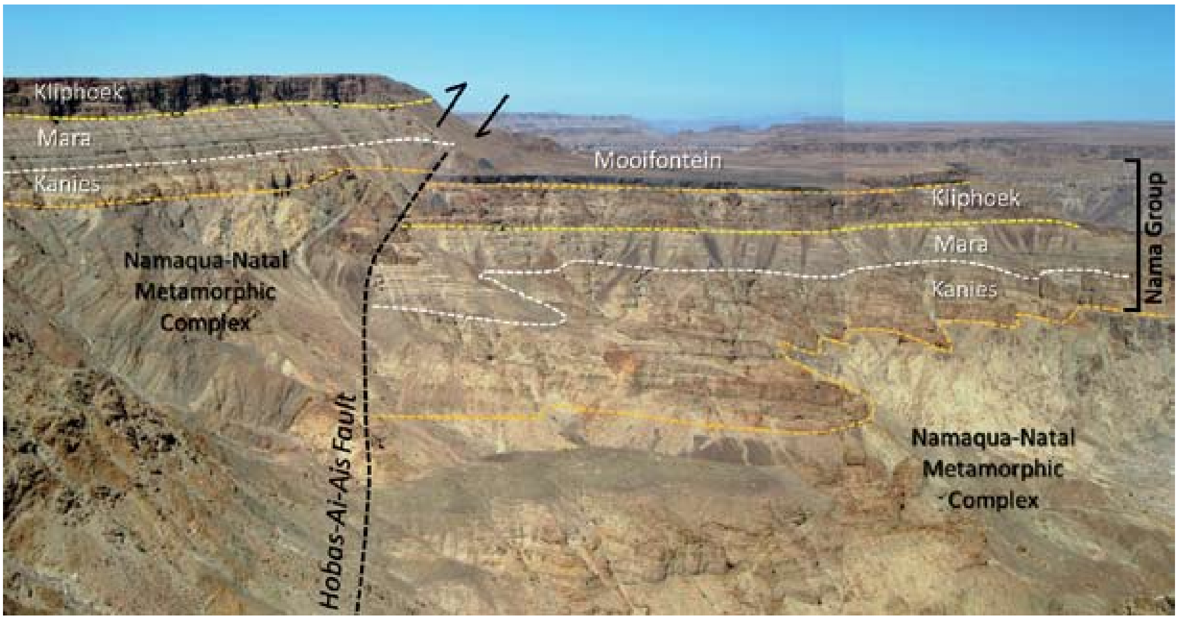


Figure 8. The displacement on the Hobas-Ai-Ais Reverse Fault is revealed by the offset of members of the lower Nama Group. Photo taken at the start of the canyon hike.

NNE-striking faults developed between Hobas and Ai-Ais causing a narrow rift valley (called a graben) to form the upper canyon. The canyon faults developed along the pre-existing fractures first formed in early Gariep rifting times and reactivated during Karoo-times. Once the graben was formed, the ancient Fish River followed this natural topographic low and over millions of years eroded the lower canyon to levels observed today, probably assisted by periods of landscape uplift. Hot springs are located along these permeable fault systems. The faults provide pathways for the hot mineral water from deeper down (2-3 km) to reach the surface of which the "Sulphur" (56°C) and "Ai-Ais" (60°C) springs are the best known along the canyon hike.

Paul Macey, Council for Geoscience

report: NSTF meeting

Will the renewed interest in science tourism be advantageous for geo-tourism? A report on the NSTF meeting on Science and Sustainable Tourism.

For years the GSSA has been promoting and developing Geotourism sites around the South Africa in an effort to bring its spectacular geological record to the attention of the general public, both locally and abroad. Recently, the concept received an indirect boost at the National Science and Technology Forum (NSTF) discussion forum on "Science and Sustainable Tourism" which was held between 3rd and 4th August 2017. The NSTF is an NGO, which works closely the with the Department of Science and Technology (DST) and represents more than 100 science and technology related organisations ranging from universities, through research institutes to the private sector, and of course the GSSA. The reason for this particular meeting was that 2017 is the United Nations International Year of Sustainable Tourism for Development, which was also used by the DST as the theme for National Science Week in early August.

At the meeting a number of speakers including officials from the DST and DT (Department of Tourism), and various academics gave enthusiastic presentations on science and sustainable tourism themes. The basic premise for science tourism is that scientific landmarks such as museums, research facilities, observatories, universities, geological and fossil sites, if correctly packaged can make very attractive tourist attractions. Often these sites are located in rural areas where tourism, if correctly managed, can result in job creation and the economic development of impoverished communities.

Science tourism is already revealing its potential with the success of attractions at the Cradle of Humankind World Heritage Site in Gauteng and at the South African Large Telescope (SALT) observatory in Sutherland. In addition, a moment of reflection will reveal that game reserves (nature based tourism) are a type of scientific tourist attraction and have been a mainstay for the South African tourism industry for many years and the majority of overseas tourists to South Africa come here to see the big five.

However, there are new and exciting forms of science tourism on the horizon. SALT has proven that Astro-tourism or Astronomy tourism and our starry Karoo skies are great tourist attractions. Billions of Rands are being invested in the development of the Meerkat and SKA radio telescope projects which will be accompanied by the development of a state of the art visitor and science centre at Carnarvon - a definite shot in the arm for this tiny town in the Northern Cape. This centre will be multidisciplinary with a focus beyond the stars to palaeosciences and cultural history. Then there is the proposal to up-grade the visitor centre at HartRAO (Hartebeeshoek Radio Astronomy Observatory). How about a centre with an Alpine roller coaster, a NASA Museum and optical/radio telescope? Of course the centre would not stand alone but could be connected to the Cradle of Humankind by an "Apeman to Astronaut" hiking trail and linked to a proposed observatory on top of Mount Kilimanjaro. Mixing serious science with amusement type pleasures seems to be a successful formula given the success of the present boat ride at Maropeng. Agri-tourism or agricultural tourism is another was another topic that was extensively discussed. Here the rural areas with their associated heritage and cultural traditions become the focus of tourist activity.

The idea of packaging tourist attractions in thematic routes is not new and at the meeting there were proposals for Astro-tourism routes, agricultural tourism routes and palaeotourism routes. South Africa's- and indeed Africa's- treasure chest of geo-heritage ranging from the origin of the continents, through the origins of life to origins of humanity is an ideal theme for a palaeotourism and geotourism route.

Numerous presentations by government departments revealed that South Africa has an impressive range of legislation, initiatives and programmes in place to stimulate and develop sustainable tourism. The problem is implementing this policy and planning for change. For example how does one involve local communities so that they can gain maximum benefits from science tourism projects? How can the tourism industry decrease its carbon footprint, and how will climate change affect the tourism industry?

One of the interesting outcomes of the meeting is that it revealed that a lot of research has already been done on how best the economic impact of science tourism can be maximised and sustained, but also a lot more research remains to be done. So in addition to pure science research there is also a considerable scope for research into palaeotourism.

At the end of the two-day meeting a number of recommendations were made, these included:

- The Department of Tourism should have a community of Practice/ Body/ Secretariat with a compendium of knowledge about all aspects i.e. science, astronomy, palaeontology, geo-science etc. to advocate and promote indigenous destinations nationally.
- Effective use of social media
- Appoint guides at all heritage sites and major tourism attractions permanently, with benefits to establish a league of inspired advocates to promote the tourism.
- Provide maps at strategic tourism information centres as well as placing corresponding signs on the routes to be travelled to ensure effective navigation.
- Attach science/tourism teachers to research chairs

GEOHERITAGE

in various disciplines in order to develop them. This will ensure that the appropriate knowledge is shared to create a large group of potential advocates in educational institutions to further the cause.

- Educate learners and educators in schools about science tourism and arrange educational tours to expose them to the tourism environment.
- Appoint well-trained guides that can transform the tour from sightseeing to educating the uninformed.
- South Africa has strong tourism and science research units/entities, however many of these operate in silos. Better communication and collaboration between different departments/sub units/ various disciplines and regions is required to achieve the best results.
- Local communities and their benefaction must be included in any research prior to developing the tourist attraction, leading to better sustainability.

An important mandate of the NSTF is to provide feedback to government. The findings of this meeting have been shared with the Department of Tourism (NDT), DST, Department of Environmental Affairs (DEA), Department of Arts and Culture (DAC) and Department of Agriculture, Forestry and Fisheries (DAFF).

More details of the meeting can be found at the NSTF website at: http://www.nstf.org.za/discussion-forum/science-and-sustainable-tourism/

Ian McKay
Education Specialist
DST-NRF Centre of Excellence in Palaeosciences

https://commons.wikimedia.org/wiki/File%3AImst_-_Alpine-Coaster_-_01.jpg

An Alpine Coaster like this 3.5 km track at Hoch-Imst in Austria could be an attraction to encourage people to visit the Hartebeeshoek Radio Astronomy Observatory in the Magaliesberg. A close connection with the Cradle of Humankind in Gauteng would create a winning tourist attraction

https://upload.wikimedia.orwikipediacommons/5/52/SA_large_telescope.jpg

The South African Large Telescope observatory is already a tourist attraction for many people to the isolated Karoo town of Sutherland.

media monitor

MINING AND EXPLORATION NEWS

Copper and cobalt

Ongoing exploration drilling at Ivanhoe Mines' Kamoa-Kakula project in the DRC has extended the length of the Kakula discovery to at least 12 km, with several holes intersecting massive zones of mineralisation between 20 and 50 m thick. A new Kakula resource estimate based on the entire current strike length is expected by the end of 2017. Kamoa-Kakula already is independently ranked as the world's fifth-largest copper deposit, and the discovery remains open for significant expansion. A preliminary economic assessment (PEA) looking at expanded production scenarios at Kamoa-Kakula is expected to be released in the fourth quarter. The new PEA is considering a mine capacity of approximately 6 Mt/a at Kakula and a similar sized mine at Kansoko Sud, giving a projected peak mine production of approximately 12 Mt/a. In addition to the new study, work on a 6 Mt/a prefeasibility study at Kakula is well under way, and will be considered as the base case for the first phase of planned development at Kamoa-Kakula.

Namibia Rare Earths Inc., which is developing the Lofdal heavy rare earths project in Namibia, is diversifying its focus through a strategic partnership with Gecko Namibia. The company will acquire a majority interest in a range of 'critical metals' projects ranging from exploration opportunities to preliminary economic assessment. The initial focus will be on the Kunene cobalt-copper project, which is claimed to be the first recorded discovery of Copperbelt-type stratabound Co-Cu mineralization in Namibia. The initial discovery, adjacent to Gecko's licenses, is being explored by ASX-listed Celsius Resources, who are conducting a 15 000 m drilling programme to complete a maiden JORC resource estimate by early 2018. Other projects include lithium (Warmbad area), tantalum-niobium (Epembe carbonatite), nickel-PGE (Grootfontein area), carbonatite-hosted minerals (Otjiwarongo), and gold (Erongo district).

Diamonds

Lucara Diamond Corp. announced a positive preliminary economic assessment for the development of an underground mine at Karowe in Botswana. Mining would be by a sublevel caving operation with all kimberlite being processed at the existing Karowe plant over a 10-year period following depletion of the current open pit operation, which is expected to occur in 2026. The highlights of the study include a total life-of-mine production of 2.72 million carats at an average grade of 12.11 carats per 100 t, with average operational costs of US$49.4 per ton, for a pre-production capital cost of US$195 million. Lucara has also commissioned its 'Mega Diamond Recovery' circuit, which is designed to maximise the upfront recovery of large stones prior to comminution, where diamond damage may occur and revenue be lost. Karowe is renowned for its production of large, exceptional-quality diamonds, notably a 1111 carat (222 g) white type IIa diamond – the second largest gem-quality diamond in history.

Platinum Group Elements

Ivanhoe Mines released the results of an independent definitive feasibility study for the planned first phase of its Platreef project on the northern limb of the Bushveld Complex. The first phase of development envisages a 4 Mt/a mechanized underground mine and concentrator producing 476 000 ounces of platinum, palladium, rhodium, and gold, plus 33 million pounds of nickel and copper per annum. The estimated pre-production capital requirement is approximately US$1.5 billion. Ivanhoe has declared an increased Probable Mineral Reserve of 124.7 Mt t at an average grade of 4.40

g/t 3PGE+Au, which would support a 32-year mine life at the initial rate of production. There is potential for relatively quick and capital-efficient expansion to 6 and 8 Mt/a, and ultimately to 12 Mt/a, using the start-up infrastructure. Shaft 1 sinking at the project has reached a depth of 500 m, and will reach the Flatreef mineralisation at approximately 783 m in the third quarter of 2018. The first concentrate production is expected by 2022.

Sibanye-Stillwater declared a mineral resource of 80.8 million ounces of platinum plus palladium at its PGM mineral assets in Montana, USA. The resource, which was estimated in accordance with the 2016 SAMREC and SAMVAL codes, comprises 49.4 million 2E ounces at a grade of 16.6 g/t in the Inferred category, and 31.3 million ounces at 17.0 g/t Measured and Indicated. The average 2E prill split at the operations is 78% palladium to 22% platinum.

RARE EARTHS

A process optimization study of Peak Resources' Ngualla rare earths project in Tanzania has shown the potential for increasing the proposed annual production of neodymium-praseodymium mixed oxide (NdPr) to 2810 t, a 16% increase on the April 2017 feasibility study, while reducing the operating costs from US$34.20 to US$32.24 per kilogram NdPr. The increased production rate is based on an accelerated mining schedule, which would reduce the operational life from 31 years to 26 years, and optimization of the flotation process to reduce the residence time. The pre-production capital cost, which includes a proposed refinery in Teeside, UK, remains unchanged at US$365 million. The project is based on an Ore Reserve of 18.5 Mt grading 4.8% total rare earth oxides (at 1% cut-off), containing 887 000 t REO, 92% of which is in the JORC Proved category. The weathered bastnaesite ore contains high levels of neodymium (0.784%) and praseodymium (0.227%), which constitute most of the market for rare earths in permanent magnets, and which are expected to contribute 90% of the predicted revenue from the project.

Zinc

Orion Minerals NL reported further positive results from the Prieska zinc-copper project in South Africa's Northern Cape Province, with an intersection of 26.8 m at 2.38% Zn and 1.22% Cu within a recently discovered extension that lies outside the historically modelled massive sulphide lens. Further drilling is being carried out to delineate this new discovery, as well as infill drilling of the Deep Sulphide Target, where the latest intersections include 4.4 m at 3.18% Zn and 0.63% Cu, and 3.6m at 5.71% Zn and 0.69% Cu. Orion has also begun a regional exploration programme with a 6025 line-km airborne electromagnetic survey (EM) over its tenements in the Areachap Belt. The belt was the focus of a short-lived exploration boom in the 1970s and early 1980s, during which several additional Zn-Cu massive sulphide and Ni-Cu occurrences were identified, but only a few of these were investigated in detail. Modern EM methods have advanced a great deal since that time, and Orion stands to benefit from its research and development on exploration techniques for massive sulphides in the Fraser Range belt in Western Australia during 2013-2014.

OTHER GEOSCIENCE NEWS

Precise dating of diamond growth is required to understand the interior workings of the early Earth and the deep carbon cycle. Radiogenic isotope studies of inclusions in combination with compositional data can constrain the conditions and timing of diamond growth, and provide information about the processes that led to the formation and modification of the lithospheric keels that underlie the oldest parts of the Earth's continents. However, owing to the low trace element concentrations and small size of peridotitic inclusions in diamonds, data from tens or hundreds of inclusions usually needs to be combined to obtain Sm-Nd isochron ages. In a recent study published in *Nature Communications* (doi:10.1038/s41467-017-00564-x), researchers from the Vrije Universiteit (VU) Amsterdam, the University of Glascow, and De Beers report Sm-Nd isotope data from 26 individual garnet inclusions from

26 harzburgitic diamonds from the Venetia diamond mine in the Limpopo Mobile Belt, South Africa. The inclusions and host diamonds were found to comprise two compositional suites formed by markedly different processes, and separated by almost two billion years – one Archaean (2.95 Ga) and one Proterozoic (1.15 Ga). This is in contrast to a previous study on pooled groups of inclusions from Venetia, which yielded an age of 2.30 Ga. The older diamond suite predates the Limpopo Mobile Belt, and is thought to be linked to volcanism during rifting of the southern shelf of the Zimbabwe Craton, while the younger Proterozoic suite formed by melt-dominated metasomatism related to the 1.1 Ga Umkondo Large Igneous Province. It is very unexpected to find harzburgitic diamonds linked to relatively recent geological activity, and since harzburgitic rocks are important markers for diamond prospecting, the findings may have implications for exploration.

Octaedral P-type diamond from Venetia with a garnet mineral inclusion
(Photo: Michael Gress, Vrije Universiteit Amsterdam).

Antony Cowey

Monument Valley, Utah - Arizona

THE GEOTRAVELLER

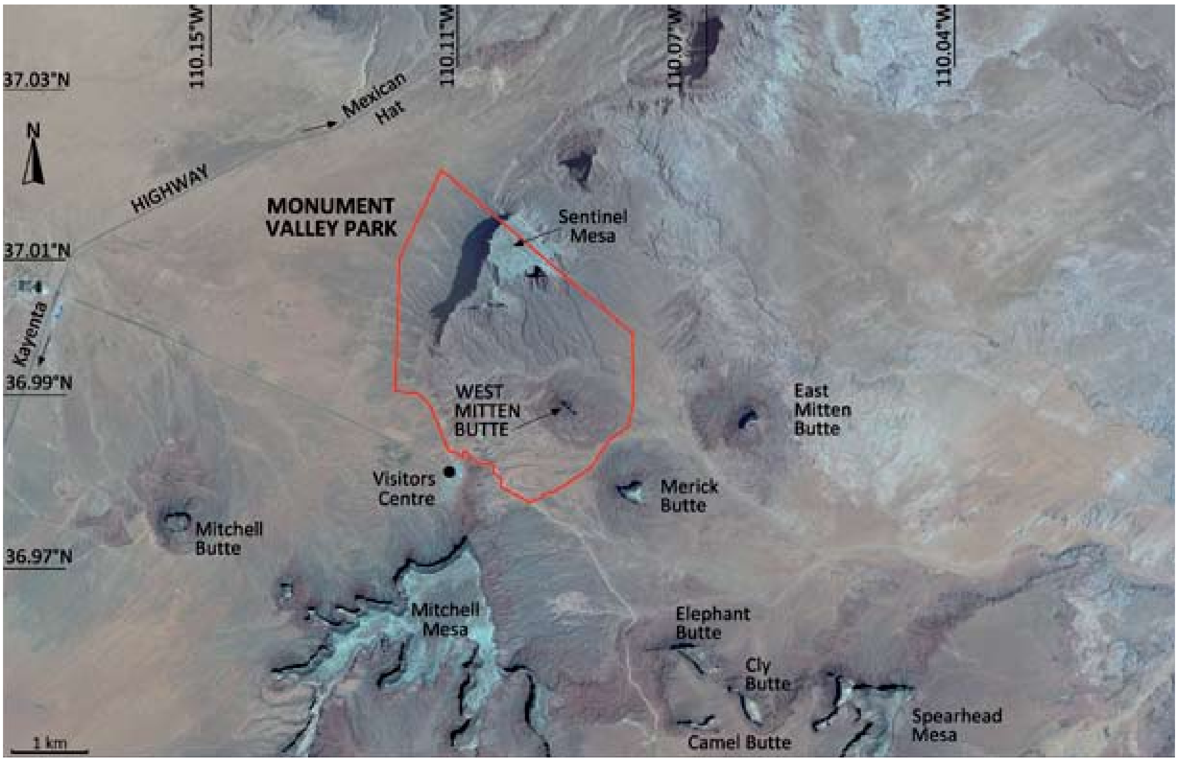
By Roger Scoon

MONUMENT VALLEY, UTAH-ARIZONA:
Mesas, Buttes, Pinnacles, and Spires in a Desert Landscape.

Monument Valley is an area of spectacular desert landscapes located on the Utah-Arizona border, USA. Despite covering only 13 km², this locality is universally known, having featured in many films and television series. The mesas (flat-topped hills), buttes, pinnacles, and columns offer an idealised view of the classic scenery for which the American West is so renowned. Some of the giant sandstone blocks rise as much as 300 m above the Colorado Plateau at an elevation of between 1.800 and 1.500 m. This area is part of an extensive, uplifted terrane, rather than a valley.

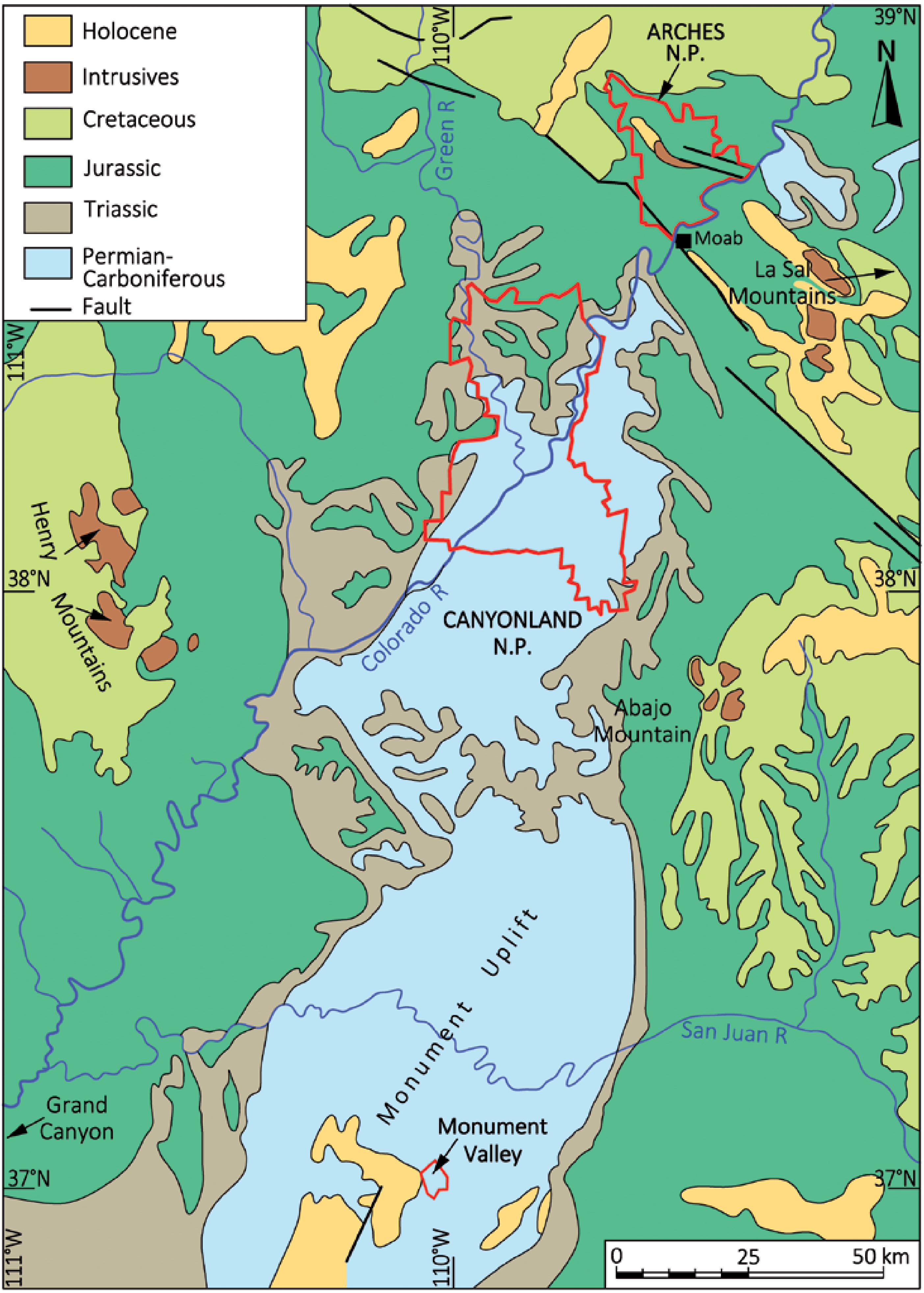
Monument Valley is located in an area controlled by the Navajo Nation. The name given by the Navajo people translates to "Valley of the Rocks", an apt description of the unusual landscape. The park is located near National Highway 163, between the northern Arizonan town of Kayenta and the southern Utah town of Mexican Hat, the latter named after a distinctive monolith. The highway reveals extensive views of the desert landscape, a seemingly endless plateau randomly dotted with mesas and buttes. Large areas are covered by red, wind-blown sands.

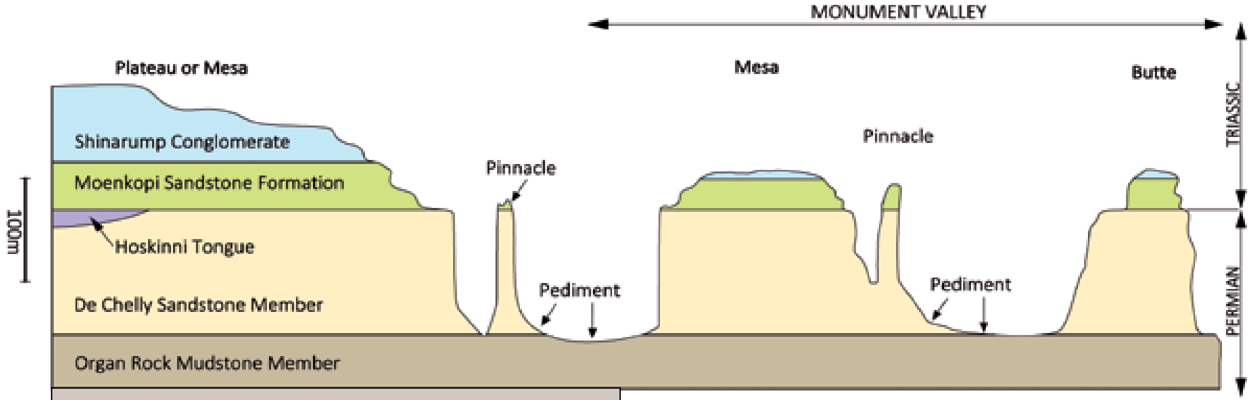
The Colorado Plateau encompasses a vast hinterland of 130.000 km², covering parts of four states, Colorado, Utah, Arizona, and New Mexico. This remarkable geological terrane contains many of the most iconic



Satellite image of the Monument Valley Navajo Tribal Park showing location of some of the well known features and tourist sites. Source: Google Earth. Rain God Mesa is located just to the south of the image.

Geological map showing location of Monument Valley and some of the other well known parks in Utah-Arizona. Simplified from maps of the Geological Survey's of Arizona (2000) and Utah (2005).


Holocene
Intrusives
Cretaceous
Jurassic
Triassic
Permian-Carboniferous
Fault
110°W
111°W
39°N
38°N
37°N
N
ARCHES N.P.
Green R
Moab
La Sal Mountains
Henry Mountains
Colorado R
CANYONLAND N.P.
Abajo Mountain
Monument Uplift
San Juan R
Grand Canyon
Monument Valley
0
25
50 km



Simplified stratigraphy of an idealised section of the Colorado Plateau in Utah-Arizona (left) and the dissected terrane of Monument Valley (right) with the characteristic mesas, buttes, and pinnacles. Large areas of the pediment are underlain by the Early Permian Organ Rock Member. The Early Permian age De Chelly Sandstone is separated from the Triassic age Moenkopi Sandstone by a 40 Ma old unconformity. Permian-Triassic boundary (the greatest mass extinction event recorded in the geological record) is not preserved.

landscapes in the USA, and also includes the greatest concentration of national and state parks. Regional uplift and erosion are key processes in the formation and preservation of the majority of the landscapes, including canyons and giant rock monoliths.

The Colorado River and major tributaries such as the Green and San Juan Rivers has dissected the Colorado Plateau into blocks separated by sinuous canyons. The Grand Canyon is located to the southwest of Monument Valley. Despite its huge size, this feature may have formed in a relatively short interval, over the previous six million years (Karlstrom et al., 2014). The Colorado Plateau has a slight westward slope. Rivers drain the Rocky Mountains and other areas of high relief, such as the Abajo and La Sal Mountains. They are swelled by snow melt in the spring, a key process in canyon formation, albeit floods are now tempered by construction of giant dams and manmade lakes, such as Lake Powell.

An intriguing feature of the Colorado Plateau is its remarkable stability; only minor deformation has affected this thick crustal block within the last 600 Ma. In contrast, surrounding terranes have been subjected to severe deformation (Flowers, 2010), e.g., the thrusting of the Rocky Mountains (to the north and east) and the lateral stretching and thinning of the Crust in the Basin and Range province (to the west and south). The dominant structural features of the Colorado Plateau are huge, asymmetrical monoclines and near-circular basins (Faulds et al., 2008). Two of the most significant features, the Uncompahgre Uplift and Colorado Lineament trend almost at right angles (northwest and northeast, respectively). The former reveals structural relief of either 2.500 m (Mesozoic strata) or 6.000 m (Proterozoic) in

View of steeply-dipping Early Permian strata on the flanks of the Monument Uplift, viewed from Highway 163.

The Petrified Forest Member constitutes the well known colourful rock layers exposed in the Painted Desert, Arizona. Source: Wikipedia.

comparison with the Paradox Basin. Structural relief in the Monument Uplift, a large north-trending monocline is approximately 2.000 m (Mesozoic).

The regional map shows that the exposed sedimentary formations in this section of the Colorado Plateau range in age from Carboniferous (Pennsylvanian) through to Holocene. The oldest formations crop out in the deep, narrow canyon of the San Juan River and progressively young westward (Baker, 1936). They constitute an average combined thickness of 2.500 m. Most formations are of continental origin; marine sediments are distinctly subordinate. The former include massive, aeolian sandstone members, such as the Cedar Mesa and De Chelly (Permian) and the Wingate, Navajo, and Entrada (Jurassic). Igneous rocks are restricted to localised outcrops in two mountainous areas; they are of either Jurassic or Cretaceous age.

One of the largest basins in the region, the San Juan contains enormous oil and gas reserves and is currently also being exploited for shale gas methane. Sections of the Monument Uplift were mined between 1945 and 1967 for uranium; scattered deposits of vanadium-copper occur to the south of Monument Valley. These deposits occur in the Lower Triassic age Shinarump Conglomerate (see below) and can be envisaged as part of the regional orefield associated with the Colorado Lineament.

Uplift and tilting of the Colorado Plateau have been ascribed to tectonic activity which commenced in the Mid Cenozoic, at approximately 20 Ma. Uplift triggered intense erosion with major rivers forming large canyons, mostly during the past 6 Ma. Some sections of the plateau located between canyons are preserved as mesas. Invasion of the lithosphere due to mantle upwelling, with the cooling asthenosphere expanding the overlying strata are thought to be responsible for the uplift.

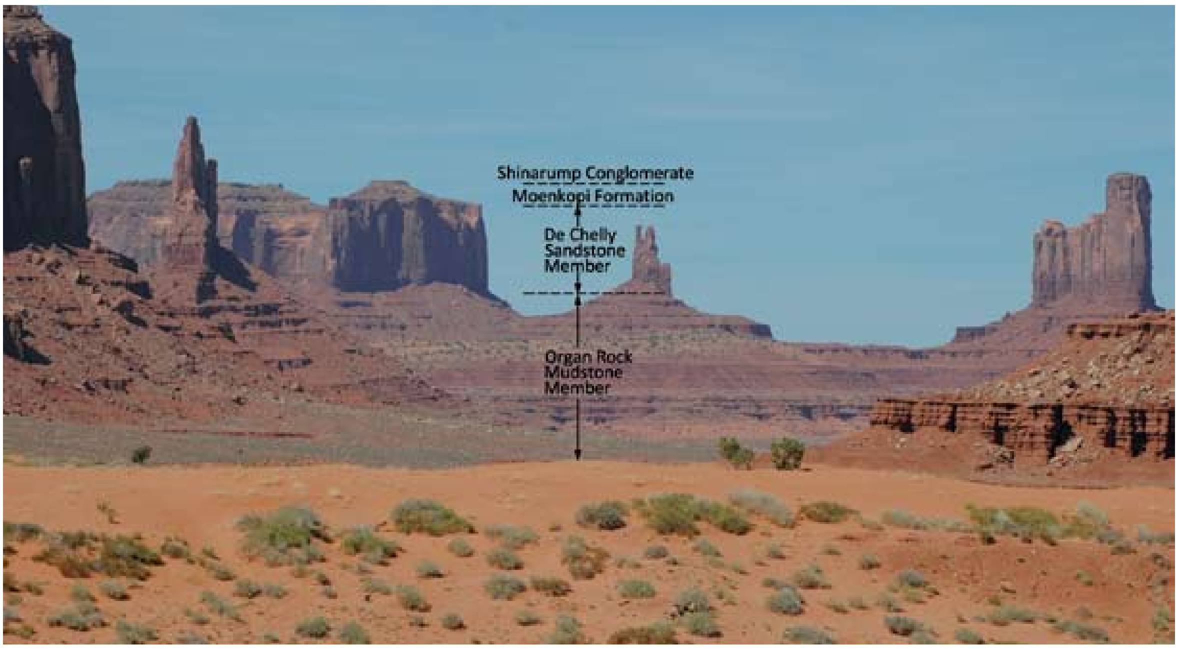
The geology of the area was described in great detail by Baker (1936). Erosion of the thick layers of sedimentary rocks, dominantly sandstone with lesser mudstone and siltstone, has dissected the mesas into buttes, pinnacles, and spires. This section of the Colorado Plateau is mostly covered by thick layers of Permian and Triassic age sandstone and mudstone. The mesas and buttes at Monument Valley are prominently stratified. Bedding is near-horizontal. Four layers can be identified in most of the features. The labels attached to the photographs here are based on Baker's (1936) stratigraphic column and his Plate 4A, a panoramic section of Monument Valley.


View of Monument Valley from the gravel road that accesses the park (looking east) reveals the desert landscape typical of southern Utah and northern Arizona. The flat-lying nature of the Permian and Triassic strata is visible in the buttes, from left to right, West Mitten, East Mitten, and Merrick.

The bases of the mesas and buttes are comprised of the Organ Rock Member, part of the Early Permian age Cutler Group. These strata underlie large parts of the regional pediment. The Organ Rock Member is dominated by red-coloured, finely bedded mudstones and siltstones. They are distinctly stratified. These relatively soft rocks are readily eroded. The red colouration is ascribed to the high content of iron oxides in the weathered rocks. Some areas reveal a blue-grey colour due to manganese oxides. These strata were deposited by meandering rivers that eroded older, Palaeozoic age rocks, as well as of the crystalline Basement, including the palaeo-Rockies.

The Organ Rock Member is overlain by the De Chelly Sandstone Member (estimated age of 280 Ma), the uppermost member of the Cutler Group. The De Chelly Sandstone reveals both extensive and high angled cross-bedding, characteristic of wind-blown sands. This hard, resistant rock constitutes the vertical faces that characterise the mesas and buttes. Some rock faces are entirely massive. Others are prominently jointed. The jointed sections of the De Chelly Sandstone erode to form massive slabs with near-vertical pinnacles and spires.

The De Chelly Sandstone Member is unconformably overlain by the Moenkopi Formation, which has a Lower Triassic age of approximately 245-240 Ma. This unconformity, despite the absence of a palaeosol and the non-angular nature represents approximately 40 Ma. The Moenkopi is dominated by rather fissile sandstones which



View looking south through the "North Window" at Monument Valley between the Cly Butte (left) and Elephant Butte (right). Background includes pinnacles of the Rain God Mesa with the Thunderbird Mesa in the far distance.

The upper part of the sheer face developed on the De Chelly Sandstone Member reveals distinctive erosion pits (or holes). The caprock to the mesa is comprised of the resistant Shinarump Conglomerate.

are readily eroded. They are underlain in some areas (but not Monument Valley) by the Hoskinni Tongue, a locally developed formation ascribed to the Permian. The Moenkopi is in turn unconformably overlain by the Shinarump Conglomerate. The latter has an estimated, mid Triassic age of 225 Ma.

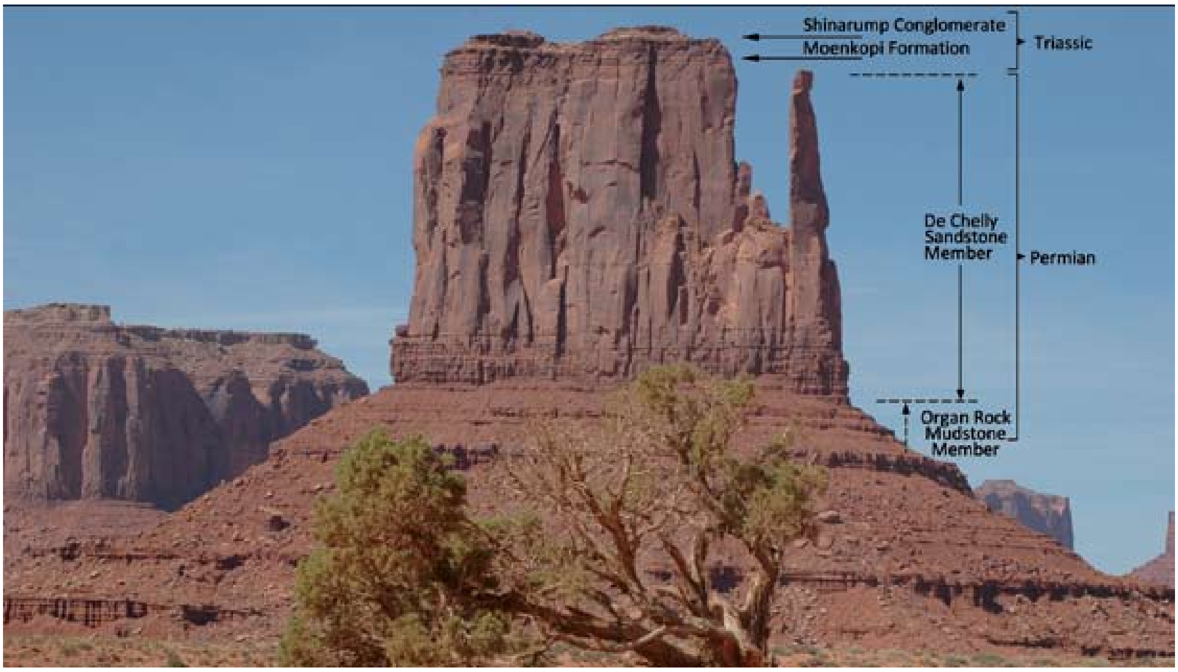
The Shinarump Conglomerate consists of resistant, coarse-grained sandstones and pebble beds, the caprock to many of the erosional relics at Monument Valley. The hard, siliceous cement or matrix is extremely resistant. The Shinarump Conglomerate is widely developed in the Colorado Plateau and caps many of the larger mesas. It is preserved on surface over large areas, including, for example, the canyon rimrock at the Canyon De Chelly National Monument.

The Permian age rocks of the Colorado Plateau probably accumulated from either palaeo-rivers or wind-blown sands. The area was subsequently inundated by an Early Triassic Sea (accumulation of the Moenkopi Sandstone). By the Mid Triassic, however, this sea, which was located on the western edge of the North American continent, was retreating northwest, resulting in deposition, first, of the Shinarump Conglomerate and, second, of the Petrified Forest Member (215 Ma) (Blakey, and Ranney, 2008). The latter constitutes the well known colourful rock layers which are exposed in the Painted Desert, Arizona and are preserved in the Petrified Forest National Park. This thick succession of fluvial and aeolian deposits is part of the Late Triassic Chinle Formation, which is widely developed in Utah and Arizona. The Shinarump Conglomerate may constitute the basal component of the Chinle; others consider it as a discrete Member.

The Monument Valley Navajo Tribal Park is accessed from a gravel road that winds over 27 km within the park. Many of the natural structures have been named by the Navajo for spiritual references. Others were named by early settlers, including prospectors, such as Merrick and Mitchell. Two of the most well known localities are the West and East Mitten Buttes. The visitors centre at the park includes a museum, the historic Gouldings Trading Post. The original trading store operated from the 1920's through to the 1960's. The first contacts with the film industry were made by Harry Golding.

The most well known of the monuments include the West and East Mitten Buttes, Merrick Butte, Three Sisters, John Ford's Point, Camel Butte, the Hub, the Totem Pole, and the Thumb. Areas that offer famous views include Artist's Point and North Window. Rain God Mesa, located to the south of the park holds special significance for Navajo spiritual ceremonies. A short hike (5 km) round the West Mitten Butte is the only walking trail which doesn't require a local guide. Other areas of interest, such as Monument Pass and Hunt's Mesa are outside the park and an additional permit is required as these are remote areas. An area which is of particular interest is Mystery Valley which includes the Honeymoon Arch, a natural sandstone structure as equally spectacular as those in the Arches National Park.

The mechanism as to why the Colorado Plateau preserved its structural integrity and remained a single tectonic block, even during the Laramide Orogeny



The name of the West Mitten Butte, the most photographed of the buttes at Monument Valley is derived from the pinnacle on the southeastern side. The four members or formations which characterise the mesas and buttes are clearly visible.

(70-40 Ma) which deformed the adjacent terranes, is not understood. This feature, however, together with the uplift and subsequent erosion is largely responsible for creating the characteristic landscapes of Utah and Arizona, including Monument Valley. Many of the scenic landscapes of southern and eastern Africa are also found in terranes which have been subjected to extensive uplift and erosion.

Photographs by the author

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The pinnacles grouped to the south of Spearhead Mesa, which include the 137 m-high "Totem Pole" (right), are dominantly comprised of the resistant De Chelly Sandstone Member.

(a) The vertical jointing which characterises the De Chelly Sandstone Member results in formation of pinnacles and spires at Monument Valley: (b) Giant slabs develop between the vertical joints.

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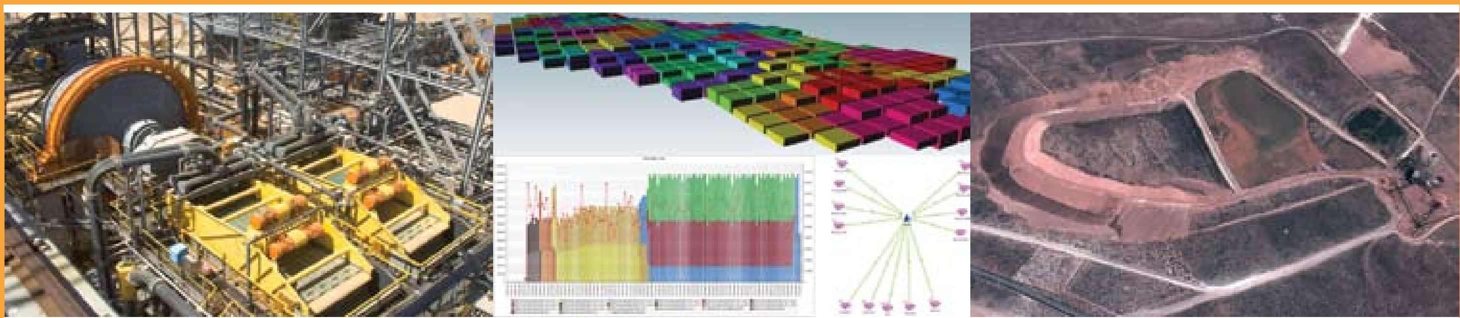

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