the Geode

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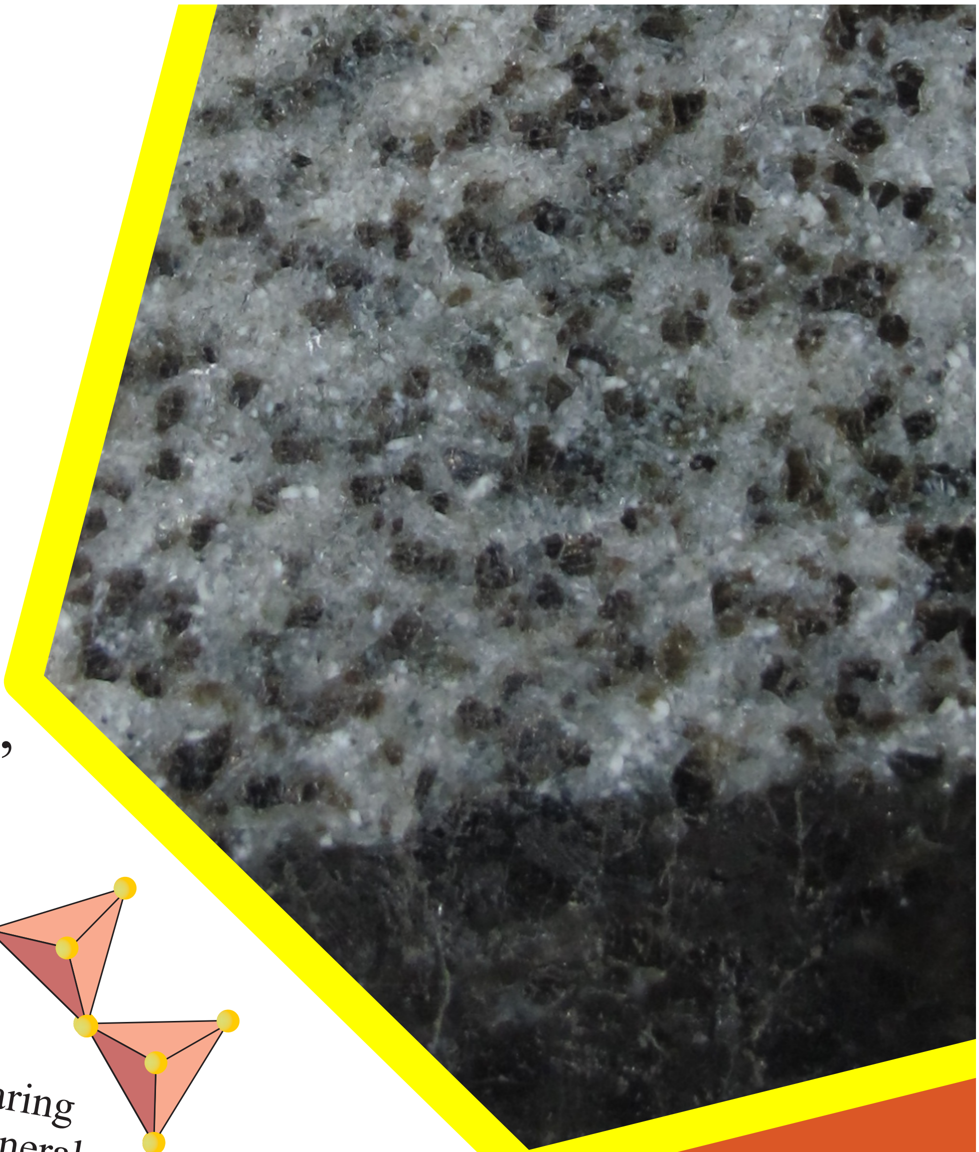
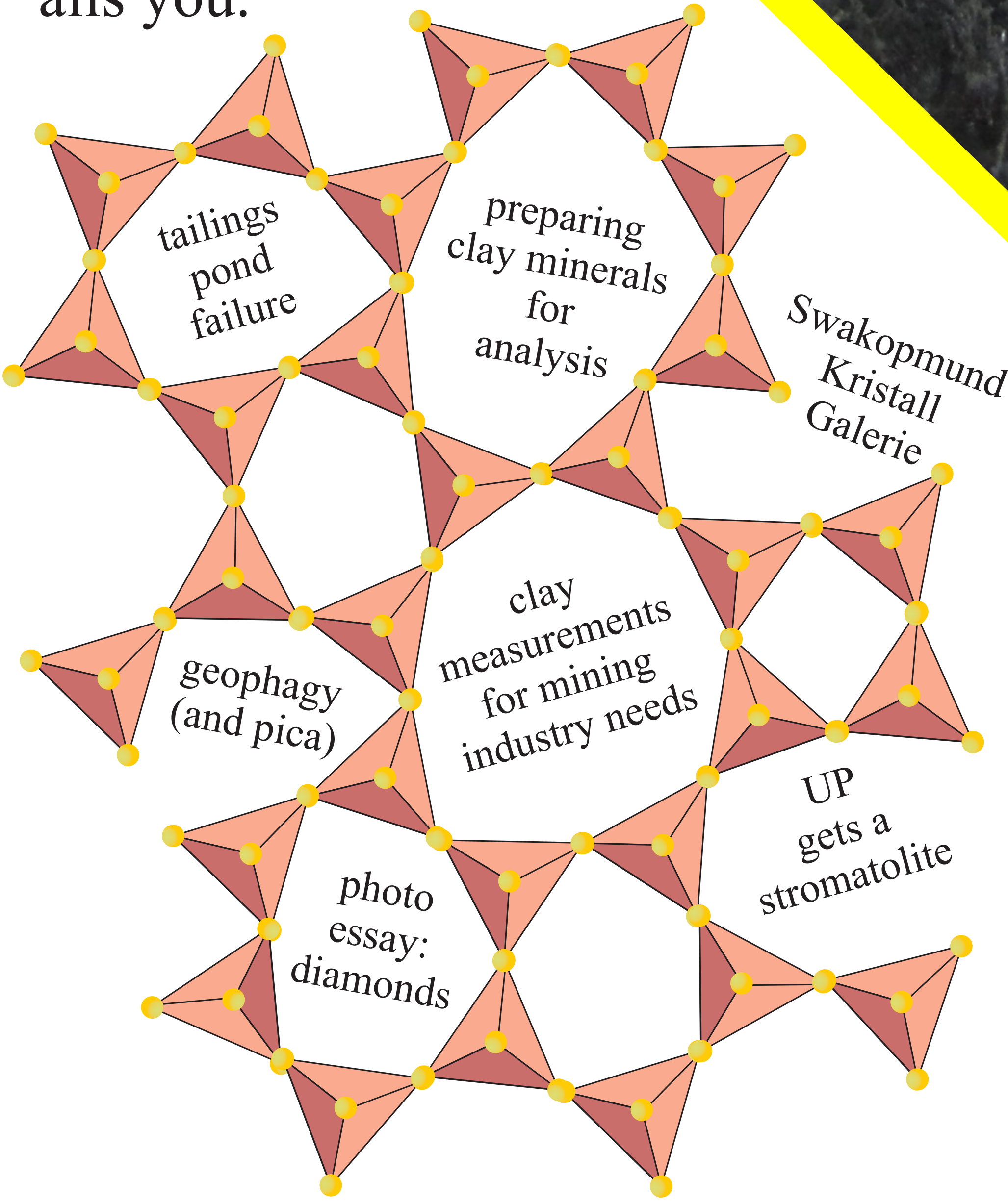
MINSA
Mineralogical Association of South Africa
A division of the GSSA

Clay minerals: awkward to analyse, a nuisance to prepare, but good for what ails you.





The GEODE

Minsa Newsletter
Volume 9
No. 4
December 2022

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Mineralogical Association of South Africa
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NEWSLETTER
Volume 9 No. 4
December 2022

2022: IMA's Year of Mineralogy

Contents

Next issue theme:

Geoscience publishing: pitfalls, priorities and permutations.
(see also pg. 17)

Forthcoming Events & Attractions

For events missing specific dates: Minsa will let you know! Watch for e-mailed announcements. All dates are 2023 unless otherwise stated.

- GSSA/IMSG combined meeting, 11-13th January 2023 in Stellenbosch. See also their website at https://allevents.eventsair.com/geocongress/.
- 2023 Powder Diffraction Conference, 16-21 April, 2023, Midgard Country Estate, Namibia.
- 9th International Platinum Symposium, 3-7 July 2023, Cardiff (U.K.).
- 5th Southern African Minerals Symposium, 25th Nov. 2023?

The Editor's Site

Steve Prevec
Geode Editor

In this final issue of the Geode for 2022, we can say a fond farewell to our "year of glass" and look forward to what the UN comes up with next for us. In this issue we feature clay minerals; how to prepare them for analysis, why we should care anyway, and what happens when we put them in our mouths.

First up is a rather unconventional President's column, where our President has been inspired by the geological elements in the film version of Stephen King's short story, The Shawshank Redemption. You never know when geology might come in handy, would be one message to take away.

Pam Allison, who contacted me to track down an analytical service for which I was immediately able to make use of the March 2022 Geode to assist her, kindly sent us an introduction to the impressive Kristall Galerie in Swakopmund, Namibia, featuring a suggestive amethyst along with some welcome promotion of the gemstones and other geomorphological delights of Namibia's coastal area. Our thematic series features a short introduction from me, along with some revealing clay mineral SEM and TEM photos from Lesley Andrews. Archie Corfield provides insights on the minefield that is clay mineral preparation for in situ analysis, Dipo Omotoso provides an applied and insightful introduction to clay mineral analysis methods appropriate to the mining industry, and Andrew Vietti offers us some insights as to why someone would want to do these things, through a case study of what can happen if you don't understand your clay mineral properties: you can get a tailings dam failure. Finally, Igor offers us a review of the medicinal properties of clay minerals for humans. There are some other odds and ends, a photo offering on diamonds from Bruce Cairncross, and this issue's crossword on 'minerals you can eat'.

And that's the Editor's site, until next year.

Steve Prevec

From the Chair

Get busy living or get busy dying.

…That's goddamn right.

"Red" from The Shawshank Redemption

I've felt for a while that the only stories worth telling have encompassed some kind of a fight for freedom, in the loosest sense, whether that be freedom from mind (The Matrix?), freedom from bondage (The Hurricane?), freedom from self (Scent of a Woman?), freedom from oppression (Braveheart?), freedom from malice (The Dark Knight?), freedom from limitation (Phenomenon?) and any number of such like. But "The Shawshank Redemption" has always had a special place in my heart…I think it's that place where my hope resides. As the protagonist, Andy Dufresne (played by Tim Robbins) points out on two separate occasions: "That there are places in the world that aren't made out of stone. That there's something inside that they can't get to, that they can't touch…that's yours…hope." And "Remember, Red (played by Morgan Freeman). Hope is a good thing, maybe the best of things, and no good thing ever dies." Indeed perhaps this movie is not so much about escape from bondage but freedom from despair…in a word "Hope".

Igor Tonžetić
Chair, 2022-23
Minsa Executive Committee

It's also a movie about rocks (so to speak). At the beginning Andy asks Red, "I wonder if you might get me a rock-hammer?" Red replies, "What is it and why?" After a line of questioning, Andy concedes, "Fair enough. A rock-hammer is about six or seven inches long. Looks like a miniature pickaxe…for rocks." Red replies "Rocks?" Andy then proceeds to toss a pebble to Red with Red exclaiming "Quartz?" Andy agrees, squats and picks up some more dirt, "Quartz…and some mica…shale…limestone."

Another subplot sees Andy trying to obtain rocks to carve a chess set. He asks Red for help in obtaining the rocks:

ANDY: Chess. Now there's a game of kings. Civilized... strategic...

RED : ...and a total f-ckin' mystery…I hate it.

ANDY: Maybe you'll let me teach you someday. I've been thinking of getting a board together.

RED: Hey, now you're talking to the right man. I'm the guy that can get things. Right?

ANDY: We might do business on a board. But I want to carve the pieces myself. One side in alabaster... the opposing side in soapstone. What do ya think?

RED: I think it'll take years.

ANDY: Years I've got. What I don't have are the rocks.

After Andy lands up in the infirmary:

RED: I'm thinkin' Andy could use a nice welcome back when he gets out of the infirmary. Man likes to play chess. Let's get him some rocks.

Which leads to some of Andy's fellow inmates, doing some manual labour in the fields. Heywood turns up a rocky chunk, and quickly shoves it down his pants (it would otherwise be considered contraband). He manoeuvres to Red and the others, pulls out the chunk and shows it to them.

HEYWOOD: I got one…I got one…look.

RED: Heywood…That isn't soapstone.

FLOYD: It ain't alabaster either.

HEYWOOD: What are you?...A f-ckin' geologist?

SNOOZE: He's right, it ain't.

HEYWOOD: Well…What the hell is it then?

RED: Horse apple.

HEYWOOD: Bullsh-t.

RED: No…horsesh-t. Petrified.

But the absolute cap on geology is Red's soliloquy towards the end:

"Oh, Andy loved geology. I imagine it appealed to his meticulous nature. An ice age here, a million years of mountain-building there...Geology is the study of pressure and time. That's all it takes, really. Pressure…and time. That… and a big goddamn poster."

I'd like to think that what saw Andy through was his tenacity…not his hardness. And I'd like to think that we as geologists fundamentally understand the difference between the two. Not all minerals that are hard are tough…and not all minerals that are tough, are hard. There's a life lesson in there somewhere, for all of us.

There has been one glaring and irritating failure in my dispensation (despite all the self-imposed mandates I feel I have achieved) …I have not been able to grow the association…and for the life of me, I don't understand why or how. I know we offer quality excursions, quality presentations, quality newsletters, quality workshops, and quality sessions at conferences. Admittedly, COVID (I would hazard to qualify that as "the political handling of COVID" rather) put a dampener (hydrothermal alteration?) on our activities, though I would suggest that we were still at least the second most active division or branch of the GSSA. I have suggested in a previous column (The Geode Vol. 5, No.4, Dec 2018) that there is no legitimate reason why Minsa cannot reached a membership of 250. And anecdotally I know this to be true. I see and have seen new faces at said excursions and presentations and yet know these people are not members of Minsa. And we humour them in good faith.

So…to those people who come to our presentations, who take part in our excursions and who read our newsletters (yes, I know you read our newsletters); I implore you…in the name of honour or integrity or virtue or honesty or principle or whatever you want to call it…please consider joining Minsa officially. It's the "barite" thing to do.

Igor Tonžetić

Minsa News

Odds and Ends

(I haven't yet contrived a cutesy mineralogically-derived name for this section of assorted Minsa-related news items from the past quarter. Submit your bright ideas to the Editor and win…something).

Igor mounts a stromatolite

Igor demonstrates the utility of the latest instalment to the UP rock garden; stromatolite, from the Transvaal Supergroup. Visitors are advised not to attempt this pose without prior approval from their doctor.

Articles

Kristall Galerie - A Hidden "Gem" In Swakopmund

Swakopmund is a coastal city, four to five hours drive from Windhoek, the capital of Namibia. If you are driving through Namibia on the way to Etosha National Park, Swakopmund is well worth a visit. There are many interesting things to do in and around Swakopmund, including visiting the Spitzkoppe granite boulders nearby, tandem skydiving, investigating prehistoric Welwitschia plants in the desert or visiting the Kristall Galerie (Figure 1), which houses the largest quartz cluster on display in the world (Figure 2). It is quite impressive, standing 3.5 m high by 3 m wide and weighing 14,100 kg. It is estimated to be about 520 million years old.

Figure 1: Kristall Galerie, Swakopmund.

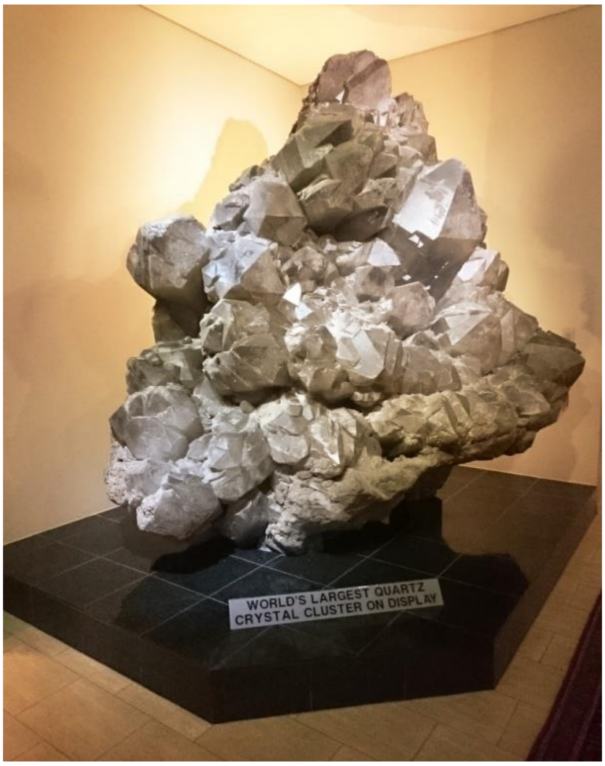

Figure 2: The world's largest quartz crystal cluster on display.

Figure 3: Exquisite purple amethyst crystals.

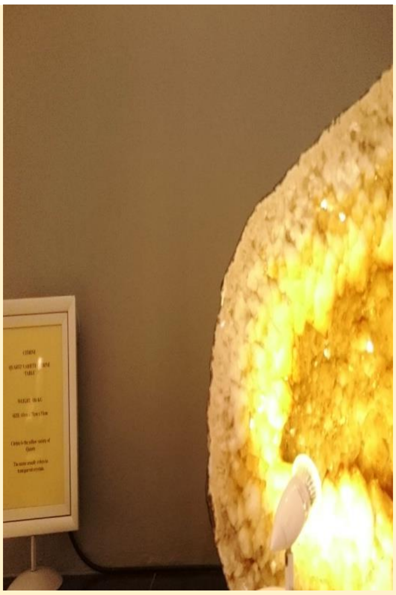

Figure 4: Yellow citrine quartz crystals.

Figure 5: A large "desert rose" type of crystal cluster of gypsum.

The yellow derives from "a submicroscopic distribution of colloidal ferric hydroxide impurities" according to Deer, Howie & Zussman. Iron in another form is also responsible for the purple of amethyst (*Ed.*).

Figure 6: Tourmaline - a six-member ring cyclosilicate that binds to three triangular borate ions and other attached mineral elements.

Tourmaline is one of the gemstones typically found within granite or marble. It is comprised of long columnar crystals that are triangular in cross-section. Tourmaline is composed of a six-member ring cyclo-silicate that binds to a large cation (e.g. Na), and to a layer of metal ions and hydroxyls or halogens, which themselves bind to three triangular borate ions. Units join together to form columns running the length of the crystal.

Tourmalines are found in a variety of colours depending on the attached elements - thirty seven of them. Crystals are found in multiple colours, from pink-red, to green, colourless, blue and yellow. The "watermelon tourmaline", which is highly prized in jewellery manufacture, is green on the outside and pink on the inside. The pink colour is due to incorporated Mn^{2+} which darkens on exposure to natural gamma radiation within the granite, and with gentle heating.

Other gemstones commonly found in Namibia include topaz, garnet, aquamarine, amethyst and Namibian "jade", a green-coloured fluorite.

Not only is Namibia a land rich in gemstones, diamonds and gold, but it also boasts a diverse range of minerals that are mined. Mining is the largest contributor to the Namibian economy, standing at about 25%. There are many natural resources including copper, lead, tin, lithium, cadmium, zinc, vanadium and uranium.

In fact, the Husab open-pit mine in Namibia, is the third largest uranium mine in the world, and it is jointly owned by a subsidiary of China General Nuclear Power Co. The fifth largest uranium mine in the world, Rossing Mine, is also located in Namibia and is now jointly owned by a Chinese company.

Figure 7: Towering iron-rich sand dunes in Sossusvlei, Namibia.

Figure 8: Rocky outcrops of the Spitzkoppe, near Swakopmund.

The world's largest and oldest sand dunes are to be found in the Namib-Naukluft National Park in Namibia. The vivid pink to orange colours of these towering dunes is due to the high concentration of iron in the sand and its related oxidation processes. With an average rainfall of about 2 mm per annum, the desert plants and creatures have adapted to living in this dry, arid environment, utilising moisture from the fog that rolls in from the adjacent cold Atlantic Ocean.

Namibia is a place that is well worth visiting. Many of its regions boast rich geological landscapes, including the "Spitzkoppe" near Swakopmund which comprise towering granite boulders that are a sight to be seen.

Contributed by Pam Allison
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The December issue theme: Clay minerals: what are they good for, and how do we analyse them?

Clays: an editorial introduction

Clay minerals might constitute a few slides in your introductory mineralogy course, and then be largely neglected in a traditional geology curriculum as a fringe group of phyllo (sheet) silicate minerals that destabilise as soon as the temperature surpasses diagenesis, and only appear otherwise to cloud up your alkali felspar grains, BUT they are a mineral group with broad applications, sufficiently specialized that they have their own dedicated research journals. How many mineral groups can claim that? And as for analysing them, you can't just slap them on the rock saw and get to cutting and polishing. Clay minerals are soft; very soft, and as the byproduct of low-temperature alteration (typically of feldspars) or crystallization from low-temperature diagenetic fluids, they are often crumbling in your hand. They do not polish well in diamond grit, either, on account of their morphology (sheets) and their softness. Before any cut penetrative handling for grain mounts even starts, impregnation with epoxy resin may be required.

Alternatively, you might rather just sprinkle some easily obtained (no crushing needed?) clay mineral powder onto a glass slide and let the XRD spit out some mineral diagnostics for us. As it happens, this can generate some useful data. However, to effectively interpret it, the sample needs to be properly prepared, and then different preparations compared, in order to effectively discriminate the various sheet silicates that commonly coexist (including micas) in nature. The preparations involve heating to dehydrate the layers, and then hydration of the layers (usually using ethylene glycol or a variant thereof, to keep the layers hydrated and expanded during analysis). The mineral structural response to heating to higher (medium grade equivalent) temperatures also serves to distinguish various micas (unresponsive) and clays (variably responsive).

For a peek into the utility of clay minerals and their applications in industrial geoscience, among other things, four articles are featured here. Read on.

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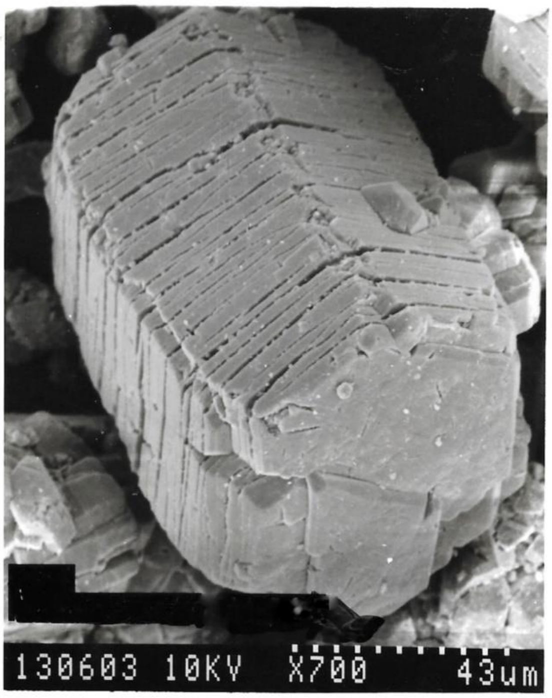
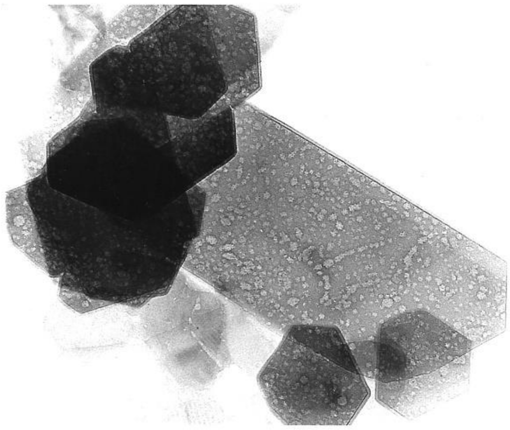
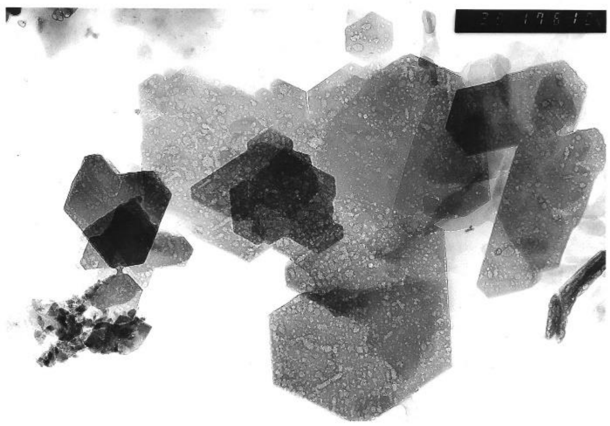
and some illustrations:



An SEM image shows the "sliced bread" appearance of kaolinite upon heating and removal of the water-bearing layers. The rest are TEM pics. We used the <2um fraction and suspended the tiny crystals on a coated TEM sieve. We did not have any analytical attachment to check, but I suspect that the mottles were more of an optical (or should I say electron) effect rather than discrete phases. I have no scales on the KZN kaolinites, but the largest crystals should be 2-4 µm.





Contributed by Lesley Andrews
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A method for the preparation of polished samples of clay minerals

Archie Corfield
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Clay minerals present a specific challenge of presentation for analysis by a variety of different mineralogical techniques. A key feature of clay minerals is that they are usually ultra fine-grained and susceptible to swelling when in a wet environment, which includes being exposed to atmospheric humidity. Conventional sample preparation techniques very often yield sections with surfaces which are practically devoid of the clay minerals which may be present in the sample. This is because water, which is conventionally used in the preparation process, rapidly softens the clay minerals which are then eroded and washed away. The only evidence that a clay mineral was ever present is often an eroded or *absent* surface.

The key to avoiding this "lack of evidence" is to prevent any contact of the sample with water during the preparation process. When preparing samples containing clay minerals it is important to first dry the samples thoroughly before attempting the preparation of sections. This is usually accomplished at a low temperature (such as ~50°C) for an extended period of time (usually several hours, dependent on how moist or wet the sample may be). Only once the sample is completely dry to touch can the preparation of sections begin. A typical preparation process is described:

- The sample must be cut and ground with a suitable non-water-based lubricant, such as paraffin.
- A plane surface should be prepared by grinding with diamond grinding discs or silicon carbide papers using paraffin. It is best to use solid-state grinding media rather than granular materials such as silicon carbide powder or alumina powder which may become impacted in the clay minerals.
- Rinse and dry the sample at 50°C until the paraffin has completely evaporated.
- Coat the surface with a thin layer of epoxy resin (while the sample is still warm, as this facilitates absorption of the epoxy resin into the clay. This epoxy resin consolidates the clay and makes it more resilient to plucking out in subsequent preparation stages. Keep applying epoxy resin onto the surface until it is no longer absorbed. Wipe off excess epoxy and allow to cure at 50°C.
- Carefully grind the surface on diamond discs or silicon carbide grinding paper, using paraffin as a lubricant, to expose a plane surface of the section being prepared.
- Rinse and dry the sample.
- Embed in epoxy resin. Once the epoxy resin has cured, carefully grind the surface to expose the underlying material. Avoid deep grinding which will expose unconsolidated clay which will render all the prior steps mute.
- Proceed to polishing.
- One may use oil-based diamond suspensions for polishing, but since these are not commonly available in most preparation laboratories, an alternative approach is to saturate cloths used for polishing with water-based diamond suspensions in the size ranges used, and allow them to dry out in an oven at 50°C. Use the cloths once dry but with paraffin as a lubricant. Don't use excess paraffin – as it will more rapidly wash the diamond abrasive off cloth.
- With paraffin as a lubricant, use similar polishing times as conventional polishing processes but reduce pressure – excess friction may preferentially erode the soft clay minerals.
- Rinse the section in paraffin and place in an oven at 50°C until dry.
- The sample is ready for observation.
- Keep sections in a dessicator as exposure to humidity will cause the clay to absorb moisture and the prepared sample will be ruined.

The procedures described above can be applied to the preparations of clay minerals in thin section as well as to any water-soluble phases.

Archie Corfield has extensive experience in sample preparation after working for almost 40 years in the mineralogical and metallurgical field, working with minerals and materials. He is currently employed at SJT Metmin (Pty) Ltd.

Measuring clays: Fit for Purpose Methods in the Mining Industry

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The need for clay measurement in the mining industry is as varied as the definition of 'clay'. Clays are often defined based on their mineral structure, particle size or plasticity. Clay mineralogists chose their measurement methods based on attributes of interest such as mineral structure, elemental composition and speciation, surface morphology and chemistry. However, the need for 'clay' information to develop or monitor mineral handling, processing or containment systems, centres around incorporating 'clay behaviour' into equations for predicting the behaviour of the fluid, slurry, or soil systems within the mine's battery limits. Traditionally, clay behaviour has been incorporated into bulk measurements of rheology, shear strength or soil consolidation. While these methods have been incredibly useful for benchmarking fluid and soil behaviour, incorporating specific attributes of clays may reduce the need for intensive sampling and testing, and provide better predictive capabilities for process design and optimization. Described below are some clay measurement techniques suited to typical mining processes with a focus on saturated clay streams.

Clay measurement drivers in a typical mine operation

Figure 1 attempts to capture the main areas where clay measurements are prominent in a typical mining and resource processing operation. At the mine face, clays may be in the overburden or interbedded with the ore and transported to ore preparation (comminution plants) en route to the separation plants.

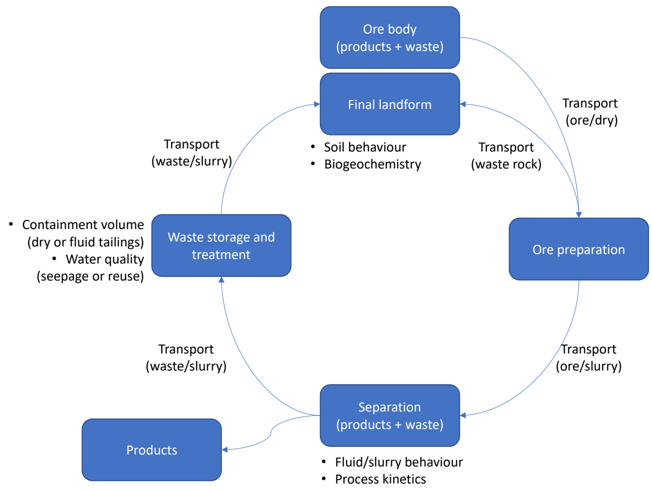

Figure 1: A generic resource processing asset. Waste refers to gangue or tailings.

Once the desired product has been sufficiently concentrated in the separation plants, the waste or tailings is often hydraulically transported to dewatering plants and to settling or water recycle basins (tailings pond). A key objective is to 'quickly' return tailings ponds into sustainable terrestrial or aquatic landforms after the life of mine (final landform). This translates to a need to understand how quickly the material moving through the plant is changing. For slurries, one approach to describe the clay attributes significant to material behaviour at any location between the mine face and the final landform is to sum the forces per unit volume (f) on a particle at the location.

$$\sum \vec{f} = \vec{f}_{pressure} + \vec{f}_{viscous} + \vec{f}_{gravity} = \rho\vec{a}$$

Equation 1

Here, the per unit volume force due to the particle acceleration ($\rho\boldsymbol{a}$) is balanced by the gravitational acceleration and surface pressure gradient and viscous forces. Depending on the solid concentration in the slurry and the slurry velocity, the need for clay measurement might differ. During slurry transport at steady state, both ($\rho\boldsymbol{a}$) and $\boldsymbol{f}_{gravity}$ are inconsequential and clays only influence $\boldsymbol{f}_{viscous}$ of the bulk fluid. However, as the slurry becomes more concentrated and undergoing settlement in the tailings pond or final landform, clays determine the particle acceleration and the rate of pore excess pressure dissipation. $\boldsymbol{F}_{viscous}$ transitions from the viscosity of the bulk slurry to the interparticle repulsion between clay particles. The following sections highlights clay measurement methods that may help to fully understand and model these forces starting from the desired final landform.

Final landform

A requirement for most mineral mines is to reclaim their tailings footprint into a landscape appropriate for the local ecosystem after the life of mine, and within a specified period. For terrestrial landforms, this means that the tailings footprint must be geotechnical stable prior to commencing reclamation activities and the reclaimed landform must meet all required geochemical attributes for both run off and seepage. For aquatic landforms, the geotechnical criteria are constrained to the stability of the containing dyke structure and the rate of settlement of the fluid tailings within the dyke structure. More important are the biogeochemical attributes of the fluid tailings and how they mediate transport of geochemical markers into the water column. Regardless of the end state of the tailings footprint, clays place a limit on the geotechnical behaviour and influence the biogeochemical behaviour of the deposit. The geotechnical engineer designing the final landform is concerned with how quickly the deposit develops effective stress, its response to shear stresses and sensitivity to remolding (or rehandling). All the parameters in equation 1 are essential to this objective and $\boldsymbol{f}_{pressure}$ and $\boldsymbol{f}_{viscous}$ are limited by the type and amount of clay minerals present in the deposit. Clays are therefore crucial to determining how quickly reclamation activities may begin and how long before a reclamation certificate can be issued.

Figure 2 for example shows how long it takes for a deposit of kaolinite or smectite to reach its equilibrium void ratio before it stops settling – typically below a void ratio of 0.5 at very high effective stresses. The void ratio is the volume of space between particles (usually air and water) and volume occupied by the solids. A small amount of smectite in a deposit may add decades or centuries to the consolidation timeline under self weight. So, in this instance, knowing the type and amounts of clay minerals in the deposit, as well as the pore water chemistry are crucial to predicting hydraulic conductivity or the trajectory of the effective stress development in a deposit. An examination of the underlying mechanisms reveals that the particle-particle surface interactions (clay – water interactions) limit this behaviour. For example, equation 2 approximates the amount of work required to bring particles together in a saturated deposit.

$$W_g\left(\frac{J}{kg}\right) = SSA\left(\frac{m^2}{kg}\right) * \sigma_q\left(\frac{C}{m^2}\right) * \psi\left(\frac{J}{C}\right)$$

Equation 2

SSA is the specific surface area of the particles, σ_q is the surface charge density and ψ is the surface potential.

With reference to the samples in Figure 2, the gravitational work required to bring two kaolinite particles together is about 0.7 kJ/kg in the high ionic strength medium and 1 kJ/kg in the low ionic strength medium. And for smectite at high ionic strength, the gravitational work required is 8 kJ/kg and 12 kJ/kg in the low ionic strength medium. These differences are directly a result of the difference in the specific hydrated surface areas of the two examples (63 m^2/g for the kaolinite sample and 745 m^2/g for the smectite sample), as well as the thickness of the diffuse double layer imposed by the ionic strength. So, it is more informative to measure the specific hydrated surface area of the bulk samples using techniques such as methylene blue adsorption (Hang & Brindley, 1970) or approximated using cation exchange capacity (Stanjek & Kunkel, 2016). N_2-BET is not appropriate because it measures only the external surfaces in a dehydrated sample.

In an aquatic landform such as end pit lakes, clays with copious amounts of Fe^{3+} may also serve as electron acceptors for microbial activities which produce gases such as carbon dioxide and sulfides. This is true for some serpentines and nontronite with high Fe^{3+} in solid solution in the tetrahedral or octahedral sheets respectively (Zhang, Dong, Kim, & Eberl, 2007). In these cases, the use of Mössbauer spectroscopy may be quite useful to determine the available capacity for electron acceptors in a deposit's mineral assemblage.

Figure 2: Hydraulic conductivity (top) and compressibility (below) of samples of saturated kaolinite and smectite. Courtesy of Suncor Energy Inc.

At high concentrations of microbial food source, methane and/or carbon dioxide gas bubbles may form in the deposit, and transport geochemical contaminants into the water column. In addition, gas bubbles may also degrade the effective stress development required for deposit stability through build up of excess pore pressure.

Waste storage and treatment

In many mining operations, tailings are mostly sandy materials which are hydraulically transported to sand dumps, where they rapidly settle and are ready to be reclaimed after a very short duration. The runoff is a fluid fine tailings stream stored within a dyke structure which serves as a water recycle basin. Fluid tailings storage during the life of mine is typically constrained by the availability of out of pit storage space as well as the rate of water recycled back to the processing facilities. Both objectives are constrained by the rate of settlement of clays in the tailings deposit ($\boldsymbol{f}_{viscous}$). A good insight into the underlying limiting parameter is provided by Stokes law, conceptually valid for fluid tailings settling under gravity at very low Reynolds number (laminar flow) where the terminal velocity(v) is a function of the particle surface area (D^2), the density difference between the liquid phase and the particle ($\Delta\rho$) and the apparent viscosity (μ) of the settling slurry.

$$v \approx {gD^2\Delta\rho}/{18\mu}$$

Equation 3

Again, measurement of the specific surface area rather than the mineral composition is far more useful for quantitative determination of water release rates in settling basis. The magnified contribution of the surface area is a reason for the use of thickeners and centrifuges to accelerate the water release rates in fluid tailings. Here, a flocculant is added to aggregate the nanometer-sized clay particles into micron or millimetre sizes, to increase the terminal velocity (v).

Fluid transport

The transport of fluid tailings via pipeline is ubiquitous in most mining operations. Often the main concern is determining the energy required for transport and keeping the particles from stratifying in the pipeline where sandy particles could quickly erode the pipeline. Operators often pay attention to the Reynolds number (Re) and the Froude number (Fr).

$$Re = {\rho v D}/{\mu}$$

Equation 4

$$Fr = {\rho v^2}/{\Delta\rho g D}$$

Equation 5

The Reynolds number describes the ratio between inertia and viscous forces, and it is a measure of the flow field from laminar (viscous forces dominated) to turbulent (inertial forces dominated). The parameter D is the hydraulic diameter, often the diameter of the pipeline (not particle diameter). So, clays are important from their contribution to the bulk viscosity. Fluid tailings at high solids concentration are non-Newtonian (viscosity varies with applied shear stress) and often require a finite shear stress (yield stress) to initiate flow. The Froude number (ratio of inertial forces to gravity forces) is important for determining the velocity where all the particles will stay in suspension during transport and has no significant dependence on clays.

Viscosity and the yield stress of slurries are usually determined from rheology measurements. At a given solids concentration, both viscosity and yield stress are known to increase as the specific surface area and asymmetry of the particles increase (de Kretser, Scales, & Boger, 1998). This is particularly important in laminar flow where viscous forces dominate the flow behaviour, and as the solid concentration increases whereby some clay slurries thicken (rheopectic) or become more fluid (thixotropic) over time during transport. Electron microscopic techniques combined with zeta potential measurements are often used to calculate the interaction energy contributing to the viscosity of the slurry. It is now common to use online near infra-red instruments calibrated to measure such as specific surface area to monitor changes to the flow behaviour in slurry transport.

Separation plants

Many primary separation processes rely on the density differences between the slurry and air bubble to drive separation. Typically, the process is operated to first enable separation between the product from the gangue or waste, and then promote attachment of the product to air bubbles for transport to a froth layer. The rise rate of the air bubble also follow equation 3, with the associated influence of bubble diameter (D), $\Delta\rho$ and μ. In addition, a significant influence of clay minerals in separation processes is their competitive affinity for hydrophobic surfaces of air bubbles or product, where they may reduce the quality of the product. Kaolinite for example is known to exhibit hydrophobic behaviour on the terminal neutral siloxane surfaces where they could bind to non-polar organic compounds (Johnston, 2017). On the other hand, clay minerals with isomorphous substitution sites tend to be more hydrophilic. Adsorption isotherms from microcalorimetry are useful for probing the impact of clays on separation of products from waste.

Orebody

The orebody provides the best opportunity to measure all the clay attributes important for downstream processes. It cannot be overemphasized that measuring all clay attributes in the ore body before it gets to plant operations is both cheaper and offer better performance prediction capabilities. As such, clay scientists in mining should master as many of these measurement methods as possible and should have more than a cursory understanding of how the attributes they measure impact the operations they support. The commoditization of machine learning and artificial intelligence would make clay measurements, especially during exploration of the ore body, even more impactful as the clay attributes would be key features in predicting downstream behaviour.

Conclusions

A recurring theme in this article is the notion of 'rate'. From how quickly and efficiently the mine shareholders can recover value from the product they mine, to how quickly the stakeholders who own the mine footprint at closure could start getting value from their land. Clays in the ore body limit these rates and measuring all relevant attributes of clays is important for predicting performance from mining to operations and closure.

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Clays and Tailings Failure

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Tailings dams are once again a hot topic, but for all the wrong reasons in the light of the recent Jagersfontein failure. To get some perspective on this particular failure, it is useful to understand the role which clay minerals and their interaction with water may have played this disaster.

Clay minerals in tailings

Most mine tailings can be classified into either coarse solids or fine solids. The coarse solids (usually overburden material) are generally stored in free-standing dumps which are dry and self-supporting. The fine solids are generated after the ore is processed to recover the valuable product. These solids are suspended as a liquid slurry which needs to be dewatered (normally by a thickener) before disposal to a tailings storage facility (TSF). Since clay minerals are ubiquitous in virtually all mine deposits, they tend to be concentrated in the fine tailings stream where their interaction with the process water chemistry greatly influences the colloidal behaviour of the tailings.

The common conceptual models of solids as spherical particles with uniform surface charge do not apply when one considers clay minerals. Clays are micron to nanometer sized plate-like particles with non-uniform surface charge distributions, which can vary in polarity depending on the chemical environment in which they find themselves (Figure 3).

Different clay minerals may make a fine tailings suspension behave in a “better” or “worse” manner. For instance, clays which have no surface charge (kaolinite and talc) tend to be well behaved and settle out naturally in a suspension. On the other hand, charged (or swelling) clay minerals such as smectite and illites can remain colloidally dispersed and, which if left unattended, can initiate a chain of mineral processing and geotechnical problems at the TSF site.

Often overlooked, is the critical role played by the mine raw water and its derivative, the plant process water. The source of raw water to the mine will in most cases determine the chemical properties of the process water and this in turn will determined the future colloidal state of the suspended clay minerals. Process water properties such as pH, sodicity, and salinity all influence the electrical charge of the clay particle surfaces and hence the interaction which suspended clay particles have amongst themselves. These net interactions are responsible for generating fine tailings slurries which are either settling (in a coagulated state) or non-settling (in a dispersive state) (Figure 2).

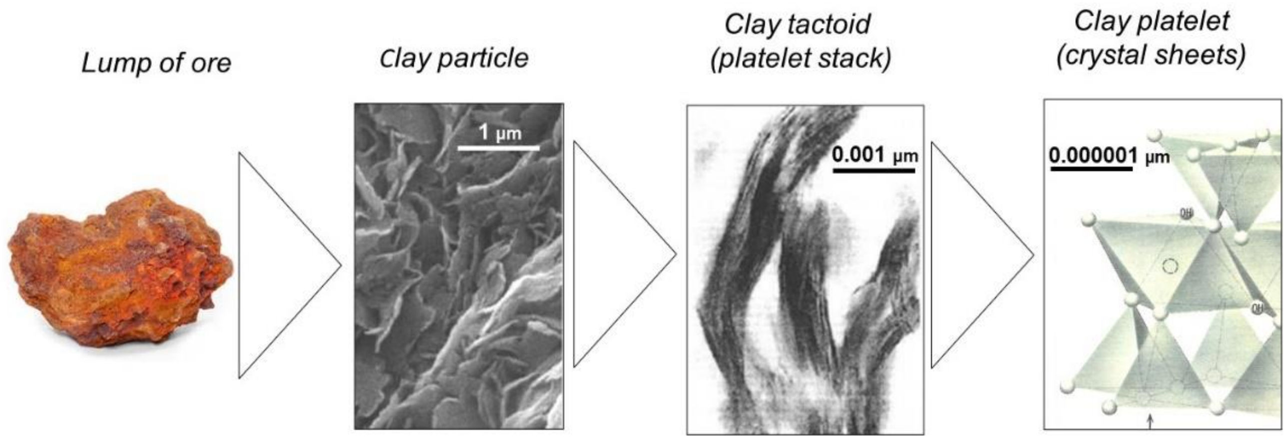

Figure 3: Progression from ore to clay crystal structure.

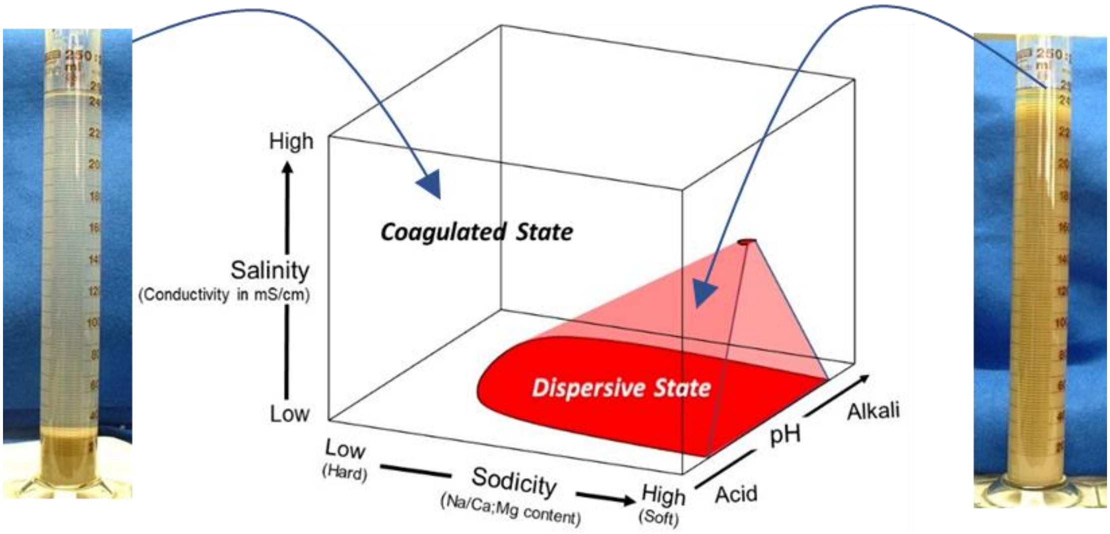

Figure 2: *Conceptual model describing clay colloidal behaviour as a function of process water chemistry.*

How are tailings disposed?

Dilute fine tailings are typically flocculated to enhance solid/liquid separation before dewatering in a thickener which will densify the solids prior to disposal to the TSF and also recover clarified process water back to the plant. Modern High Density or Paste thickeners are designed to consolidate the clays to a greater degree to recover more water and dispose high density solids to the TSF. However, it stands to reason that the clays in the thickener feed need to be in a "coagulated state" before solid/liquid separation and subsequent consolidation will take place. Clays in a dispersive state will not necessarily settle and thicken even when dosed with a flocculant reagent. Therefore, irrespective of the efficiency of the thickener, if the clays are dispersive, it is likely that dilute thickener underflows containing high volumes of water will be pumped to the TSF.

Many factors affect the selection of a particular TSF dam design, such as the properties of the tailings, the type of dewatering process used and the topography of the land. Most mine sites in South Africa are located on relatively flat topography and consequently, TSF designs such as Ring Dyke dams using Upstream and Downstream construction methods have been used successfully.

It is clear, however, that the vast majority of tailings should be dewatered as much as possible and that the existing TSF designs should be phased out in favour of Best Available Technology (BAT) methods which utilise High Density/Paste thickening to build Paste dams using Central Thickened Discharge or Down-Valley Discharge construction methods (**Error! Reference source not found.**).

What happened at Jagersfontein?

As with all tailings dam failures, a combination of factors conspired to contribute to the moment of failure. In the case of Jagersfontein, the mine was reprocessing legacy kimberlite waste dumps which contain a significant proportion of smectite clay minerals. In addition, the chemical quality of the raw and plant process waters allowed the smectite clays to become naturally dispersive and non-settling. The irony of this, was that even though the mine had installed a state-of-the-art thickener capable of generating high density underflows, the clays in the thickener feed were incapable of undergoing solid/liquid separation and hence very dilute thickener underflow was pumped out to the TSF over a prolonged period of time.

Finally, the Jagersfontein TSF was constructed as a Ring Dyke facility on flat topography which meant that the fine dilute tailings were stored above ground level and were contained by a dam wall constructed using coarse solids. This design of TSF is not suitable for storing watery tailings as the basin of the facility is elevated above the surrounding land and can easily become unstable when filled with large volumes of water (Figure 4).

Figure 3: *A “Paste” TSF Design in Kimberley (above);*

The Jagersfontein “Ring Dyke” TSF design (right).

Figure 4: Time sequence for the Jagersfontein TSF failure.

In the final analysis, the management/ operators at Jagersfontein did not understand the consequences of the clay mineral properties in their tailings material. They also did not recognize that it is practically possible to solve the problem by conditioning the process water circuit chemistry so that the clays become naturally settling in order for the thickener to operate properly.

And some light mineralogical filler, from online:

In 2021, a geode originally found in Soledade, Brazil was passed on to California gem collector Mike Bowers by gemologist Lucas Fassari, who had called him to say, “You need to see this." The rest is internet history, as “The Cookie Monster” stone went viral, eventually ending up on my WhatsApp account, and now your magazine. What’s the P-T-t path for that?

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Minsa invites its members to contribute submissions for our next issue of the Geode, on the theme of "***Geoscience publishing: pitfalls, priorities and permutations***" (see below), for March 2023.

Submissions can be sent to minsa@gssa.org.za and should reach us by 28th February 2023.

"Publish or perish" has been the mantra in the academic community for decades now. How critical is this really, for academic (university-based) researchers, and for technical industry-based researchers? How is quantity of output weighed against quality, and by whom? What are the implications? What is a predatory journal, and what is not? What is an "open source" journal? Why do I get asked to pay page publication fees? Your thoughts are invited!

Geophagy…talk about having an apatite!

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The term "geophagy" (sometimes "geophagia" when connotated as an eating disorder – see the "Diagnostic and Statistical Manual of Mental Disorders") probably elicits similar responses to words that have similar etymologies like "oesophagus", "bacteriophage", "glucophage" …and perhaps it has every right to. Because "Geophagy" is the deliberate and intentional practise of eating earth, soil, snow, ash, chalk, or clays. It is peculiar that consuming salt is not usually recognised as geophagy, though technically it should be. It is also peculiar that ingesting clays like smectite or kaolinite, which are the main ingredients in medications like "Smecta" and "Kaopectate"/ "Kaomagma" respectively (used in treating diarrhoea) are also not usually considered geophagy though once again technically should be. A plethora of animals (especially primates) are known to practise it, as are humans, in various guises, from traditional, cultural applications to "weird" cravings (like clay, ice or ash cravings during pregnancy or simply the desire to eat dirt as a child – which might be an evolutionary adaptation to offset the ill effects of accidentally ingested parasitic worms). In the case of clay cravings during pregnancy, many soils may contain high levels of calcium, copper, magnesium, iron, and zinc…minerals that are critical for developing foetuses which can cause metallic, soil, or ice cravings in pregnant women. These cravings, and their subsequent mineral consumption (as well as in the case of cravings for cold vasoconstricting food, namely ice, which aid in increasing brain oxygen levels by restricting neck vein diameters) are therapeutically effective in decreasing infant mortality (Young et al., 2011).

As an "excipient", medicinal clay is often used as a substance formulated alongside the active ingredient of a medication. The reasons for this may include:

1. for the purpose of long-term stabilization, or the bulking up of solid formulations that contain potent active ingredients in small amounts (they are thus often referred to as "bulking agents", "fillers", or "diluents").
2. to confer a therapeutic enhancement on the active ingredient in the final dosage form, such as facilitating drug absorption, altering viscosity, or enhancing solubility.

Archaeological nutritionist Timothy Johns (1986) proposes that geophagy may be the earliest form of medicine and concludes that, although some soils can be a source of nutrients (minerals and/or trace elements), the primary benefit of clay consumption is its effect of countering dietary toxins and, secondarily, the effects of parasites. This explains why plant eaters need to eat earth, and why this practice is more common in the tropics, where plants are more heavily defended by toxic secondary compounds. As an empirical example of this, Klaus (1998) states, "In the rain forests of the Central African Republic, forest elephants and other mammals have created large treeless licks on outcrops of ancient subsoils. Most are high in minerals, but almost a third of the licks have lower levels of minerals than surrounding soils. The one thing all the sites have in common is a clay content of over 35%. These elephants feed primarily on leaves all year round, except for 1 month—September—when ripening fruit is so abundant that they change to eating mainly fruits. Leaves generally contain defensive secondary compounds to deter herbivores; ripe fruits do not. A change from eating leaves to fruits would therefore dramatically reduce the consumption of toxic secondary compounds—a natural experiment to see whether toxin consumption equates with clay consumption. The only month in which elephants reduce their visits to the clay licks is during that fruit-eating month—September!" Another example, involving Amazonian parrots, is cited by Diamond (1999), "Because many of these chemicals become positively charged in the acidic stomach, they bind to clay minerals which have negatively charged cation-exchange sites, and are thereby rendered safe. Their preferred soils have a much higher cation-exchange capacity than the adjacent, rejected layers of soils because they are rich in the minerals smectite, kaolin, and mica."

The benefits of clay to animal health have been known for some time. Addition of bentonite clay improves food intake, feed conversion efficiency, and absorption patterns in domestic cattle by 10% to 20%. Clay-fed cattle also experience less diarrhoea and fewer gastrointestinal ailments (Kruelen, 1985). In addition, veterinarians find clay an effective antacid. Kaolinite helps reduce the symptoms of diarrhoea by absorbing fluids within the intestine (Mahaney, 1995). Other scenarios have been suggested, namely that folivorous (leaf/foliage eating) monkeys may add to the beneficial intestinal bacterial flora needed to efficiently digest hard-to-process plant materials. This connection has especially been correlated with eating termite mound soils by Sifakas of the genus Propithecus (Norscia et al., 2005). Termites are thought to incorporate symbiotic bacteria in the walls of their mounds that could be beneficial cellulose-digesting flora (Ankel-Simons, 2007).

One early traditional use of clays in the culinary craft, that is still commonly practiced by Andean farmers around Lake Titicaca, involves geophagy (de Haan et al. 2016). Potatoes are boiled and consumed with a clay dip called ch'ago. The clay has a detoxification function and neutralizes the human intake of potentially harmful glycoalkaloids (lest we forget that potatoes are part of the notoriously toxic nightshade family). Furthermore, Johns and Duquette (1990) state, in another example of the use of clays in the culinary craft, "Parallel uses of clay in the traditional preparation of unpalatable acorns in California and Sardinia provide a case study for testing hypotheses on the detoxification function of geophagy. In laboratory simulations of the traditional methods, the addition of clays collected at the specific sites reduced the tannic acid digested from acorns by up to 77%. Reduction in tannic acid would make these nuts palatable and less toxic and provides a rational for the empirical practices. Adsorption and catalysis on clay surfaces are the most likely mechanisms accounting for the elimination of tannic acid activity."

The effects of weightlessness on the human body were studied by NASA in the 1960s. Experiments demonstrated that weightlessness leads to a rapid bone depletion, so various remedies were sought to counter that. A number of pharmaceutical companies were asked to develop calcium supplements, but apparently none of them were as effective as clay. The special clay that was used in this case was "Terramin" (a reddish type of Ca-rich montmorillonite clay), found in California. Benjamin Ershoff of the California Polytechnic Institute demonstrated that the consumption of clay counters the effects of weightlessness. He reported that "the calcium in clay ...is absorbed more efficiently [and] contains some factor or factors other than calcium which promotes improved calcium utilization and/or bone formation." (taken from Ubick, 2005)

So the next time you accidentally ingest rutile, calcite, "colloidal silica" or apatite in your toothpaste or purposefully ingest dolomite, zeolite or bentonite supplements or medically ingest "Smecta", know that you have unknowingly joined the "geophagy club".

List of medicinal clays:

- Bentonite/montmorillonite – also known medically as diosmectite ("Smecta"); used as a bulking laxative and to treat infections, indigestion, and other medical problems through ingestion.
- Palygorskite/attapulgite - a very absorbent clay, somewhat similar to bentonite. When used in medicine, it physically binds to acids and toxic substances in the stomach and digestive tract and, as such, is/was used in several anti-diarrheal medications.
- Kaolinite - not as absorbent as most clays used medicinally (it has a low shrink-swell capacity). Also, it has a low cation exchange capacity. Was a common ingredient in western medicines such as Kaopectate, Rolaids and Maalox.

The positive mechanisms involved in treating some ailments with clay may include (Johns & Duquette, 1991; Mahaney et al., 1995a,b; Davies & Baille, 1988; Henry & Cring, 2012; Thieu et al., 2008; Williams & Haydel, 2010):

1. Soil adsorbs toxins such as phenolics and secondary plant metabolites.
2. Soil can aid in heavy metal chelation (extraction of heavy metals).
3. Soil ingestion has an antacid action and adjusts the gut pH protecting the gut lining from corrosion.
4. Soil acts as an antidiarrheal buffering agent.
5. Soil (uncontaminated) counteracts the effects of endoparasites.

6. Soil adds minerals or trace elements to the diet (nutritional supplementation through bioavailabilty of Ca, Na, Cu, Mg, Zn and Fe).
7. Soil supplements and bulks nutrient-poor diets.
8. Humans are not able to synthesize vitamin B12 (cobalamin), so geophagy may be a behavioural adaption to obtain it from bacteria in the soil.
9. Clays can bind mycotoxins which cause aflatoxicosis (fungal toxins), endotoxins (internal toxins), manmade toxic chemicals, bacteria and various other pathogens.

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And did you know?

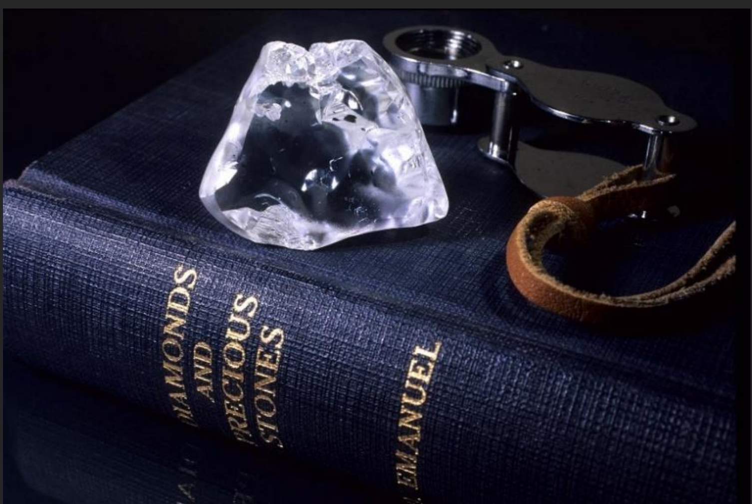
There is a fish, native to the Amazon basin and found throughout South America, called the geophagus; it subsists by eating mouthfuls of river floor soils and ingesting the good bits. *(Ed.)*

Bruce's Beauties: Diamonds

Diamond is the featured species for this issue for no other reason than who does not like seeing large, impressive diamond crystals! All photos are Bruce Cairncross photo ©.

A parcel of alluvial diamond crystals mined from the Vaal River gravels, Barkly West region. The yellow octahedron is 65 carats and the pink stone 9 carats. Surrounding these are an assortment of various other crystals. Diamonds courtesy of CS Diamonds, Kimberley.

Two pale yellow modified octahedral diamonds. Top stone is 47 carats, bottom one 49 carats. Diamonds courtesy of CS Diamonds, Kimberley.



A near flawless (Bruce wrote "lawless", but I'm pretty sure this is what he meant) 138-carat alluvial diamond from the Vaal River diggings. Diamond courtesy of CS Diamonds, Kimberley.

Not all life was easy pickin's. A gravestone at the small cemetery close to Waldeks Plant. It reads: "In memory of J.J. Kennedy of Port Bretton Canada, who died November 23rd 1885 aged 48 years. RIP." The cause of death is not known.

And not all is high tech and glamorous in the alluvial diamond mine workings. This is the apparatus of a one-man operation at Waldeks Plant on the Vaal River, Barkly West.

New meteoritic minerals identified

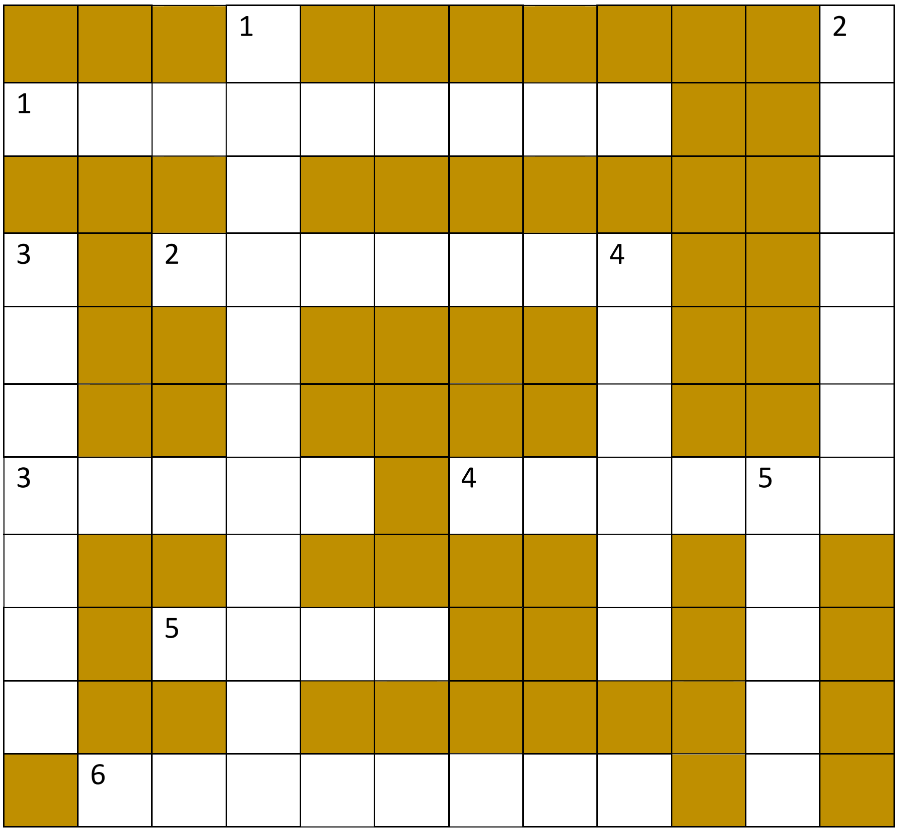
In other mineralogical news from December 2022, workers investigating an iron meteorite found in Somalia have discovered two, and possibly three, new minerals. The meteorite, now named El Ali, after the nearest town, is a boulder in excess of fifteen tons found in the sand in a limestone-hosted valley, making this the ninth-largest "space rock" found on the Earth's surface (the really big impactors get broken up, or even vapourised and melted, so they don't leave big chunks behind). The rock had already been locally named ("Nightfall") and acquired local cultural significance over the last century and more. The rock was encountered and sampled by opal prospectors in 2019 (prompting this author to wonder how that went down with locals who had apparently memorialised it in local folklore. My guess is that "The one who smacks a piece off the sacred stone with their Estwing" does not become the true king.).

Regardless, subsequent study of a small slice at the University of Alberta led mineralogist Andrew Locock (who was an undergrad student there when I was finishing my Ph.D. there; now he's analysing meteorites, and I'm writing about it. I'm sure I must have helped teach him mineralogy. Just saying.) identified two new minerals, with a third pending confirmation. The two confirmed minerals are iron-phosphorus-oxygen compounds. Elaliite, which is named after the town El Ali, has the formula $Fe^{2+}{}_8Fe^{3+}(PO_4)O_8$. Elkinstantonite, which is named for planetary scientist Lindy Elkins-Tanton (Arizona State University), has the formula $Fe_4(PO_4)_2O$. Dr Elkins-Tanton is known for her contributions to the understanding of the origins of planetary cores and iron meteorites. There are numerous websites available for more information, but the one I poached most of this from is here at Science Alert.

Contributed by Steve Prevec

Minsa Crossword for December 2022

The theme is geophagy: minerals you can eat (i.e., for an actual reason, not 'on a bet'.)



ACROSS:

1. A variety of montmorillonite, this aluminous clay is eaten as a paste and extracts harmful metals and aflatoxins, mold-generated chemicals which are toxic to the liver. It is named for its largest deposit, in Wyoming.
2. An inorganic salt, NH4Cl, this is the prime flavourant in Nordic salty liquorice.
3. A mineral compound eaten for its kaolin content particularly by pregnant women from West Africa as a treatment for morning sickness (nausea), the "calabash" variant derives from fossilized sea shells.
4. Probably the best-known ingested mineral, this ionic compound known as rock salt is widely used as a flavourant and a curing (preservative) agent in meat, in particular.
5. The name for the disorder in which materials not normally considered to be food are craved or eaten.
6. The name for the group of alkaline three-layer swelling clays (including or synonymous with montmorillonite, and also with #1 across), which can absorb up to 30% of its weight in water (as I myself aspire to, on weekends).

DOWN:

1. A type of fibrous magnesian palygorskite clay, it is one of the compounds known as "fuller's earth" for its ability to extract the colour from oils or other solutions. It is mined prominently in southwestern Georgia, where its name comes from the local indigenous word meaning "dogwood".
2. The "other salt", it used in much the same capacity as #4 across, with which it is isomorphous, and features a tangy, more bitter taste than its counterpart. It is the official mineral of the Canadian province of Saskatchewan.
3. The principal mineral constituent of lime, which itself acts as a neutralising agent, reducing stomach acidity.
4. The most cation-free clay mineral, which does not contain potassium in spite of its name, and is widely used as an anti-diarrheal remedy, both artisanal and commercially. It is named for the town in southeastern China from which porcelains made from it attracted the attention of 18th century European visitors.
5. The porcelaneous fluorapatitic body parts through which all geophagous materials must pass, and which will end up contributing irreplaceable phosphate to your system if you grind them down chewing on quartz-bearing clay-rich soils.

Minsa Crossword solution for September 2022

Last issue's theme was retrograde metamorphism; the replacement of one mineral by another, relatively isochemically equivalent one (or ones) as a consequence of decreasing pressure, temperature or both, and typically associated with increasing water content (and associated dissolved ions).

1 P			2 H									
A			A			3 L		1 A	4 T	O	5 M	S
2 L	A	P	I	L	L	I			E		A	
A			R			B			P		S	
G						Y			H		K	
3 O	B	6 S	I	D	I	A	N		4 R	I	E	S
N		P							A		L	
I		A						7 P			Y	
5 T	A	C	H	Y	L	I	T	E			N	
E		E						6 L	A	K	I	
			7 P	U	M	I	C	E			T	
											E	

ACROSS:

1. The smallest units (plural) of mass whose disordered organisation manifests as an amorphous structure.
2. The term for volcanic ejecta, typically glassy particles, between 2 and 64 mm in diameter. It is Latin for "little stones".
3. The second half of the formal name assigned to the well-preserved impact crater in Bavaria (Germany), deriving from the name of the pre-Roman tribe occupying the area, the Raetians (less helpful than you'd think). It is the site of a UNESCO Global Geopark. Suevite from this crater features elsewhere in this issue.
4. Silicic (typically >70 wt.% SiO2) volcanic glass, usually black to dark brown in colour, found associated with rhyolitic volcanism.
5. Silica-poor volcanic glass, associated with basaltic volcanism, it is common to modern Icelandic and Hawaiian volcanism.
6. A mountain bisected by a volcanic fissure in southern Iceland, its eruption in ca. 1784 resulted in the death of more than half of Iceland's livestock, and subsequently a quarter of its human population, and caused global cooling and drought across the northern hemisphere.
7. The rock consisting of highly microvesicular volcanic glass, typically light in colour. Its former Latin name means "froth of the sea", where it is often found floating, as a product of submarine eruptions..

DOWN:

1. The common alteration product of basaltic volcanic glass reacting with water, often containing sideromelane glass as a principal constituent.
2. The descriptive suffix of the "body part" of the Hawaiian volcano goddess (see also 7 DOWN) used to describe masses of long strands of volcanic glass.
3. The blanket term for volcanic pyroclastic ejecta of any particle size, which includes both glassy materials as well as volcanic rock fragments.
4. Feldspathic (labradoritic plagioclase) glass found in some impact craters and meteorites, produced by shock melting and quenching.
5. The country in north Africa in which green tektite glass is found distributed, known as this nation's "desert glass". It consists mainly of the mineraloid lechatelierite, which was too long for my crossword, and which also constitutes most fulgurites.
6. The place, in the broadest sense, where impact bolides (meteorites & comets) originate prior to impact, as in "outer ___". Also, the category of symmetry group characteristically absent in glasses.
7. The name of the Hawaiian goddess of volcanoes and fire. Examples of 2 ACROSS are often referred to as her tears. Removing specimens from Hawaii and taking them home invokes her curse. Unless they're for research…presumably.

Note: The recommended deadline for submissions for the next issue of the Geode is February 28, 2023.