

Research and Innovation



### **SESAME - AFRICA ONLINE WORKSHOP**

# Synchrotron light applied to the African Earth Sciences

#### Bjorn von der Heyden

Stellenbosch University

Integrated Mineral and Energy Resource Analysis

**DST-NRF** Centre of Excellence for



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Support and Advancement



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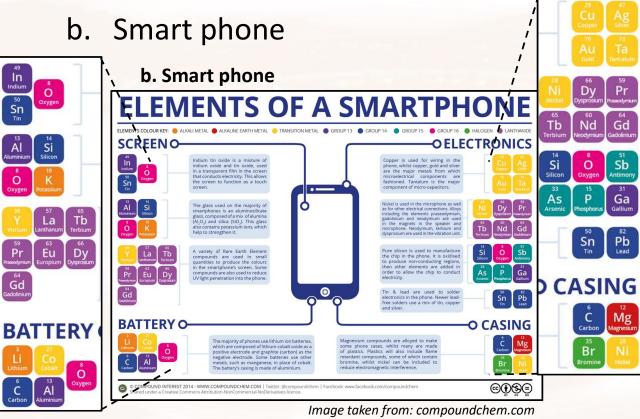
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## How did you dial into this presentation?

- a. Computer
- b. Smart phone

## How did you dial into this presentation?

a. Computer



#### a. Computer

| Material<br>name | Content (% of total<br>weight) | Weight of material in<br>computer (kg) | Use                                     | Location                                      |
|------------------|--------------------------------|--|---|---|
| Plastics         | 22.9907                        | 6.26                                   | Insulation                              | Cable, Housing                                |
| Lead             | 6.2988                         | 1.72                                   | Metal joining                           | Funnel glass in CRTs, PWB                     |
| Aluminum         | 14.1723                        | 3.86                                   | Structural, Conductivity                | Housing, CRT, PWB, connectors                 |
| Germanium        | 0.0016                         | < 0.1                                  | Semiconductor                           | PWBs  |
| Gallium          | 0.0013                         | < 0.1                                  | Semiconductor                           | PWBs  |
| Iron             | 20.4712                        | 5.58                                   | Structural, Magnetivity                 | Housing,CRTs, PWBs                            |
| Tin              | 1.0078                         | 0.27                                   | Metal joining                           | PWBs, CRTs                                    |
| Copper           | 6.9287                         | 1.91                                   | Conductivity                            | CRTs, PWBs, connectors                        |
| Barium           | 0.0315                         | < 0.1                                  | Å                                       | Panel glass in CRTs                           |
| Nickel           | 0.8503                         | 0.23                                   | Structural, Magnetivity                 | Housing, CRT, PWB                             |
| Zinc             | 2.2046                         | 0.6                                    | Battery, Phosphor emitter               | PWB, CRT                                      |
| Tantalum         | 0.0157                         | < 0.1                                  | Capacitor                               | Capacitors/PWB, power supply                  |
| Indium           | 0.0016                         | < 0.1                                  | Transistor, rectifier                   | PWB   |
| Vanadium         | 0.0002                         | < 0.1                                  | Red Phosphor emitter                    | CRT   |
| Terbium          | 0                              | 0                                      | Green phosphor activator,<br>dopant     | CRT, PWB                                      |
| Beryllium        | 0.0157                         | < 0.1                                  | Thermal Conductivity                    | PWB, connectors                               |
| Gold             | 0.0016                         | < 0.1                                  | Connectivity, Conductivity              | Connectivity, conductivity/PWB,<br>connectors |
| Europium         | 0.0002                         | < 0.1                                  | Phosphor activator                      | PWB   |
| Titanium         | 0.0157                         | < 0.1                                  | Pigment, alloying agent                 | Housing                                       |
| Ruthenium        | 0.0016                         | < 0.1                                  | Resistive circuit                       | PWB   |
| Cobalt           | 0.0157                         | < 0.1                                  | Structural, Magnetivity                 | Housing, CRT, PWB                             |
| Palladium        | 0.0003                         | < 0.1                                  | Connectivity, Conductivity              | PWB, connectors                               |
| Manganese        | 0.0315                         | < 0.1                                  | Structural, Magnetivity                 | Housing, CRT, PWB                             |
| Silver           | 0.0189                         | < 0.1                                  | Conductivity                            | Conductivity/PWB, connectors                  |
| Antinomy         | 0.0094                         | < 0.1                                  | Diodes                                  | Housing, PWB, CRT                             |
| Bismuth          | 0.0063                         | < 0.1                                  | Wetting agent in thick film             | PWB   |
| Chromium         | 0.0063                         | < 0.1                                  | Decorative, Hardner                     | Housing                                       |
| Cadmium          | 0.0094                         | < 0.1                                  | Battery, blue-green Phosphor<br>emitter | Housing, PWB, CRT                             |
| Selenium         | 0.0016                         | 0.00044                                | Rectifiers                              | rectifiers/PWB                                |
| Niobium          | 0.0002                         | < 0.1                                  | Welding                                 | Housing                                       |
| Yttrium          | 0.0002                         | < 0.1                                  | Red Phosphor emitter                    | CRT   |
| Rhodium          | 0                              | Å                                      | Thick film conductor                    | PWB   |
| Platinum         | 0                              | A                                      | Thick film conductor                    | PWB   |
| Mercury          | 0.0022                         | < 0.1                                  | Batteries, switches                     | Housing, PWB                                  |
| Arsenic          | 0.0013                         | < 0.1                                  | Doping agent in transistors             | PWB   |
| Silica           | 24.8803                        | 6.8                                    | Glass, solid state devices              | CRT.PWB                                       |

Source: Microelectronics and Computer Technology Corporation (MCC). 1996. Electronics Industry Environmental Roadmap. Austin, TX: MCC.

Image taken from: specialtymetals.com

# Earth Sciences and the African economy

- The African economy is still highly reliant on the 'primary sector' as a major income generator which sustains millions of livelihoods.
- Direct linkages between earth sciences and mining, less direct linkages with forestry, fishing and agriculture.
- However, these latter sectors certainly require a healthy natural environment.
- Focus on the mining sector and its effect on the natural environment

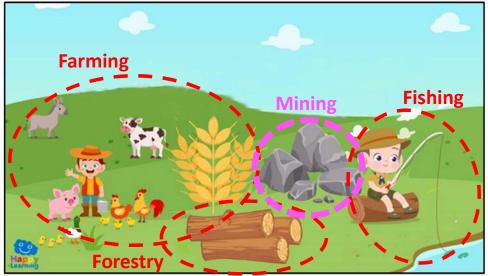


Image taken from: happylearning.tv

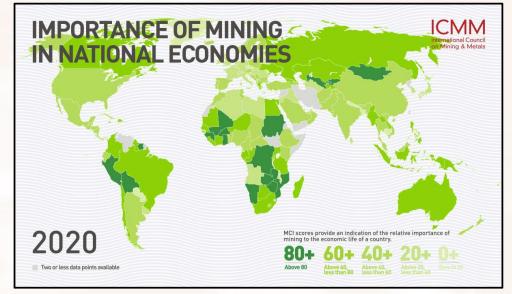
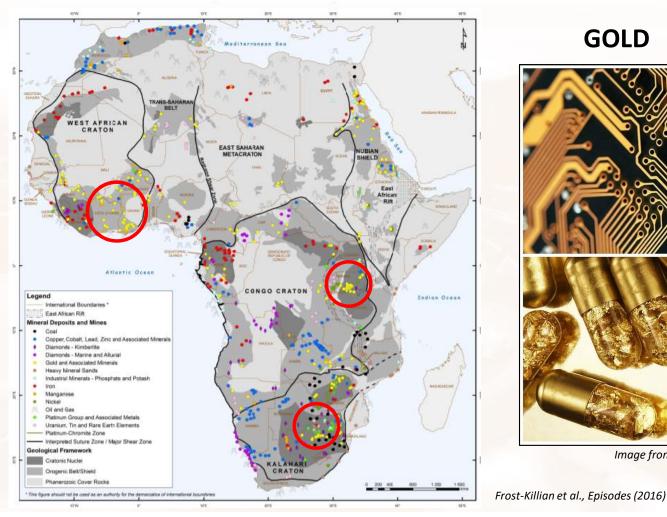


Image taken from: www.icmm.com (5<sup>th</sup> Mining Contribution Index (2020))

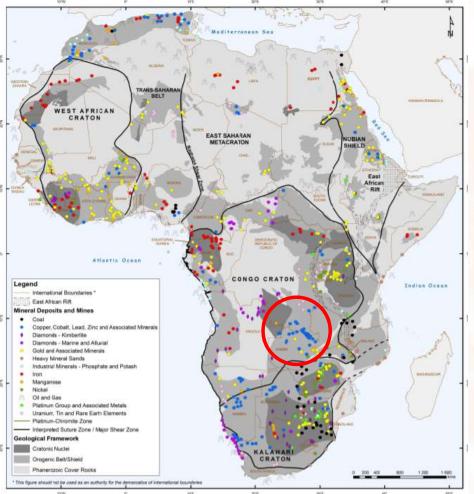
- Africa is blessed with a rich mineral • endowment.
- Examples of great mineral fields include: •
  - Lake Victoria, West African, and Witwatersrand gold fields
  - **Central African Copper Belt** ٠
  - Karoo-aged coal fields ٠
  - Kalahari Manganese Fields ٠
  - Moroccan sedimentary phosphate •
  - Southern African diamond fields •
  - West African Bauxite ٠
  - Bushveld igneous complex ٠
- Associated environmental degradation • influenced by speciation, mobility and chemical fate of deleterious elements released during mining.



GOLD

Image from: legit.ng

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#### **COPPER**

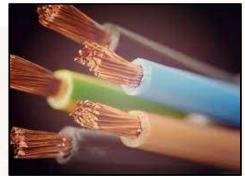


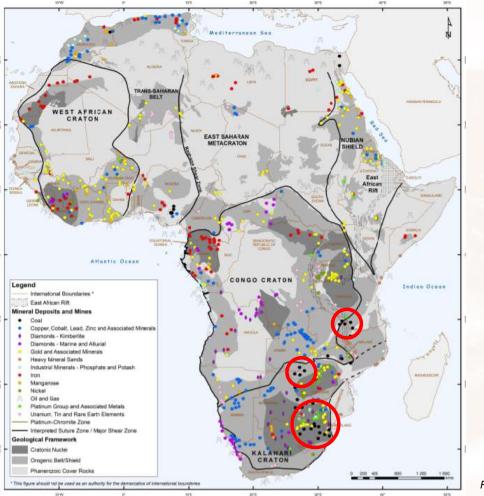
Image from: globaltrading.com

#### COBALT



Image from: investingnews.com

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COAL

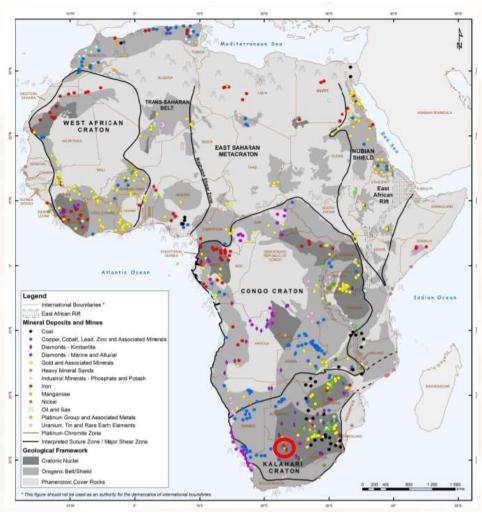


Image from: usgs.gov



Image from: sustainable-carbon.org

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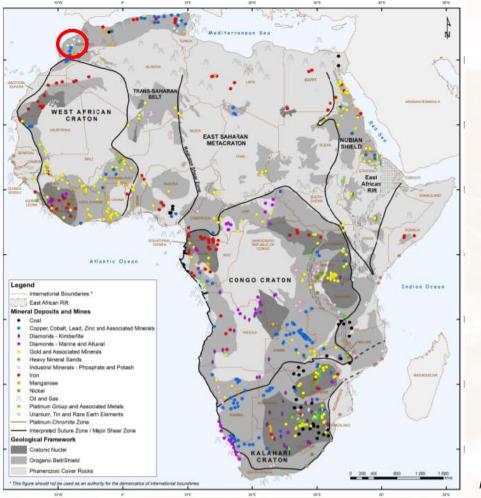


#### MANGANESE



Image from: relianttechnologyinstitute.com

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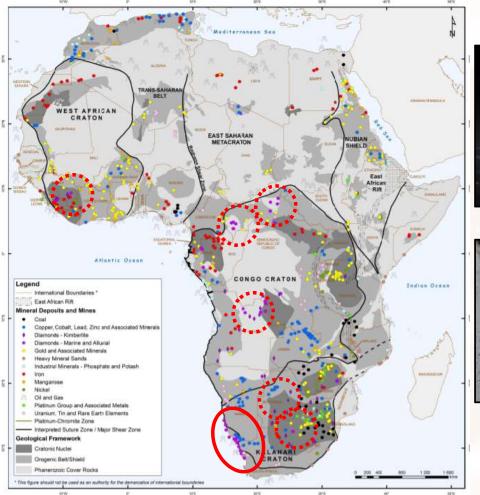


Phosphate



Image from: Alibaba.com

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#### Diamonds

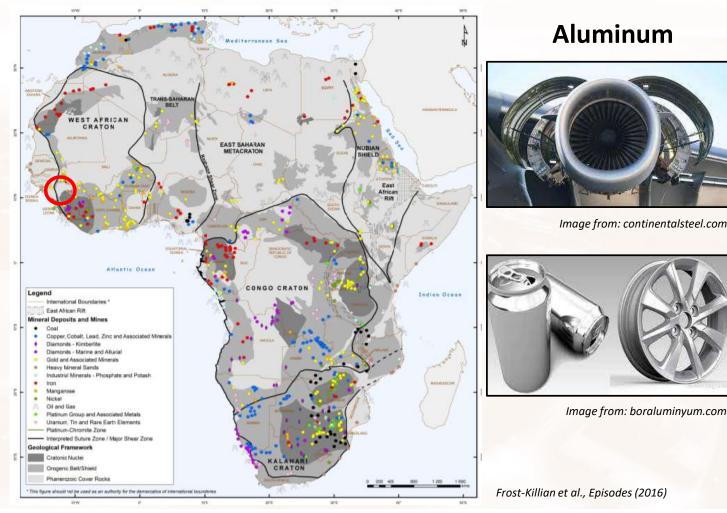


Image from: advancedsciencenews.com

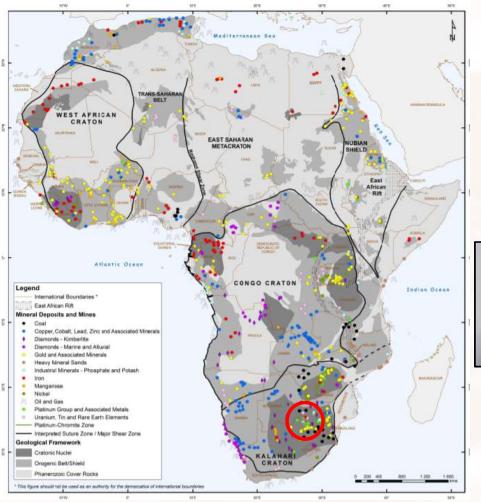


Image from: strategiesonline.net

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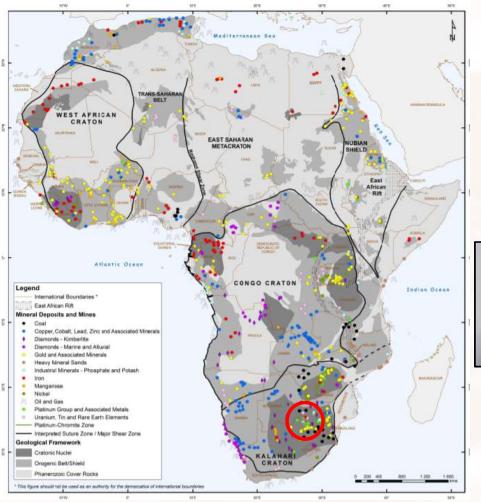


Platinum Palladium Chromium Vanadium Andalusite



Image from: platinum-info.weebly.com

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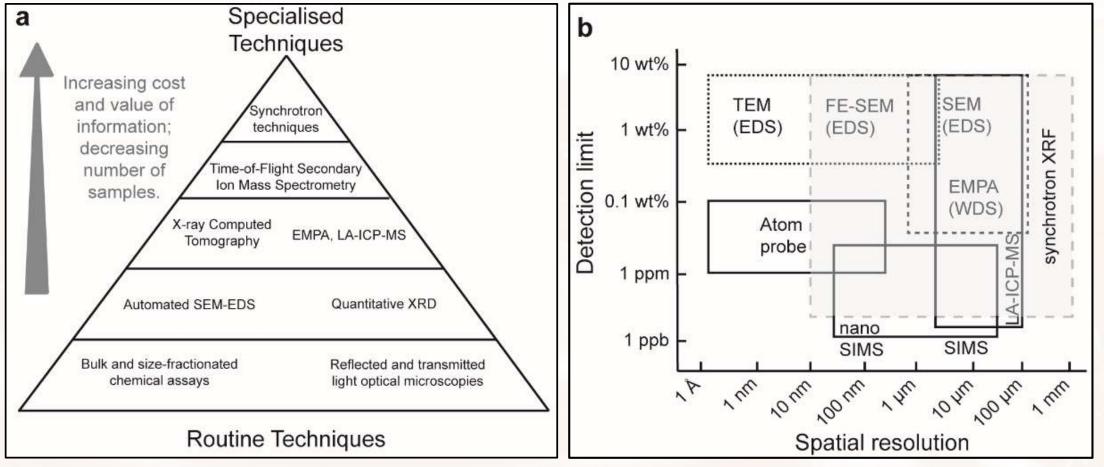


Platinum Palladium Chromium Vanadium Andalusite



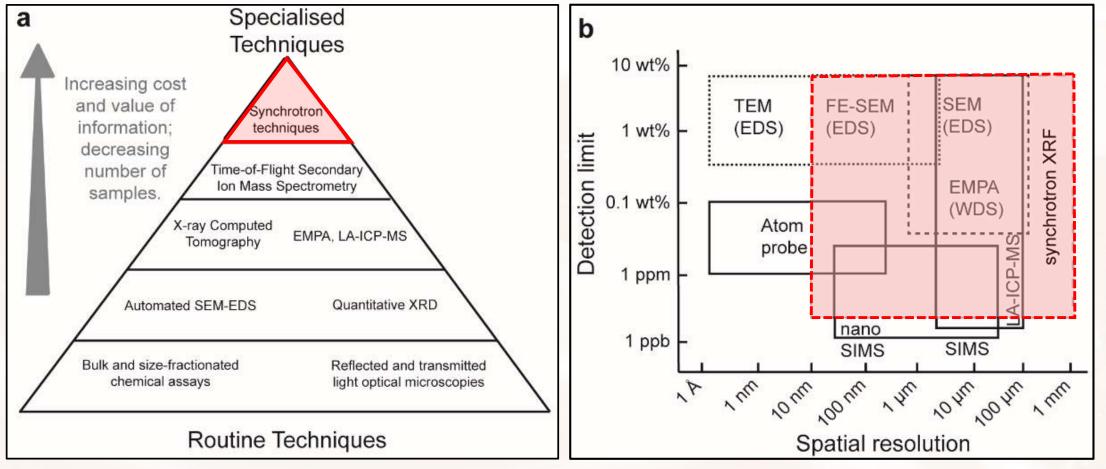
Image from: platinum-info.weebly.com

## How can we study these mineral endowments?



Figures from von der Heyden et al. (2020), originally adapted respectively from Becker et al. (2016), and Reich et al. (2017) and Stromberg et al. (2019).

## How can we study these mineral endowments?



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# But what about impacts on the environment?

 Inasmuch as legislature serves to protect the natural environment, it does not guarantee that spills, leakages from tailings facilities and other forms of emissions will not take place.

Niger delta oil spills

 Strong need to understand the fate and degradation products associated with addition of deleterious moieties into the natural environment.

> Merriespruit tailings dam disaster (1994)



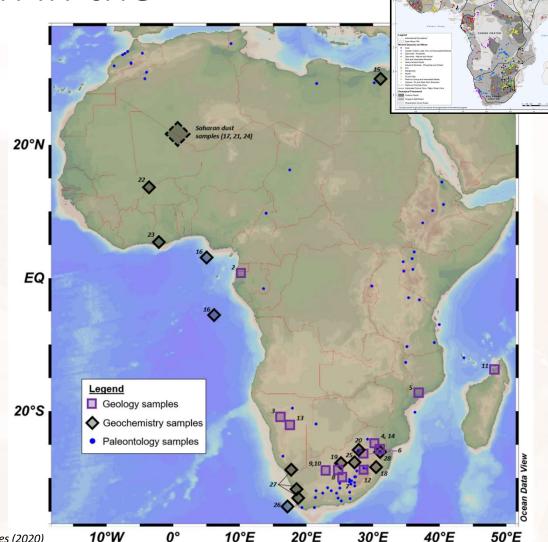
Image from: dw.com



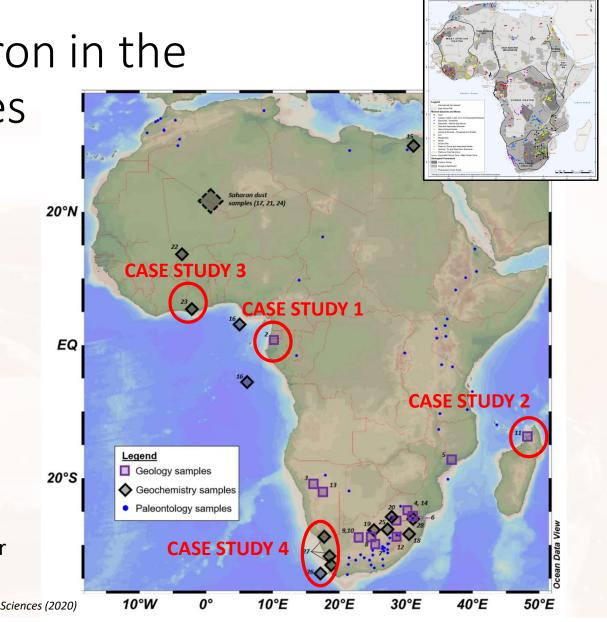
Image from: floodlist.com

# Past use of synchrotron in the African earth sciences

|  | Study   | Sample location   | Technique  | Beamline (Facility)  | Key findings   |
|--|---|---|--|--|--|
| Geol   | ogical Sciences:  | 1.1   |  |  |  |
| 1.   | Acres et al. (2010)   | Gauteng, South Africa   | eXPS   | 14ID (AS)  | Effect of bornite on oxidation and leaching of chalcopyrite  |
| 2.   | Barnes et al.   | Monte de Cristal igneous complex  | eXRF mapping   | XFM beamline (AS)  | High Pt concentrations associated with As- and Cu-Ni sulphides and   |
|  | (2016)  | (Gabon)   |  |  | forme during Pt eaturation during magmatic crystallization.  |
| S.   | Buhn et al. (1999)  | Kalkfeld carbonatite complex  | aXRF   | Beamline L   | Chemistry of REE-carbonate burbankite crystals hosted in carbonatite   |
|  |   | (Namibia)   |  | (HASYLAB)  | fluid inclusions.  |
| 4.   | Darin et al. (2016)   | UG1 chromitite (South Africa)   | aXRF   | Elemental Analysis   | Scanning of 20 trace elements' distribution in a layered sequence, with  |
|  |   |   |  | station (SSTRC)  | special emphasis on POB.   |
| 5.   | Pigueiredo et al.   | Licungo pegmatite (Mosambique)  | Fe K-edge  | ID21 (ESRF)  | Pe in octahedral Al sites possibly gives rise to blue colouration in beryla  |
|  | (2008)  |   | XANES  |  |  |
| 6.   | Gauert et al.   | Witwatergrand and Barberton   | XRF  | BAMLine (BESSY-  | Inter-calibration for trace element fingerprinting in gold (aXRF, EMPA,  |
|  | (2015)  | gold (South Africa)   |  | ID   | LA-ICP-MS).  |
| 7.   | Quilhaumou et al.   | Jagerafontein kimberlite (South   | FTIR   | MIRAGE beamline  | Chemical evaluation of µm-scale melt inclusions from kimberlite garnets  |
|  | (2005)  | Africa)   | S. 138   | (LURE)   | reveals a complex ascent history for 'ultra-deep' kimberlite material.   |
| B  | Hanger et al.   | Wesselton kimberlite (South   | Fe K-edge  | XFM beamline (AS)  | Re2+/SPe ratios used to evaluate oxidation conditions during kimberlite  |
|  | (2015)  | Africa)   | XANES  | AT AT DEMILIARE (110)  | metanomation.  |
| 0  | Johnson et al.  | Kalahari Mn Pielda  | Mn K-edge  | Beamlines 4-1 and  | Mn redox chemistry indicates Mn oxidation in the absence of O2 (i.e.,  |
|  | (2013)  | Natarial'i Will Fields  | Mn R-edge<br>XAS   | Deamlines +-1 and<br>10-2 (SSRL)   | Mn redox chemistry indicates Mn oxidation in the absence of O <sub>2</sub> (i.e.,<br>prior to the great oxygenation event).  |
| 10.  | Johnson et al.  | Kalahari Mn Pields (South Africa)   | Mn K-edge  | Beamlines 2-3 and  | Mn redox chemistry shows a change in the primary mineralogy between  |
| .0.  | (2016)  | Analahari nin Pielus (south Alrica)   | Mn R-edge<br>XAS   | 10-2 (SSRL)  | Mn redox chemistry shows a change in the primary mineralogy between<br>ancient- and more modern sedimentary Mn depositz.   |
|  |   |   |  |  |  |
| 11.  | Ram et al. (2019)   | Amparibitika intrusion  | aXRF; Ce L-  | XPM beamline (AS)  | Diverse Ce chemical speciation in ion adsorption clays (associated with  |
|  |   | (Madagascar)  | edge XAS   |  | Zr, with clay minerals as Ce <sup>3+</sup> , and with Fe/Mn oxides as Ce <sup>4+</sup> ).  |
|  |   |   |  |  | Implications for LREE cycling in surficial deposits.   |
| 12.  | Song et al. (2001)  | Lecotho Highlands (Lecotho)   | aXCT   | X27C (NSLS)  | Quantitative characterization of vesicle morphology provides insight   |
|  |   |   |  |  | into magmatic processes (e.g., volatile content, lava flow, etc.).   |
| 13.  | Sommer et al.   | Robert Victor kimberlite (South   | aFTIR  | (ANEA)   | Detection of C:O:H volatiles in defect sites in gamets suggest   |
|  | (2014)  | Africa)   |  |  | microdiamond growth in eclogites.  |
| 14.  | Takahashi et al.  | Onganja mine (Namibia)  | Re and Os L-   | BL12-C (PF);   | Determination of Re and radiogenic Or local coordination environments  |
|  | (2007)  |   | edge XAS   | BL37XU (SPring-S)  | in molybdenite mineral structure. Difference in relative diffusion rates   |
|  |   |   |  |  | has implications for Re-Os geochronology.  |
| 15.  | Vekaler et al.  | UG2 chromitite (South Africa)   | aXRF   | Elemental Analysis   | Variable trace element distributions in chromitite seams interpreted to  |
|  | (2018)  |   |  | station (SSTRC)  | reflect permeability and element diffusivity in crystallising matic melts.   |
|  |   |   |  |  |  |
| Envi   | ronmental Geochemist  | ry Sciences:  |  |  |  |
| -  | ronmental Geochemist  |   | 0205   | THOLE  |  |
| -  | Abotied et al.  | ry Sciences:<br>Giza (Egypt)  | SXRF   | FLUO beamline,   | Elemental analysis of urban serosols   |
| 16.  | Aboxied et al.<br>(2015)  | Giza (Egypt)  |  | (KIT)  |  |
| 16.  | Abozied et al.<br>(2015)<br>Bourry et al.   |   | SXRP<br>SXRD   |  | Small concentrations of $\rm H_2S$ and $\rm CO_2$ affect the type 1 $\rm CH_4$ clathrate   |
| 16.  | Abosied et al.<br>(2015)<br>Bourry et al.<br>(2007)   | Gina (Egypt)<br>Congo-Angola basin  | SXRD   | (KIT)<br>ID31 (ESRF)   | Small concentrations of $\rm H_2S$ and $\rm CO_2$ affect the type 1 $\rm CH_4$ clathrate cubic lattice structure.  |
| 16.<br>17.<br>18.  | Abotied et al.<br>(2015)<br>Bourry et al.<br>(2007)<br>Doherty (2012)   | Giza (Egypt)<br>Congo-Angola basin<br>Weat Africa   | SXRD<br>SXRD, sXRF   | (RIT)<br>ID31 (ESRF)<br>X26 (NSLS)   | Small concentrations of H <sub>2</sub> S and CO <sub>2</sub> affect the type 1 CH <sub>4</sub> clathrate<br>cubic lattice structure.<br>Elemental map, mineralogy  |
| 16.<br>17.<br>18.<br>19.   | Abotied et al.<br>(2015)<br>Bourry et al.<br>(2007)<br>Doherty (2012)<br>Eascott (2010)   | Giza (Egypt)<br>Congo-Angola basin<br>West Africa<br>KwaZulu Natal (South Africa)   | SXRD<br>SXRD, sXRP<br>SXRD, sXRP   | (R(T)<br>ID31 (ESRF)<br>X26 (NSLS)<br>X26A (NSLS)  | Small concentrations of H <sub>2</sub> S and CO <sub>2</sub> affect the type 1 CH <sub>4</sub> clathrate<br>cubic lattice structure.<br>Elemental map, mineralogy<br>Paint samples on artifacts  |
| 16.<br>17.<br>18.<br>19.   | Abotied et al.<br>(2015)<br>Bourry et al.<br>(2007)<br>Doherty (2012)<br>Eaccott (2010)<br>Ereglu et al.  | Giza (Egypt)<br>Congo-Angola basin<br>West Africa<br>KwaZulu Natal (South Africa)<br>Neoarchean Campbellirand-  | SXRD<br>SXRD, sXRF   | (RIT)<br>ID31 (ESRF)<br>X26 (NSLS)   | Small concentrations of H <sub>2</sub> S and CO <sub>2</sub> affect the type 1 CH <sub>4</sub> clathrate<br>cubic lattice structure.<br>Elemental map, mineralogy  |
| 16.<br>17.<br>18.<br>19.   | Abotied et al.<br>(2015)<br>Bourry et al.<br>(2007)<br>Doherty (2012)<br>Eascott (2010)   | Giza (Egypt)<br>Congo-Angola basin<br>West Africa<br>KwaZulu Natal (South Africa)<br>Neoarchean Campbellrand-<br>Malmani carbonate platform   | SXRD<br>SXRD, sXRP<br>SXRD, sXRP   | (R(T)<br>ID31 (ESRF)<br>X26 (NSLS)<br>X26A (NSLS)  | Small concentrations of H <sub>2</sub> S and CO <sub>2</sub> affect the type 1 CH <sub>4</sub> clathrate<br>cubic lattice structure.<br>Elemental map, mineralogy<br>Paint samples on artifacts  |
| 16.<br>17.<br>18.<br>19.   | Abotied et al.<br>(2015)<br>Bourry et al.<br>(2007)<br>Doherry (2012)<br>Earcott (2010)<br>Ereglu et al.<br>(2018)  | Giza (Egypt)<br>Congo-Angola basin<br>West Africa<br>KwaZulu Natal (South Africa)<br>Neoarchean Campbellirand-  | SXRD<br>SXRD, sXRP<br>SXRD, sXRP   | (R(T)<br>ID31 (ESRF)<br>X26 (NSLS)<br>X26A (NSLS)  | ümali concentrations of H <sub>2</sub> O and CO <sub>2</sub> affect the type 1 CH <sub>4</sub> clathrate<br>cubic lattice structure.<br>Elemental may, mineralogy<br>Paint samples on artifacti<br>Pe speciation in carbonate rich shelf sediments   |
| 16.<br>17.<br>18.<br>19.<br>20.  | Abotied et al.<br>(2015)<br>Bourry et al.<br>(2007)<br>Doherty (2012)<br>Eascott (2010)<br>Eroglu et al.<br>(2018)<br>Herries et al.  | Giza (Egypt)<br>Congo-Angola basin<br>West Africa<br>KwaZulu Natal (South Africa)<br>Neoarchean Campbellrand-<br>Malmani carbonate platform   | SXRD<br>SXRD, sXRP<br>SXRD, sXRP   | (R(T)<br>ID31 (ESRF)<br>X26 (NSLS)<br>X26A (NSLS)  | Small concentrations of H <sub>2</sub> S and CO <sub>2</sub> affect the type 1 CH <sub>4</sub> clathrate<br>cubic lattice structure.<br>Elemental map, mineralogy<br>Paint samples on artifacts  |
| 16.<br>17.<br>18.<br>19.<br>20.<br>21.   | Abocied et al.<br>(2015)<br>Bourry et al.<br>(2007)<br>Doherty (2012)<br>Eacott (2010)<br>Eroglu et al.<br>(2013)<br>Herries et al.<br>(2014)   | Gisa (Egypt)<br>Congo-Angola basin<br>West Africa<br>KwaZuluu Natal (Gouth Africa)<br>Neoarcheas Campbellrand-<br>Malmani carbonate platform<br>(South Africa)<br>Haasgat (South Africa)  | SXRD<br>SXRD, sXRP<br>SXRD, sXRP<br>XANES<br>SXRP  | (RT)<br>ID31 (ESRP)<br>X26 (NSLS)<br>X26A (NSLS)<br>ID24 (ESRP)<br>(AS)  | Umail concentrations of H <sub>2</sub> O and CO <sub>2</sub> affect the type 1 CH <sub>4</sub> clathrate<br>cubic lattice structure.<br>Blenestail maps, minesalogy<br>Paint samples on artifacts<br>Pe speciation in carbonate rich shelf addiments<br>Elemental maps of Karst samples  |
| 16.<br>17.<br>18.<br>19.<br>20.<br>21.   | Abotied et al.<br>(2015)<br>Bourry et al.<br>(2007)<br>Doherty (2012)<br>Eascott (2010)<br>Eroglu et al.<br>(2018)<br>Herries et al.  | Giza (Egypt)<br>Congo-Angola basin<br>West Africa<br>KwaZulu Natal (South Africa)<br>Nearchean Campbellrand-<br>Malmani carbonate platform<br>(South Africa)  | SXRD<br>SXRD, #XRP<br>SXRD, #XRP<br>XANES  | (KIT)<br>ID31 (ESRF)<br>X26 (NSLS)<br>X26A (NSLS)<br>ID24 (ESRF)   | ümali concentrations of H <sub>2</sub> O and CO <sub>2</sub> affect the type 1 CH <sub>4</sub> clathrate<br>cubic lattice structure.<br>Elemental may, mineralogy<br>Paint samples on artifacti<br>Pe speciation in carbonate rich shelf sediments   |
| 16.<br>17.<br>18.<br>19.<br>20.<br>21.<br>22.  | Abocied et al.<br>(2015)<br>Bourry et al.<br>(2007)<br>Doherty (2012)<br>Eacott (2010)<br>Eroglu et al.<br>(2013)<br>Herries et al.<br>(2014)   | Gisa (Egypt)<br>Congo-Angola basin<br>West Africa<br>KwaZuluu Natal (Gouth Africa)<br>Neoarcheas Campbellrand-<br>Malmani carbonate platform<br>(South Africa)<br>Haasgat (South Africa)  | SXRD<br>SXRD, sXRP<br>SXRD, sXRP<br>XANES<br>SXRP  | (RT)<br>ID31 (ESRP)<br>X26 (NSLS)<br>X26A (NSLS)<br>ID24 (ESRP)<br>(AS)  | Umail concentrations of H <sub>2</sub> O and CO <sub>2</sub> affect the type 1 CH <sub>4</sub> clathrate<br>cubic lattice structure.<br>Blenestail maps, minesalogy<br>Paint samples on artifacts<br>Pe speciation in carbonate rich shelf addiments<br>Elemental maps of Karst samples  |
| 16.<br>17.<br>18.<br>19.<br>20.<br>21.<br>22.  | Abocied et al.<br>(2015)<br>Bourry et al.<br>(2007)<br>Doherty (2012)<br>Eascott (2010)<br>Eroglu et al.<br>(2018)<br>Herrise et al.<br>(2014)<br>Longo (2016)  | Gica (Egypt)<br>Congo-Angola basin<br>Weet Africa<br>KwaZulu Natal (Gouth Africa)<br>Naoarchean Campbellrand-<br>Malmani carbonate platform<br>(Gouth Africa)<br>Sahara Desert  | SXRD<br>SXRD, aXRP<br>SXRD, aXRP<br>XANES<br>SXRF<br>XANES   | (KIT)<br>ID31 (ESRF)<br>X26 (NSL6)<br>X26A (NSL6)<br>ID24 (ESRF)<br>(AS)<br>2ID-D (APS)  | Small concentrations of H <sub>2</sub> S and CO <sub>2</sub> affect the type 1 CH <sub>4</sub> clathrate<br>cubic lattice structure.<br>Elemental map, mineralogy<br>Paint sample on availants<br>Pe speciation in carbonate rich shelf sediments<br>Pe speciation in carbonate such shelf sediments<br>Elemental maps of Kavet samples<br>Pe oxidation state and structural arrangement of atoms  |
| 16.<br>17.<br>18.<br>19.<br>20.<br>21.<br>22.<br>23.   | Aboxied et al.<br>(2015)<br>Bourry et al.<br>(2007)<br>Doherty (2012)<br>Eacost (2010)<br>Excglu et al.<br>(2016)<br>Herrice et al.<br>(2014)<br>Longo (2016)<br>Marol et al.<br>(2007)   | Oica (Egypt)<br>Congo-Angola basin<br>Weet Africa<br>KwaZulu Natal (South Africa)<br>Neoarcheas Campbellrand-<br>Malmani carbonate platform<br>(South Africa)<br>Gouth Africa)<br>Sahara Desert<br>Mali   | SXRD<br>SXRD, sXRP<br>SXRD, sXRP<br>XANES<br>SXRF<br>XANES<br>SFTIR, sXRP  | (RT)<br>ID31 (ESRP)<br>X26 (NSL6)<br>ID24 (ESRP)<br>(AS)<br>2ID-D (AP6)<br>ID21 (ESRP)   | Small concentrations of H <sub>2</sub> S and CO <sub>2</sub> affect the type 1 CH <sub>4</sub> clathrate<br>cubic lattice structure.<br>Beneratial map, mineralogy<br>Performance of the structure of the structure of the<br>Performance of Karst samples<br>Pe oscilation state and structural arrangement of atoms<br>Vibration bands, Elemental maps   |
| 16.<br>17.<br>18.<br>19.<br>20.<br>21.<br>22.<br>23.   | Abocied et al.<br>(2015)<br>Bourry et al.<br>(2007)<br>Doherty (2012)<br>Bascott (2010)<br>Ercoglu et al.<br>(2013)<br>Herries et al.<br>(2014)<br>Longo (2016)<br>Marel et al.   | Gica (Egypt)<br>Congo-Angola basin<br>Weet Africa<br>KwaZulu Natal (Gouth Africa)<br>Naoarchean Campbellrand-<br>Malmani carbonate platform<br>(Gouth Africa)<br>Sahara Desert  | SXRD<br>SXRD, aXRP<br>SXRD, aXRP<br>XANES<br>SXRF<br>XANES   | (KIT)<br>ID31 (ESRF)<br>X26 (NSL6)<br>X26A (NSL6)<br>ID24 (ESRF)<br>(AS)<br>2ID-D (APS)  | Small concentrations of H <sub>2</sub> S and CO <sub>2</sub> affect the type 1 CH <sub>4</sub> clathrate<br>cubic lattice structure.<br>Elemental map, mineralogy<br>Paint sample on availants<br>Pe speciation in carbonate rich shelf sediments<br>Pe speciation in carbonate such shelf sediments<br>Elemental maps of Kavet samples<br>Pe oxidation state and structural arrangement of atoms  |
| 16.<br>17.<br>19.<br>20.<br>21.<br>22.<br>23.<br>24.   | Abocied et al.<br>(2015)<br>Bourry et al.<br>(2007)<br>Doherty (2012)<br>Eascott (2010)<br>Erogiu et al.<br>(2018)<br>Herries et al.<br>(2014)<br>Longo (2016)<br>Masel et al.<br>(2007)<br>Menah et al.  | Gisa (Egypt)<br>Congo-Angola basin<br>West Africa<br>KwaZulu Natal (Gouth Africa)<br>Neoarcheas Campbellrand-<br>Malmani carbonate platform<br>(Gouth Africa)<br>Haagat (Gouth Africa)<br>Gahara Desert<br>Mali<br>Cold mine in western region of   | SXRD<br>SXRD, sXRP<br>SXRD, sXRP<br>XANES<br>SXRF<br>XANES<br>SFTIR, sXRP  | (RT)<br>ID51 (ESRP)<br>X26 (NSL6)<br>ID24 (ESRP)<br>(AS)<br>2ID-D (AP6)<br>ID21 (ESRP)   | Gmail concentrations of H <sub>2</sub> S and CO <sub>2</sub> affect the type 1 CH <sub>4</sub> clathrate<br>cubic lattice structure.<br>Elemental map, mineralogy<br>Performance of the structure of the selfments<br>Performance of Karst samples<br>Pe oscilation state and structural arrangement of atoms<br>Vibration hands, Elemental maps<br>As K-edge for As speciation in coll samples  |
| 16.<br>17.<br>19.<br>20.<br>21.<br>22.<br>23.<br>24.   | Abotied et al.<br>(2015)<br>Bourry et al.<br>(2007)<br>Deherty (2012)<br>Encott (2010)<br>Encott (2010)<br>Herrise et al.<br>(2014)<br>Longe (2016)<br>Massi et al.<br>(2007)<br>Massi et al.<br>(2020)<br>Petroselli et al.  | Oica (Egypt)<br>Congo-Angola basin<br>Weet Africa<br>KwaZulu Natal (South Africa)<br>Neoarcheas Campbellrand-<br>Malmani carbonate platform<br>(South Africa)<br>Sahara Decert<br>Mali<br>Oold mine in western region of<br>Ohana   | SXRD<br>SXRD, sXRP<br>SXRD, sXRP<br>XANES<br>SXRF<br>XANES<br>SPTIR, sXRP<br>XANES<br>XANES  | (KIT)<br>IDS1 (ESRP)<br>X264 (NSL6)<br>ID24 (ESRP)<br>(A5)<br>2ID-D (AP5)<br>ID21 (ESRP)<br>TLS 07A (NSRRC)  | Small concentrations of H <sub>2</sub> S and CO <sub>2</sub> affect the type 1 CH <sub>4</sub> clathrate<br>cubic lattice structure.<br>Beneratal map, mineralogy<br>Performance of the structure of the solution of the solution<br>Performance of Karst samples<br>Pe oscilation state and structural arrangement of atoms<br>Vibration bands, Elemental maps  |
| 16.<br>17.<br>18.<br>19.<br>20.<br>21.<br>23.<br>24.<br>25.  | Abotid et al.<br>(2015)<br>Bourry et al.<br>(2007)<br>Doherry (2012)<br>Exegue et al.<br>(2014)<br>Longe (2016)<br>Massi et al.<br>(2014)<br>Longe (2016)<br>Massi et al.<br>(2007)<br>Menash et al.<br>(2020)  | Oica (Egypt)<br>Congo-Angola basin<br>West Africa<br>KwaZulu Natal (South Africa)<br>Neoarchean Campbellrand-<br>Malmani carbonase platform<br>(South Africa)<br>Haasgat (South Africa)<br>Sahara Desert<br>Mali<br>Oold mine in western region of<br>Ohana<br>Sahara Desert  | SXRD<br>SXRD, ±XRP<br>SXRD, ±XRP<br>XANES<br>SXRF<br>XANES<br>SFTIR, ±XRP<br>XANES<br>XANES<br>XANES,<br>EXAPS   | (RT)<br>ID31 (ESRF)<br>X26 (NSLD)<br>X264 (NSLD)<br>ID24 (ESRF)<br>(AS)<br>2ID-D (APS)<br>ID21 (ESRF)<br>TLE 07A (NERRC)<br>EM06 (ESRF)                                    | Gmail concentrations of H <sub>2</sub> S and GO <sub>2</sub> affect the type 1 CH <sub>4</sub> clathrate<br>cubic lattice structure.<br>Benesatial mays, mineralogy<br>Paint samples on artifacts<br>Pe speciation is carbonate sich shelf sediments<br>Elemental maps of Karst samples<br>Pe oxidation state and structural arrangement of atoms<br>Vibration bands, Elemental maps<br>As K-edge for As speciation in soil samples<br>Pe K-edge, Pe coordination structure  |
| 16.<br>17.<br>18.<br>19.<br>20.<br>21.<br>23.<br>24.<br>25.  | Aboxied et al.<br>(2015)<br>Bourry et al.<br>(2007)<br>Encoder (2012)<br>Encoder (2010)<br>Herrice et al.<br>(2014)<br>Massil et al.<br>(2007)<br>Massil et al.<br>(2007)<br>Petroselli et al.<br>(2020)<br>Petroselli et al.<br>(2019)<br>Encoder et al.   | Oica (Egypt)<br>Congo-Angola basin<br>Weet Africa<br>KwaZulu Natal (South Africa)<br>Neoarcheas Campbellrand-<br>Malmani carbonate platform<br>(South Africa)<br>Sahara Decert<br>Mali<br>Oold mine in western region of<br>Ohana   | SXRD<br>SXRD, sXRP<br>SXRD, sXRP<br>XANES<br>SXRF<br>XANES<br>SPTIR, sXRP<br>XANES<br>XANES  | (KIT)<br>IDS1 (ESRP)<br>X264 (NSL6)<br>ID24 (ESRP)<br>(A5)<br>2ID-D (AP5)<br>ID21 (ESRP)<br>TLS 07A (NSRRC)  | Gmail concentrations of H <sub>2</sub> S and CO <sub>2</sub> affect the type 1 CH <sub>4</sub> clathrate<br>cubic lattice structure.<br>Bienestial map, mineralogy<br>Performance of the structure of the structure of the structure<br>Performance of Karst samples<br>Pe oscilation state and structural arrangement of atoms<br>Vibration bands, Elemental maps<br>As K-edge for As speciation in coll samples  |
| 16.<br>17.<br>18.<br>19.<br>20.<br>21.<br>23.<br>24.<br>25.<br>26.                                     | Aboried et al.<br>(2015)<br>Bourry et al.<br>(2007)<br>Doherry (2012)<br>Eacout (2010)<br>Ecopia et al.<br>(2014)<br>Longe (2016)<br>Manal, et al.<br>(2007)<br>Menanh, et al.<br>(2020)<br>Perrocall et al.<br>(2020)<br>Demonent al.,<br>(2005), 2009   | Oica (Egypt)<br>Congo-Angola basin<br>West Africa<br>KwaZulun Natai (South Africa)<br>Neoarchean Campbellrand-<br>Malmani carbonate platform<br>(South Africa)<br>Haasgat (South Africa)<br>Sahara Desert<br>Mali<br>Gold mine in western region of<br>Ohana<br>Sahara Desert<br>Free State Province (South Africa)   | SXRD<br>SXRD, =XRP<br>SXRD, =XRP<br>XANES<br>SXRF<br>XANES<br>SYTIR, =XRP<br>XANES<br>XANES,<br>EXAPS<br>XANES,<br>EXAPS<br>XANES  | (NT)<br>ID31 (ESP)<br>X26 (NEL2)<br>X26 (NEL2)<br>ID24 (ESP)<br>(AS)<br>2ID-D (APG)<br>ID21 (ESP)<br>TL2 07A (NSERC)<br>BM00 (ESP)<br>X19A (NL2)                           | Gmail concentrations of H <sub>2</sub> S and GO <sub>2</sub> affect the type 1 CH <sub>4</sub> clathrate<br>cubic lattice structure.<br>Beanearial mays mineralogy<br>Paint samples on artifacts<br>Pe speciation is carbonate rich shelf ardiments<br>Elemental maps of Karst samples<br>Pe oscilation state and structural arrangement of atoms<br>Vibration bands, Elemental maps<br>As K-edge for As speciation in soil samples<br>Pe K-edge, Pe coordination structure<br>& K-edge for S speciation in arable soils   |
| 16.<br>17.<br>18.<br>19.<br>20.<br>21.<br>23.<br>24.<br>25.<br>26.                                     | Aboxied et al.<br>(2015)<br>Bourry et al.<br>(2007)<br>Exeguit et al.<br>(2014)<br>Herries et al.<br>(2014)<br>Herries et al.<br>(2014)<br>Massil et al.<br>(2007)<br>Massil et al.<br>(2007)<br>Petrosell et al.<br>(2019)<br>Ecolomon et al.,<br>(2008), 2009<br>von det Heyden   | Gisa (Egypt)<br>Congo-Angola basin<br>West Africa<br>KwaZuluu Natal (Gouth Africa)<br>Neoarcheas Campbellrand-<br>Malmani carbonate platform<br>(Gouth Africa)<br>Bahara Desert<br>Mali<br>Oold mine in western region of<br>Ghana<br>Sahara Desert<br>Free State Province (South Africa)<br>Cape Basin (South Africa) and  | SXRD<br>SXRD, sXRP<br>SXRD, sXRP<br>XANES<br>SXRF<br>XANES<br>SFTIR, sXRF<br>XANES<br>XANES<br>SXANES<br>STXM, Fe L-   | (RT)<br>ID31 (ESRF)<br>X26 (NSLD)<br>X264 (NSLD)<br>ID24 (ESRF)<br>(AS)<br>2ID-D (APS)<br>ID21 (ESRF)<br>TLE 07A (NERRC)<br>EM06 (ESRF)                                    | Email concentrations of H <sub>2</sub> S and CO <sub>2</sub> affect the type 1 CH, clathrate<br>cubic lattice structure.<br>Elemental maps immenology<br>Paint tamples on artifacts<br>Pe speciation in carbonate rich chelf sediments<br>Elemental maps of Karst samples<br>Pe oxidation state and structural arrangement of atoms<br>Vibration bands, Elemental maps<br>As K-edge for As speciation in soil samples<br>Pe K-edge, Pe coordination structure<br>2 K-edge of S speciation in arable soils<br>Determination of valence and local coordination environment of Pe in  |
| 16.<br>17.<br>18.<br>19.<br>20.<br>21.<br>23.<br>24.<br>25.<br>26.                                     | Aboried et al.<br>(2015)<br>Bourry et al.<br>(2007)<br>Doherry (2012)<br>Eacout (2010)<br>Ecopia et al.<br>(2014)<br>Longe (2016)<br>Manal, et al.<br>(2007)<br>Menanh, et al.<br>(2020)<br>Perrocall et al.<br>(2020)<br>Demonent al.,<br>(2005), 2009   | Oica (Egypt)<br>Congo-Angola basin<br>West Africa<br>KwaZulun Natai (South Africa)<br>Neoarchean Campbellrand-<br>Malmani carbonate platform<br>(South Africa)<br>Haasgat (South Africa)<br>Sahara Desert<br>Mali<br>Gold mine in western region of<br>Ohana<br>Sahara Desert<br>Free State Province (South Africa)   | SXRD<br>SXRD, =XRP<br>SXRD, =XRP<br>XANES<br>SXRF<br>XANES<br>SYTIR, =XRP<br>XANES<br>XANES,<br>EXAPS<br>XANES,<br>EXAPS<br>XANES  | (NT)<br>ID31 (ESP)<br>X26 (NEL2)<br>X26 (NEL2)<br>ID24 (ESP)<br>(AS)<br>2ID-D (APG)<br>ID21 (ESP)<br>TL2 07A (NSERC)<br>BM00 (ESP)<br>X19A (NL2)                           | Gmail concentrations of H <sub>2</sub> S and CO <sub>2</sub> affect the type 1 CH <sub>4</sub> disturate<br>cubic lattice structure.<br>Elemental maps minerology<br>Paint samples on artifacto<br>Pe upeciation in carbonate rich shelf aediments<br>Elemental maps of Karst samples<br>Pe ossilation state and structural arrangement of atoms<br>Vibration bands, Elemental maps<br>As K-edge for As speciation in soil samples<br>Pe K-edge, Pe coordination structure<br>& K-edge for S speciation in arable soils<br>Determination of valence and local coordination environment of Pe in<br>impreded maxime particulates and annoparticles provides insight in the  |
| 16.<br>17.<br>18.<br>19.<br>20.<br>21.<br>22.<br>23.<br>24.<br>25.<br>25.<br>27.                       | Aboxied et al.<br>(2015)<br>Bourry et al.<br>(2007)<br>Encode (2010)<br>Encode (2010)<br>Herrise et al.<br>(2014)<br>Massi et al.<br>(2004)<br>Massi et al.<br>(2007)<br>Petroselli et al.<br>(2009)<br>Petroselli et al.<br>(2019)<br>Solomon et al.<br>(2019)<br>et al.<br>(2019)<br>Ecolomon et al.<br>(2019)<br>Ecolomon et al.<br>(2019)<br>Ecolomon et al.<br>(2019)  | Gisa (Egypt)<br>Congo-Angola basin<br>West Africa<br>KwaZuluu Natal (Gouth Africa)<br>Neoarchean Campbellrand-<br>Malimani carbonate platform<br>(Gouth Africa)<br>Bahara Desert<br>Mali<br>Oold mine in western region of<br>Ohana<br>Sahara Desert<br>Free State Province (South Africa)<br>Cape Basin (South Africa) and<br>Southern Ocean   | SXRD<br>SXRD, =XRP<br>SXRD, =XRP<br>XANES<br>SXRF<br>XANES<br>STIR, =XRP<br>XANES<br>XANES<br>STXM, Fe L-<br>edge XAS  | (RT)<br>ID31 (EGRF)<br>X264 (NGL6)<br>X264 (NGL6)<br>ID24 (EGRF)<br>(AS)<br>ID24 (EGRF)<br>TL6 07A (NGRC)<br>BM00 (EGRF)<br>X19A (NSL6)<br>11.0.2 (LBNL)                   | Email concentrations of H <sub>2</sub> S and CO <sub>2</sub> affect the type 1 CH, clathrate<br>cubic lattice structure.<br>Elemental maps immesslogy<br>Paint tamples on artifacti<br>Pe speciation in carbonate rich thelf sediments<br>Elemental maps of Karst samples<br>Pe oxidation state and structural arrangement of atoms<br>Vibration bands, Elemental maps<br>As K-edge for As speciation in soil samples<br>Pe K-edge, Pe coordination structure<br>E K-edge, Co Speciation in arable soils<br>Determination of valence and local coordination environment of Pe in<br>suppended matice particulates and annoparticles provides insights into<br>biogeochemical orginal of the source are structure.  |
| 16.<br>17.<br>18.<br>19.<br>20.<br>21.<br>22.<br>23.<br>24.<br>25.<br>25.<br>26.<br>27.                | Abozied et al.<br>(2015)<br>Bourry et al.<br>(2007)<br>Doherry (2012)<br>Encode (2012)<br>Encode et al.<br>(2014)<br>Longo (2016)<br>Herrise et al.<br>(2017)<br>Messah et al.<br>(2007)<br>Messah et al.<br>(2007)<br>Personelli et al.<br>(2008), 2009<br>von der Heyden  | Gira (Egypt)<br>Congo-Angola basin<br>Weet Africa<br>KwaZulu Natai (South Africa)<br>Neoarchean Campbellrand-<br>Malmani carbonate platform<br>(South Africa)<br>Haasgat (South Africa)<br>Sahara Desert<br>Mali<br>Gald mine in western region of<br>Ohana<br>Sahara Desert<br>Pree State Province (South Africa)<br>Cape Basin (South Africa) and<br>Southern Ocean<br>Orange, Olifanta and Berg Rivers | CXRD<br>CXRD, =XRP<br>CXRD, =XRP<br>XANES<br>SXRF<br>XANES<br>STIR, =XRF<br>XANES<br>EXAFG<br>XANES<br>STXM, Fe L-<br>edge XAS<br>STXM, Fe L-  | (NT)<br>ID31 (ESP)<br>X26 (NEL2)<br>X26 (NEL2)<br>ID24 (ESP)<br>(AS)<br>2ID-D (APG)<br>ID21 (ESP)<br>TL2 07A (NSERC)<br>BM00 (ESP)<br>X19A (NL2)                           | Gmail concentrations of H <sub>2</sub> S and CO <sub>2</sub> affect the type 1 CH <sub>4</sub> clathrate<br>cubic lattice structure.<br>Elemental maps minerology<br>Paint samples on artifacts<br>Pe uperiation in carbonate rich shelf sediments<br>Elemental maps of Karst samples<br>Pe ossidation state and structural arrangement of atoms<br>Vibration bands, Elemental maps<br>As K-edge for As speciation in soil samples<br>Pe K-edge, Pe coordination structure<br>E K-edge for S speciation in arable soils<br>Determination of valence and local coordination environment of Pe in<br>impended market and local coordination environment of Pe in<br>impended market and local coordination environment of A within Petiotic<br>biogeochemical cycling of this important bio-active trace nutrient. |
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#### von der Heyden et al., Journal of African Earth Sciences (2020)

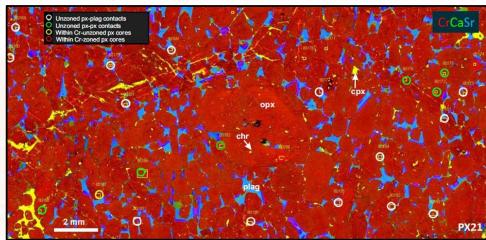


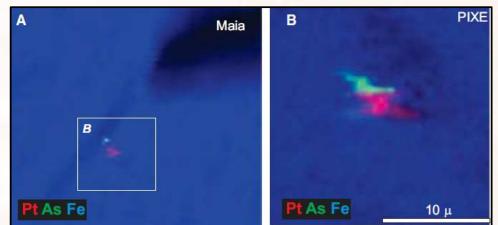
# Past use of synchrotron in the African earth sciences

- Case study 1: Mineral resources geology
  - Platinum associations in a Cu-Ni magmatic sulphide system (Barnes et al. 2016)
- Case study 2: Mineral resources geology
  - LREE cycling in surficial deposits (Ram et al. 2019)
- Case study 3: Environmental geochemistry
  - As speciation in soils (Mensah et al. 2020)
- **Case study 4:** Environmental geochemistry
  - Fe speciation in aquatic systems (von der Heyden et al. 2012, 2014, 2018)

# Case study 1: Platinum in the Monts de Cristal Complex, Gabon (Barnes et al., 2016)

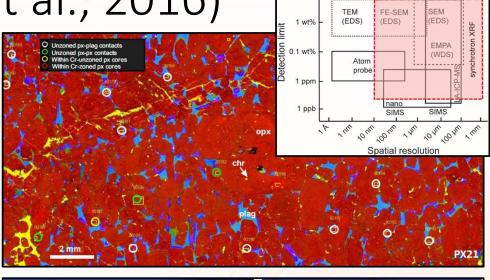
- XFM beamline at the Australian Synchrotron (equipped with Maia detector array).
- "Pt minerals less than 5 μm in diameter can be detected in samples containing 10 s of ppb Pt, with scanning times of a few hours per standard sized thin section."
- Synchrotron used to locate grains of interest for both further synchrotron study and interrogation using µPIXE.
- Studies concludes that Pt alloys (and arsenides) can crystallize directly from magmatic systems when saturation occurs at the Pt solubility limit.

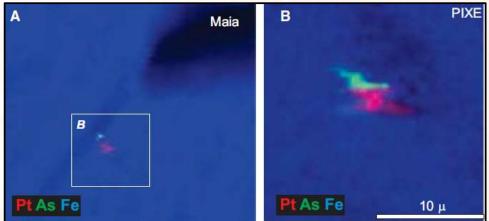




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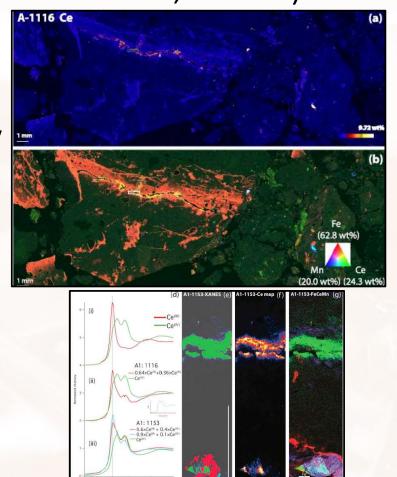
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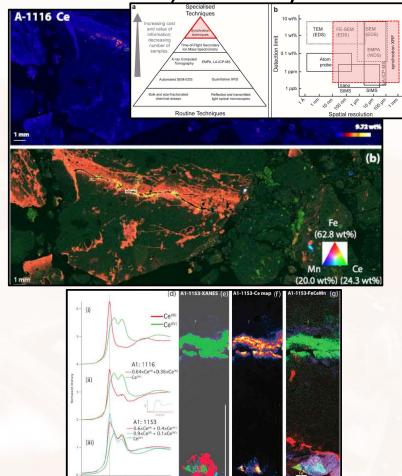
## Case study 2: REE characterization in ionadsorption clays in Madagascar (Ram et al., 2019)

- XFM beamline at the Australian Synchrotron (equipped with Maia detector array).
- REE distributions within a heterogeneous clay mineralogy using sXRF. Show some associations with Zr and Fe-Mn oxides.
- Additional insights related to Ce speciation obtained from XANES analysis.
- Identification of Ce(IV) has implications for beneficiation strategies, with a net result of increasing the HREE grade of the deposit.



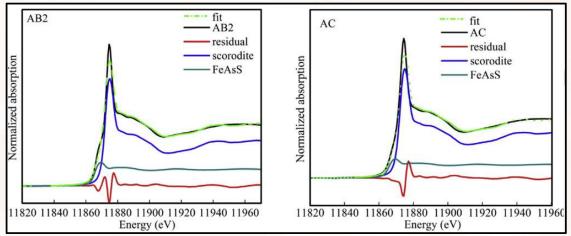
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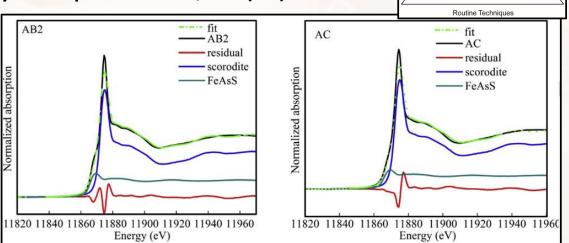
Case study 3: Arsenic speciation in tailing materials from gold mines in Ghana (Mensah et al., 2020)

- TLS 07A beamline, National Synchrotron Radiation Research
- Centre (NSRRC), Taiwan.
- Au and As are strongly associated. Au mining can be a notable point source of As release into the environment.
- As toxicity is strongly controlled by its speciation, As(III) more toxic than As(V).
- Scorodite and arsenopyrite are the two major forms of As in the spoils, typically associated with fine fractions.



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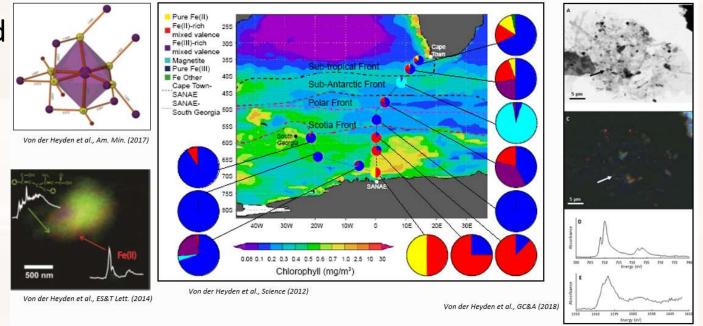
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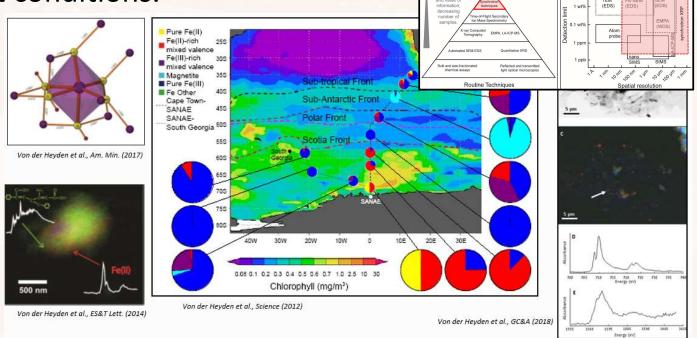
# Case study 4: Fe speciation in aquatic particles, South Africa (von der Heyden et al.)

- Beamline 11.0.2 at the Advanced Light Source, USA.
- Soft X-ray spectroscopy allows evaluation of natural colloids and nanoparticles at ambient conditions.
- Series of studies showed differences in Fe speciation, associations between Fe(II) and organic matter, and variable levels of Al substitution.



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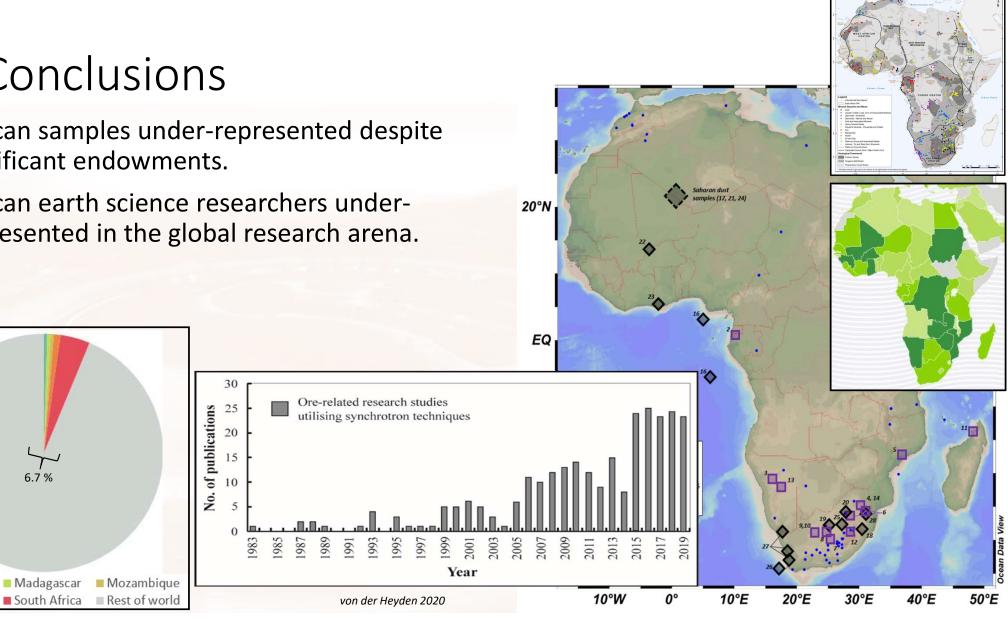
# Conclusions

6.7 %

Gabon

Namibia

- African samples under-represented despite significant endowments.
- African earth science researchers underrepresented in the global research arena.



# Conclusions

6.7 %

Gabon

Namibia

Madagascar Mozambigue

South Africa Rest of world

- African samples under-represented despite significant endowments.
- African earth science researchers underrepresented in the global research arena.
- African light source or collaborations with partners to mitigate these under representations.

30

25

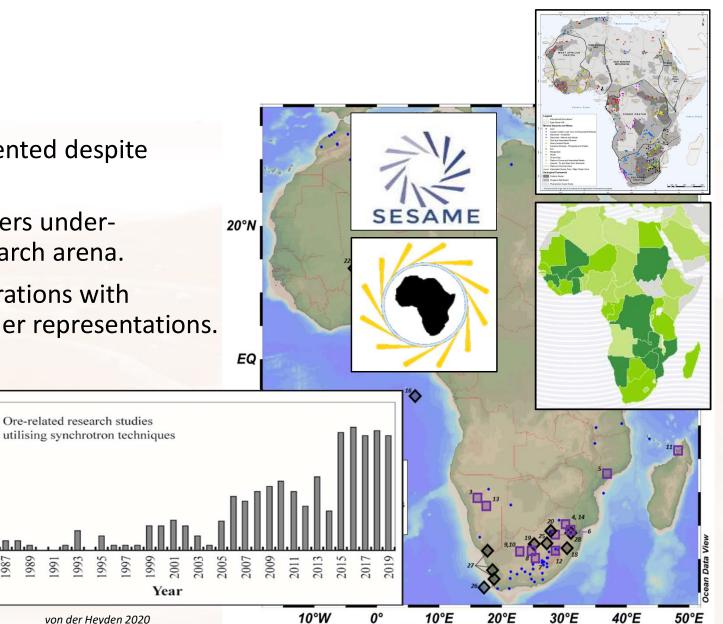
20 15

10 5 0

983

991

No. of publications







### **SESAME - AFRICA ONLINE WORKSHOP**

# Acknowledgements

- You as the audience.
- The African Light Source Conference- and Steering committees.
- Co-authors (A. Roychoudhury; J.Benoit; V. Fernandez) of the Journal of Africa Earth Sciences publication.
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- Funding agencies including NRF-DSI CIMERA.



DST-NRF Centre of Excellence for Integrated Mineral and Energy Resource Analysis

Background photo credit: www.esrf.eu





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# Questions??



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Background photo credit: www.esrf.eu

# Ongoing interventions towards advancing earth sciences interactions

- African Light Source (AfLS) conceptual design report
  - Letters of interest can be emailed to <u>bvon@sun.ac.za</u>
- African Strategy for Fundamental and Applied Physics (ASFAP): Earth Sciences working group
  - Letters of interest can be emailed to <u>ASFAP-EarthScience@cern.ch</u>



# What are the Earth Sciences?

- Broad umbrella term: necessarily an interdisciplinary and 'systems science' field of study.
- 'Multi-spheric' comprising lithosphere, hydrosphere, biosphere, cryosphere, troposphere, stratosphere, and all the way out to the exosphere.
- Selected sub-disciplines include:
  - geology, meteorology, climatology, oceanography, environmental science, hydrogeology, astronomy, tectonics, seismology, mineralogy and petrology, geochronology, ecotoxicology, among others...



Image taken from: https://science.nasa.gov/earth-science

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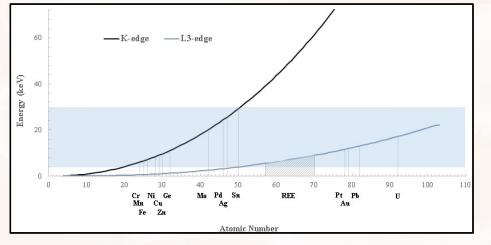
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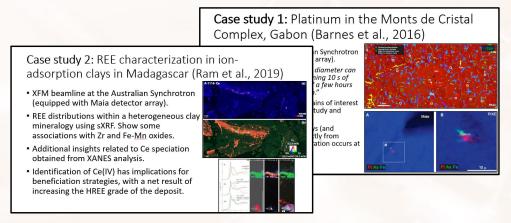
# Overview of the synchrotron needs of the African Earth Sciences community

#### Geological sciences

- Hard X-ray beamline
- Should access an energy of at least 40 keV to evaluate important metal K-edges.
- Tuneable spot size.
- Possibly a specialized end-station configuration.

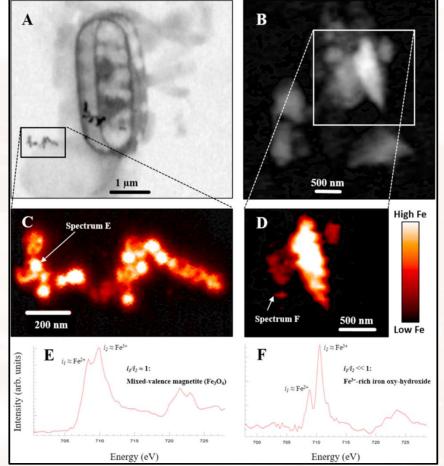


- Multi-detector array
- An array of 384 silicon-based detector elements which enables fast (0.2 ms per pixel) elemental mapping at spatial resolutions as small as 2 μm over relatively large sample areas (e.g., 7 cm<sup>2</sup>).
- Preferably accessing X-ray energies up to 40 keV with spot size as small as 2 μm.



# Overview of the synchrotron needs of the African Earth Sciences community

- Environmental geochemistry beamline
  - Soft X-ray spectroscopy
  - Environmental samples are commonly composed of low molecular weight elements, contain biological fractions or are analysed as thin films that are prone to beam damage when exposed to high energy beams.
  - Soft X-ray beamline (50 eV–2000 eV) and should have both spectroscopic and microscopic capabilities (e.g., STXM).
  - Spectral resolution of at least 0.2 eV, and spatial resolution of 10 nm or better.
  - Operate under atmospheric and high vacuum conditions.
  - Time resolved measurements



von der Heyden et al., 2019, 2020