

Geosites in the Makuleke Contract Park¹



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Limpopo River Section

Modern sedimentation processes can be observed in the flowing Limpopo River and on its banks. In the water, one can see ripples forming in the sand as the current flows over it. One can also observe how sand grains are differentially distributed—the lighter particles are transported up and over the ripple crest and deposited on the other side, whereas the dark-coloured, heavier minerals are left behind.

A small trench cut down into the sand reveals a series of layers of slightly different colour or texture, representing successive batches of sand deposited by the river. Slight changes in water flow and sediment input can change the proportion of fine and coarse particles deposited. The faster the flow of the water, the higher the energy, and the larger the particle that can be carried in suspension. When the current speed drops, the largest particles are the first to be deposited. Tiny clay particles are the last to drop out of suspension, when the flow is very slow or not moving at all. The current speed is fastest in the centre of the river or in the outside bends of meanders, and slowest near the banks or in the inside curve of meanders. The river also changes course with time, causing a shift in the nature of sediments deposited in one place.

Relatively recent river deposition processes are also seen in the incised banks of the Limpopo where the unconsolidated sediment shows variable clay and sand content, as well as shrink-swell structures, indicative of changing depositional environment and weather patterns in the ancient Limpopo system (Figure 1). There is also evidence of biological activity (plant roots, worm burrows) that can be preserved in the rock once it is lithified.

¹ In April 2017, Clive Thompson convened a field excursion opportunity for geologists Grant Bybee and Trish Owen-Smith to scout and then write up observations on geosites in the Makuleke Contract Park to assist local trail guides as they provide interpretations to trail participants. Clive and fellow trail guide Calvin de la Ray accompanied Grant and Trish. For some foundational geological context for Makuleke, see the notes compiled by Prof Ray Durrheim following his visit to Makuleke in 2009. Some minor editing and photo additions to these notes have been done by Clive Thompson. See also the notes compiled for RETURNAfrica by Johna Turner in 2017, and the KNP's own Trail Guides geology materials.

Interestingly, the Limpopo River System has been in existence in various forms since about 180 million years ago, when it had its headwaters in the Angolan highlands, and has survived supercontinent breakup and the subsequent geodynamic changes at 60 Ma and more recently.

This would be a useful geosite to visit first up as one can highlight active sedimentary processes and structures that can then be observed in the approx. 250-180 Ma Elliot and Clarens Formations of the Karoo Supergroup at geosites like Lanner Gorge.



Figure 1: Layering in a section of the bank of the Limpopo River. Darker, finer layers indicate a higher proportion of clay minerals, whereas lighter, coarser layers contain a higher proportion of sand. The hard, white layer in the centre likely formed when salts precipitated between the sediment grains during a particularly arid period.

Lanner Gorge (top and bottom)

The rocks of Lanner Gorge preserve an ancient sedimentary system, now lithified. Approximately 230-million year-old sedimentary structures, similar to those observed at the modern-day Limpopo River Geosite (see above), are preserved in the rock in various places in Lanner Gorge, including at the lookout point and in the E-W section of the gorge. The sidewalls of the gorge show a stratigraphic change from the Elliot Formation to the Clarens Formation, marking a dramatic shift in climate on the Gondwana supercontinent. The Elliot formation consists mainly of fluvial (river-deposited) mudstones and sandstones formed in a floodplain environment, whereas the Clarens rocks are aeolian (wind-deposited) sandstones formed in a desert environment. During

this time-period, the Gondwana supercontinent was slowly drifting northwards and warming as a result.



Elliot formation at the very base of Lanner Gorge, just below the Lookout point (pictures above and below: Clive Thompson)



The rocks at the lookout point are white, relatively fine-grained Clarens sandstones, which represent ancient dune sands, analogous to the Kalahari today. The material deposited by wind

is generally finer and more homogenous than that carried by river water (wind can only carry sand and dust-sized particles), so there is not the same variation in grain size and textures as one sees in the Limpopo River sediments, for example.

On some rock faces, one can observe faint **cross-bedding** between the layers (Figure 2)—remnants of the foresets of migrating dunes, formed in the same way as ripples, but on a larger scale (Figure 3).

In some places in the sandstone, one can also see darker-coloured spots, rings or nodules called **calcareous concretions** (Figure 4). Concretions form once the sediment has already been laid down, but before it becomes solid rock. During this lithification process, any moisture the sediment contains dries up. This moisture usually carries dissolved salts that then precipitate out—they are left behind in the sediment as a solid residue. This precipitation usually occurs around a nucleus—a solid object such as a soil granule or piece of organic matter that provides a surface for the salt crystals to grow on. As more material precipitates, the concretion grows radially outwards to form a rounded nodule. Because slightly different salts may precipitate out at different times, the nodule can be zoned, giving the appearance of concentric rings. The salts grow in the pore spaces between sediment granules, effectively cementing them together. Therefore when the rock is later on exposed to the elements and weathers, this part of the rock is more difficult to break apart, so remains behind sticking up out of the rock. The most common mineral to form by this process is calcite (CaCO_3)—a combination of the Ca ions and CO_2 gas dissolved in the pore water—hence the term ‘calcareous’.

Although we have not walked the river section of the gorge due to the high-water levels in April 2017, various sources indicate that there are abundant sedimentary structures and potential fossils (as well as trace fossils) in these strata.

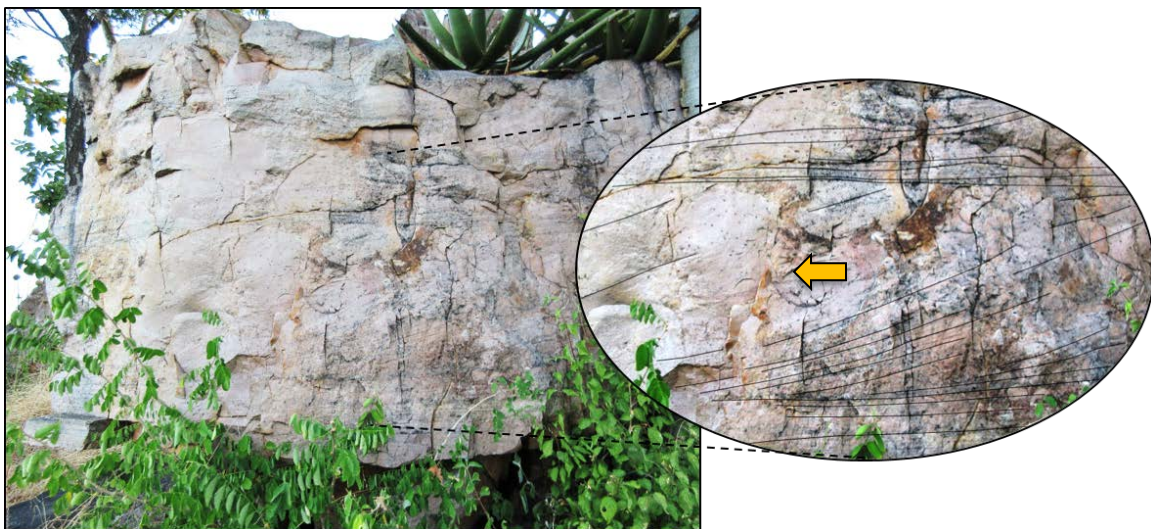


Figure 2: White Clarens sandstone at the Lanner Gorge lookout, showing cross-bedding (delineated in zoomed-in view). These remnants of ancient dune foresets indicate the direction of dune migration, i.e. the palaeowind direction (arrow).



Figure 3: Diagram showing the formation of cross-bedding by dune migration.



Figure 4: Round, zoned calcareous concretions in Clarens sandstone at the Lanner Gorge lookout point.

Hutwini Gorge

A section of Clarens sandstone is also preserved in the sidewalls of the Hutwini Gorge. Similar sedimentary structures may be observed to at the Lanner lookout point, but on a smaller scale. It is also clear that the bedding (layering) in the sandstones is tilted at a relatively steep angle towards the north-east. Since we know that the sediments were originally deposited horizontally, we can conclude that the rock was affected by tectonic processes subsequent to lithification.

Fluids travelling through fractures and joints in the rock (once already lithified) precipitated layers of calcite to form white veins in the rock and smooth coatings along joint planes (Figure 5b). Whereas the sandstone appears granular (one can distinguish individual grains of quartz), the calcite forms interlocking crystals that are difficult to detect with the naked eye and feel smooth

to the touch. A small drop of acid will make the calcite effervesce as the CO_2 gas is released from the mineral structure. Quartz (SiO_2) will show no reaction, so this is an easy test to distinguish the two minerals. Quartz is very unreactive in general and therefore the sandstones are quite resistant to weathering processes and stand out as prominent hills in the area.

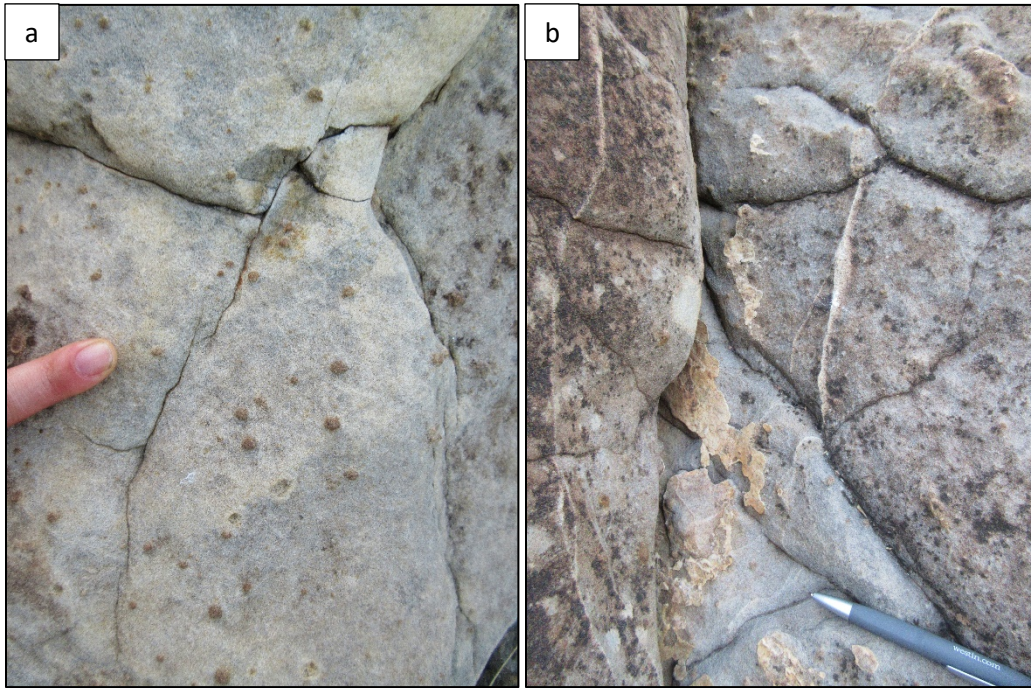


Figure 5: a) Small calcareous concretions and b) calcite veins in the white Clarens sandstones in Hutwini Gorge.

Mashisiti and/or Palm Springs (with Milkwood Gorge)

The Makuleke Contract Park hosts numerous, perennial, natural springs that occur both in the Clarens sandstones and the Lebombo basalts and commonly emanate close to the contact between these two units. Springs usually occur where an aquifer (a water-bearing rock layer) intersects the land surface, causing a seepage/flow of water. Why are these springs, which undoubtedly play a crucial role in sustaining the ecosystem during the dry season, so common in the Park and what promotes their formation?

The geological terrane of the Park is heavily faulted; the rocks are criss-crossed with numerous weaknesses. Deep beneath the Earth's surface, these faults allow rock masses to move (or jerk) relative to one another—this movement releases energy (seismic waves), which we feel in the form of earthquakes. When these faults are exposed on the surface, they act as weaknesses along which water can more easily erode the rock, forming the valleys and gorges that are so prominent in the Park.

Milkwood Gorge is a good example of a gorge created by the action of water along a fault line. How do we know this? Towards the bottom of Milkwood, a sub-vertical rock surface is observed with clear striations indicating the scraping/gouging action of two rock masses against each other (Figure 6). This striated surface also preserves evidence for the direction of movement along the fault plane. If you run your hand along the striations, the direction of movement feels smooth, whereas the opposite direction has small wedges that feel resistant against your fingertips. In the gorge sidewall on the opposite side of the river to the striated surface, one can also see a fault splay (a secondary branch of the main fault) running through the rock, with intense fracturing of the rock around it (Figure 7).



Figure 6: Striated rock surface formed by two rock masses grinding against each other along a fault plane. The pen points in the direction of movement.



Figure 7: The crack running up the sidewall is a fault splay. Note how fractured and jointed the rocks appear near the fault.

Faults can also act as conduits that allow water in aquifers to reach the surface. This is the most reasonable mechanism explaining the abundance of springs in the Park. In addition to these surface-intersecting conduits, the appearance of springs can also be facilitated by barriers to water flow in aquifers beneath the surface. Intrusions of magma cut across the sedimentary rock layers and solidify as masses of interlocking crystals, which are impermeable to fluid flow. Water percolating through the pore spaces in the sedimentary rock aquifer backs up against this barrier and can be forced up to surface. This scenario is likely for several springs in the Park including the Mashisiti and Mataphela Springs. In the case of Mashisiti, a vertical intrusion, or dyke, with SE-NW orientation, can be clearly observed on satellite imagery running from the airstrip towards Mashisiti. This dyke could act as a barrier to southerly aquifer flow in the rocks beneath Mashisiti, forcing water to the surface along faults and fractures in the rock and consequently forming a spring upslope from the dyke. The composition of this dyke is unknown at this point but it could be basaltic or similar in composition to that found at Mataphela.

Prominent chalky white layers of rock containing variably sized pebbles of other rock material are commonly associated with springs in the Park. Both Mashisiti and Palm Springs preserve excellent examples of these layers, known as **calcrete** (Figure 8, 9). Calcrete normally forms in water-saturated soil that begins to dry out during extensive arid periods, causing the pore water in the sediment to become super-saturated in its dissolved ions, such as Ca, which then precipitate out together with carbonate (CO_3). This process of precipitation cements the soil, or larger particles

like river boulders, together to form a layer of calcrete. Palm Springs represents an example where large river boulders have been incorporated into the calcrete (Figure 8).

Calcrete is commonly associated with springs in the Park, but there is not a direct casual relationship between the two. The presence of perennial springs simply allows the soil to become water logged, so there is a constant supply of salt-bearing pore water. Evidence that calcrete is not only associated with springs can be found on the Rhino Boma Road where the basaltic soil is peppered with calcareous nodules—the beginnings of calcrete formation during long dry periods.



Figure 8: White calcrete enveloping river boulders at Palm Springs.



Figure 9: A thick calcrete layer containing basaltic granules from the original soil layer cemented together by calcareous salts.

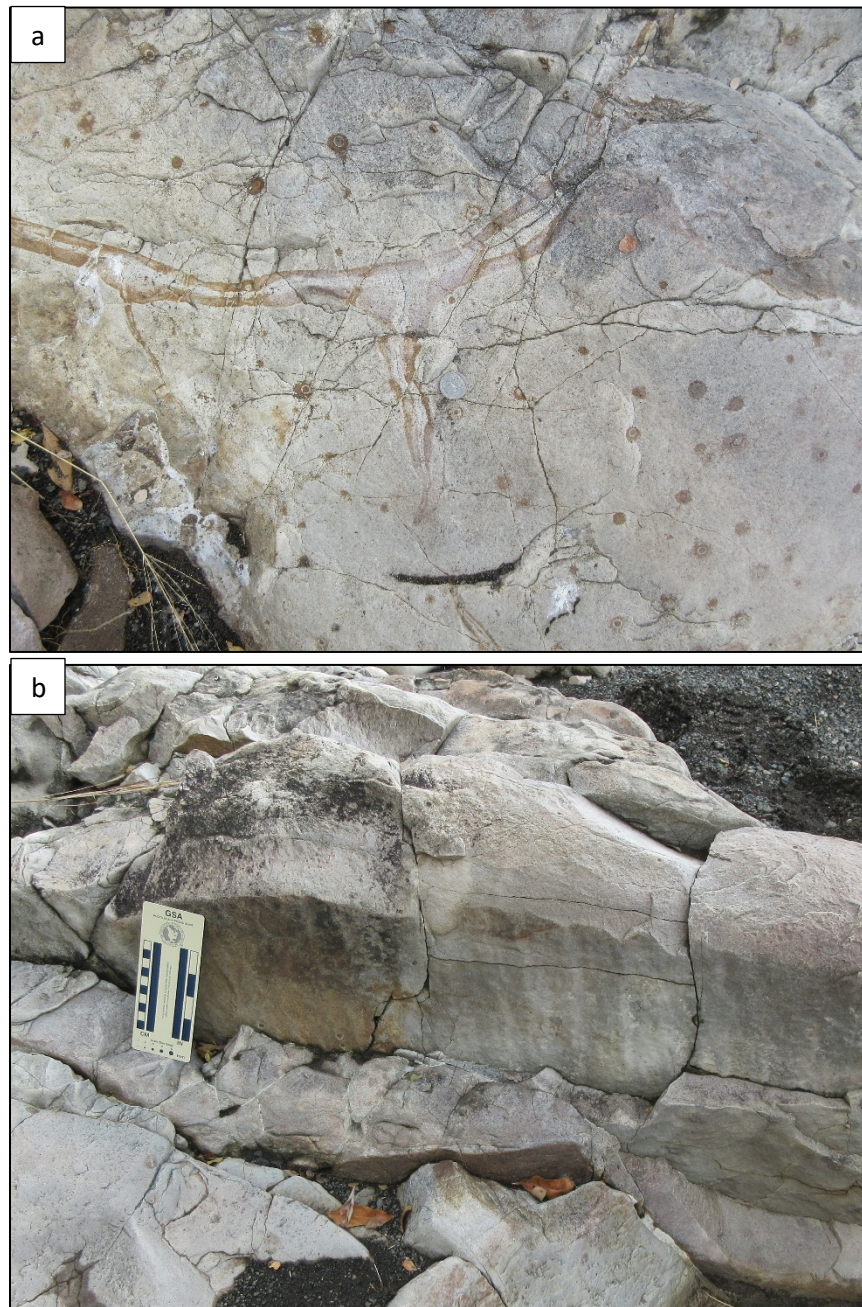


Figure 10: The Clarens sandstone at Palm Springs also shows a) calcareous nodules and veins, and b) well-preserved ripples (note that the original flat-lying bedding surface is now tilted to almost vertical).

Basalt Drive

The road between Caracal Link and Palm Springs (or alternatively, the section of Middle Road near the Eco Training camp) offers a good opportunity to observe the lavas that cover a large portion of the Park.

The lavas are not as resistant to weathering as the sandstones, so they don't stand out as hills, but rather make up the valleys and plains in the region. The lavas here are predominantly basalt—a dark-coloured rock that is rich in magnesium and iron. Because of this composition, these rocks contain very little of the resistant mineral quartz, but have high proportions of feldspars, which readily weather to form clays. Basalt outcrops generally appear very crumbly, and are surrounded by dark clay soils. Basalts also commonly show spheroidal weathering (also known as 'onion-skin' weathering, where layers peel off as concentric shells, leaving a rounded bolder of unweathered rock in the core (Figure 11).

The rock itself is made up of very tiny crystals, sometimes too small to distinguish by eye. This is because this rock formed when hot magma erupted on surface, and as it came into contact with air it cooled and crystallised very quickly, giving insufficient time for large crystals to develop. In some places on this road section, the basalts do show larger crystals of a dark mineral. These probably formed at depth and were carried up to surface by the rising magma, as we discuss in the section below.

In some places, the basalts also show white spots or streaks called **amygdales**. These represent cavities in the rock formed by gas bubbles in the erupting lava that were later (after the rock had solidified) filled by the precipitation of minerals from fluids percolating through the rock. The white minerals in these amygdales are likely either quartz or calcite. A high concentration of amygdales can signify the top of an individual lava flow in the volcanic pile—the gas bubbles rise up through the magma until they are captured by the solidifying rock near the top surface of the lava that is exposed to the air.

In a few places, such as at the intersection with Caracal Link, the lavas are not basaltic in composition but more rhyolitic. This is a rock that is not iron and magnesium rich, but instead has higher levels of silica and potassium. These rocks appear pink to red-brown, in contrast with the dark grey of the basalts. The rhyolite rocks in this area commonly contain fragments of other volcanic material with a range of sizes and shapes, and likely reflect ashy, pyroclastic eruptions as opposed to magma flows.

These volcanic rocks record a significant time period in Earth's history, approximately 180 million years ago, when huge volumes of lava erupted and covered most of southern Africa, flooding the Clarens dunefields and terminating the Karoo sedimentation. At this time, the supercontinent Gondwana started to break up into the continental fragments we are familiar with today. The

thickest section of these lavas is currently preserved in the Drakensberg Mountains. The volcanic succession in the Makuleke area is part of the Lebombo Group.



Figure 11: An example of ‘onion-skin’ weathering in Lebombo basalt, showing a rounded core surrounded by several concentric layers.

Mataphela Spring and Porphyritic Dyke

On the western side of the road leading to Mataphela spring, two prominent sandstone ridges are separated by a saddle in the topography created by an intrusion of magma, forming a dyke. The age of this dyke is uncertain, but it must be younger than sedimentary rocks into which it intrudes, making it less than 200 Ma. The texture preserved in these outcrops is intriguing—large well-formed crystals of pyroxene are hosted by a fine-grained groundmass (Figure 12, 13). Occasionally the larger crystals are seen radiating from a central nucleation point forming a rosette pattern. In other places these elongate crystals are aligned in a sub-parallel manner indicating flow in a moving magma (Figure 13). The bimodal grain size in this dyke suggests two phases of cooling in the magma, at different levels in the crust. Slow cooling deep within the Earth allows crystals to grow large; whereas lavas that erupt on surface and cool rapidly have tiny crystals. It is likely that this dyke formed from a magma conduit feeding the lavas on the palaeosurface.



Figure 12: Large prismatic crystals of pyroxene in a fine, dark grey crystalline groundmass in the Mataphela dyke.



Figure 13: The subtle alignment of pyroxene crystals is evidence of magma flow within the conduit prior to solidification.

Cretaceous Koppie

Although the vast majority of rocks within the Park were deposited as part of the massive Karoo basin between 240 and 180 million years ago, small areas of younger sedimentary rocks can also be found within the Park. During the breakup of the Gondwana supercontinent, between 140 and 65 Ma, small basins formed around southern Africa, into which water transported a variety of sediments. This sediment deposition occurred in a high energy environment, as seen by the grain size of the rocks. The sedimentary particles are greater than a few millimeters in diameter and up to several centimeters across (Figure 14), indicating deposition in fast flowing water. Rocks with this grain size are known as conglomerates and gritstones.

Compare the sedimentary grains in these rocks with those of the Clarens sandstones at Lanner Gorge, or the sediments in the Limpopo river banks. There is much more variability in the colour and composition of the grains in the Cretaceous gritstones and the grains tend to be angular rather than well rounded. This indicates that they are fairly immature sediments, not having travelled far from their source. The fine sand in the Limpopo river, which at this point is nearing its mouth, is the product of a long history of sediment transport and abrasion.

The gritstones towards the top of the Cretaceous Koppie preserve rare fragments of vertebrate fossils (Figure 15) as well as possible shell and plant material. It is difficult to identify the animals that these bones originated from, given that the preservation is very fragmentary. However, this period was a time when dinosaurs roamed the Earth.



Figure 14: Cretaceous conglomerate showing a wide range of grain sizes and pebbles from multiple different sources.



Figure 15: Fossil bone fragment in Cretaceous gritstone.

Concept Notes on a Geological Trail in the Makuleke Contract Park:

The Earth on which we live represents a dynamic system where the underlying geology plays a crucial role in influencing the surface environment, including rich ecosystems like the Makuleke Contract Park, preserved in the northern Kruger National Park. Alongside the spectacular fauna and flora that can be observed during walking trails in this part of Kruger is a wide range of rock types, spanning at least 250 million years of Earth's history.