KRUGER BIG 5 GEOLOGY SAFARI*

Wes Gibbons 2019

This guide describes a self-drive tour of Kruger National Park that provides the opportunity not only for abundant wildlife viewing but also to learn about the geology underlying the scenery of the savanna. Many people seem to visit Kruger obsessed with the intention of photographing the "Big 5" (buffalo, elephant, leopard, lion and rhinoceros), completely unaware that there is another Big 5 waiting to be enjoyed in the rocks. So here it is: a Holiday Geology Guide to Kruger National Park. It is something of an adventure. If you have never visited Kruger before, then you are in for a treat. The route has been carefully chosen to maximise wildlife and scenic geology viewing, although note that this is mostly car seat geology as you can only leave your vehicle in a very few designated areas, and then at your own risk. Kruger is a zoo in which the humans are restricted to confined spaces, not the other animals.

Rock exposure is generally poor across the deeply weathered and magnificently ancient African land surface, although there are notable exceptions in some parts of the park. The varied and beautiful landscapes found in the park however are a direct expression of the underlying geology which impacts on the scenery, soils, ecology and therefore wildlife distribution. The rocks range from some of the oldest found on planet Earth to relatively young sediments and volcanic lavas produced when Africa split from Antarctica during Jurassic supercontinental break-up and the world's oceans as we know them began to form. The west side of Kruger is underlain by Precambrian rocks, most of which belong to the ancient nucleus of the African continent (the "craton") and are over 3 billion years old. In contrast, the eastern side of the park exposes Mesozoic Era Jurassic sandstones, basalts and rhyolites that are a little less than 200 million years old. The sharp line between these fundamentally different two geological units, Precambrian versus Mesozoic, runs north to south for 330km from Pafuri to Crocodile Bridge.

This guide is written for the general tourist rather than the professional geologist. Your geological understanding will gradually develop as you drive the route and at the end of the guide you will understand how you have seen and learnt about the Kruger Geological Big Five. Thus you are not expected to make an effort to learn geology before arriving: it will just happen.

Arrival and Departure Logistics

The route enters the park at Phalaborwa Gate in the central west, heads north to the border with Zimbabwe, then turns back south to cross the full length of Kruger to the Crocodile River at Malelane Gate. The journey involves a minimum of 7 nights in the park base camps operated by Sanparks, accommodation in which must be booked in advance (https://www.sanparks.org/bookings/). The accommodation is simple but comfortable enough, especially if you choose the more expensive options such as perimeter fence bungalows with verandas and, in Punda Maria, the "luxury" safari tents.

For those arriving by air, there are three airports on the west side of the park, namely Phalaborwa, Hoedspruit (Eastgate) and Mbombela/Nelspruit (Kruger), and one inside the park (Skukuza). There is also, of course, the O. R. Tambo international airport in Johannesburg, although this involves a long, tiring drive (not good after a long, tiring flight) that requires you to find somewhere to stay overnight before entering the park. For those hiring a car at the airport, choose a vehicle with high ground clearance: the route described is mostly on good tarmac

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roads and we have tried to avoid using dirt roads with poor surfaces, but in places the terrain can be quite rough, especially in bad weather and times of flood. An ideal plan would be to fly into Phalaborwa or Hoedspruit airports and out from Mbombela/Nelspruit (Kruger) or Skukusa airports.

Phalaborwa town makes an excellent entry point into the park and conveniently has overnight accommodation options, a Spar supermarket, bottle shop and Total filling station just west of the gate: stock up with plenty of water, beer and snack food before entering Kruger. Plan to pass through the Phalaborwa Gate in the morning, and absolutely no later than 14.00. Once in the park relax and take it easy, always obeying the speed limits and being cautious with the animals, especially the elephants who, you will quickly learn, demand respect. Be aware that travelling distances inside the park usually take longer than expected: calculate an average of 25kph maximum on the surfaced roads.

The Route

The route plan suggested here has been tried and tested and it works as long as the rivers are not in flood and you watch the clock as the day progresses. You may, of course, wish to make your own changes/additions, but be careful with your planning. Some of the dirt roads (such as for example the long and isolated S50 running south from Shingwedzi are (in 2019) treacherously corrugated and excruciatingly slow going if your vehicle is more suited to urban travel than the bush. Such roads eat up the hours at an alarming rate: you have to be back at base camp before they close before nightfall. It is always, in any case, best to start the day early, getting up at or soon after sunrise.

The route described in this guide is subdivided into 7 days as summarised below:

Day 1: Phalaborwa Gate to Mopani Rest Camp

Day 2: Mopani to Punda Maria Rest Camp

Day 3: Northern border around Pafuri; return to Punda Maria

Day 4: Punda Maria to Shingwedzi Rest Camp

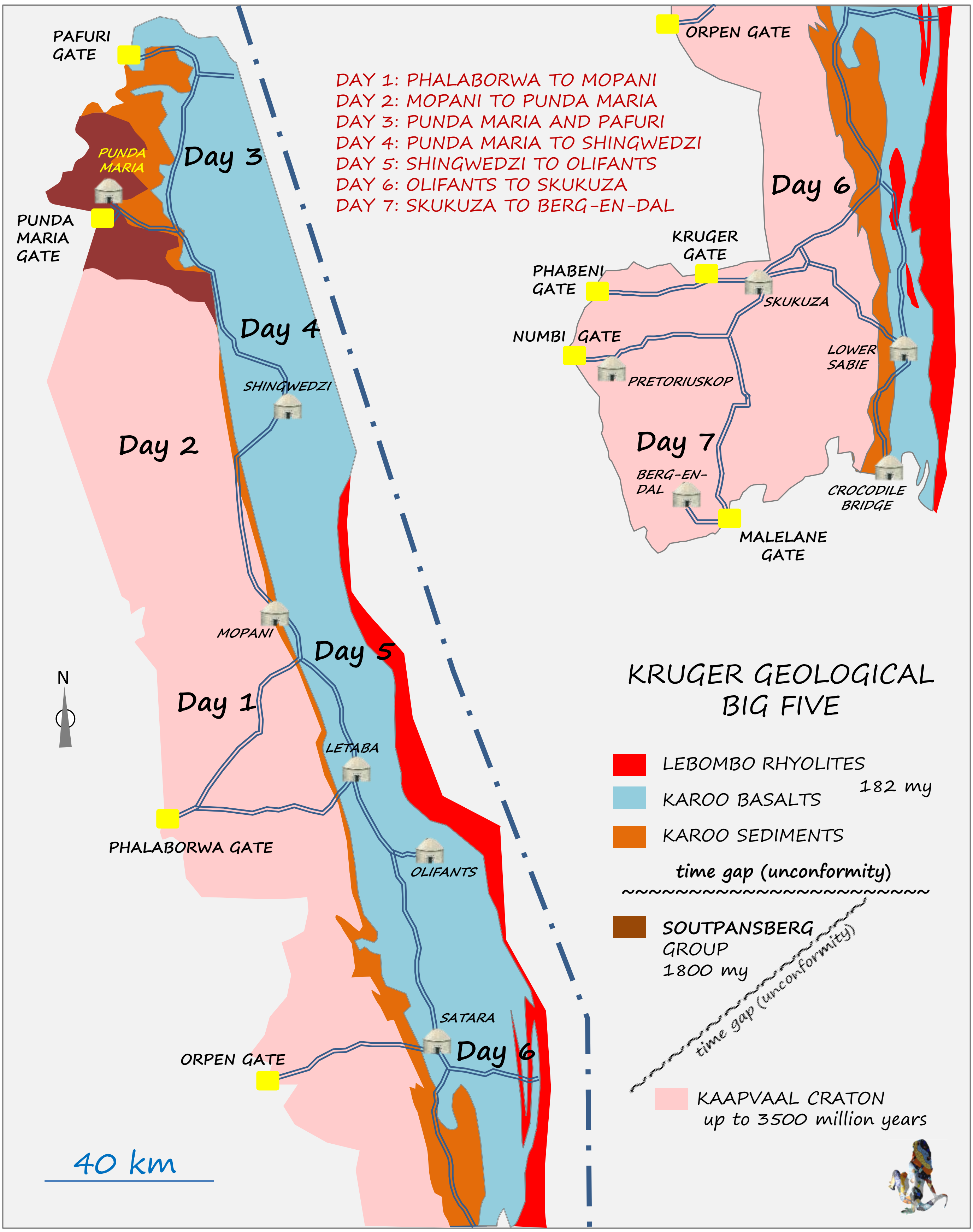
Day 5: Shingwedzi to Olifants Rest Camp

Day 6: Olifants to Skukuza Rest Camp

Day 7: Skukuza to Berg-en-Dal Rest Camp

Day 1: Phalaborwa to Mopani Rest Camp

The town of Phalaborwa lies in the flat lowveld some 350m above sea level and around halfway between the great Drakensberg Escarpment to the west and the Lebombo Hills that run along the South African border with Mozambique. The town is dominated by a huge mine (not seen on the approach to Kruger) from which a wide range of minerals and elements have been extracted in modern times, notably phosphates (since 1934) and copper (since 1966). This is one of the largest open pit copper mines in the world, measuring nearly 2km across. Copper- and iron-rich surface ores have been mined and smelted by local people in this area for well over a thousand years.



Simplified geological map of Kruger Park with 7-day route described in this Holiday Geology Guide.

Register your visit at the Information Centre just outside the gate, check that there is no flooding at the Letaba River crossing on the H14, and buy a Kruger Park Map (that published in book form by Tinkers is perfectly adequate: http://www.tinkers.co.za/). Enter the park though Phalaborwa Gate and head east on the H9 through undulating mopane tree woodlands for 8km then turn right onto the gravel Sable Loop Road (S51) which runs east of a lake created by the Sable Dam (built across the Mashangani River in 1972). After 2kms there is a track on the right leading to a view over the reservoir. The main S51 track continues south to Sable Hide (on the right) where you can emerge from your vehicle at your own risk and enter the protected hide with views across the lake. The drainage here runs south into the Lepelle (Olifants) River.

From Sable Hide continue following the S51 loop track anticlockwise, driving over young sandy deposits and turning north to pass excellent examples of small hills known as "koppies" on the way back to the H9. These hills mark rocks that are more resistant to erosion, and they are commonly hard, massive and granite-like in texture and form.

Koppie scenery on Sable Loop Road. Geomorphologically outstanding landforms such as these are known as "koppies" (Afrikaans = little head), small versions of "inselbergs" (German= island mountain) or "monadnocks" (Indigenous North American = smooth or isolated mountain). They gradually emerge as erosion proceeds, preferentially leaving the harder rock standing proud from the softer surrounding ground. They typically comprise massive, relatively unfractured, bare rocks with little or no soil cover. In Kruger they erode extremely slowly, just 2-3 mm every thousand years, and are thus eloquent testimony to the vastness of geological time. They have been shaped over deep time to form familiar upstanding navigational landmarks that encourage the development of local ecologies distinct from those in the surrounding Mopaneveld.

Impalas at base of syenitic koppie to the east of Sable Loop Road (S51)

Turn right into the H9 then, in <1km, right again to access the Masorini Hill Archaeological Site where you can leave the vehicle for a comfort stop and, if time allows, be guided over a reconstruction of an iron age village formerly built here on the koppie, at the watershed between the Lepelle and Letaba river drainage systems.

Masorini Hill, a classic example of a syenite koppie, was home to iron smelters and forgers belonging to the ba-Phalaborwa people. Iron age cultures are thought to have arrived in the Kruger savanna over 1,500 years ago, leading to the replacement of Stone Age hunter-gatherers who had previously inhabited the area. The Masorini village society in turn did not survive the emergence of the Zulu Kingdom in the 19th century.

Masorini Syenite. Syenite is a hard, massive, granite-like rock formed mostly of interlocking pale crystals of potassium feldspar and less well defined black crystals of dark minerals (amphiboles, pyroxenes, and micas). This is a plutonic igneous rock, crystallised deep underground at high temperatures and cooled slowly enough to allow large crystals to grow. The Phalaborwa syenite is one of several circular satellite plug-like pipes that surround the copper mine of Phalaborwa. Both the syenites and the rocks hosting the metal mineralisation at Phalaborwa (the "Phalaborwa Igneous Complex") crystallised from molten magma just over 2 billion years ago. This magma rose through the Earth's crust to feed volcanoes erupting high above but long since eroded away so that we can now view the deep magmatic plumbing system that once lay beneath them. The Masorini syenite pipe has intruded and solidified within an ancient basement of even older rock that is more weathered and therefore not exposed in the surrounding lower ground of the mopaneveld.

Drive back west on the H9 then north on the H14, passing the prominent syenite koppie of Shikumu (452m) on the right. Twelve km from the H9 turn right into the dirt track leading to the Nandzana waterhole alongside the Ngwenteni River. The sandy soils forming this part of Kruger are underlain by quartz-rich rocks (granites and gneisses) that are rarely exposed. The commonest underlying rock type is the "Makhutswi Gneiss" which has yielded an age of over 3 billion years (more precisely 3,228,000,000 years), placing it amongst some of the oldest rocks known on Earth. We shall see exposed examples of similarly ancient gneissic basement in the Red Rocks loop to be visited on Day 2.

Continue northeast on the H14, crossing the Ngwenyeni River which now runs to the right side of the road. Five km northeast of the Ngwenyeni Bridge the H14 curves clockwise (right) from north to southeast across the flat mopaneveld as it follows a prominent meander in the Ngwenyeni River. In this area the underlying rocks have changed radically from more granitic compositions covered by sandy soils to dark, iron- and magnesium-rich rocks known as the Timbavati Gabbro. The change from pale sandy quartz-rich ground on the Makhutswi Gneiss to dark soils formed from the weathering of the gabbro is particularly obvious from the Google satellite map which clearly marks how the gabbro outcrop forms a band running N-S and around 1-2km wide. We shall observe exposures of the Timbavati Gabbro during the Red Rocks loop planned for Day 2.

The H14 continues ENE, back on the Makhutswi Gneiss outcrop as it crosses the Ngwenyeni River then curves north to cross the Letaba River, a major water course that runs southeast across the park to join the Lepelle River at the Lebombo Hills near the Mozambique border. After the Letaba crossing, the H14 winds for a further 5km across the gently undulating savannah with no rock exposures, which is a pity because here beneath the mopane trees are some very interesting rocks. Instead of quartz-rich Makhutswi Gneiss there is the "Murchison Greenstone Belt" (MGB), a (geologically) famous zone of >3-billion-year old volcanic and sedimentary rocks that can be traced west from here for over 100km. The MGB forms the northern boundary of the Makhutswi Gneisses. A few kilometres further up the H14 we pass from the MGB on to more gneisses, but again there is no sign of this on the road, and we shall have to content ourselves with waiting for the next day's geology.

Just over 20kms from the Letaba River crossing, the H14 turns east then makes a sweeping gentle curve left toward the north. Once a north-south orientation has been achieved you will see on the right a low rocky ridge of brown sandstones. This sandstone belongs to the Clarens Formation and it marks the boundary between the two fundamental different geological sides to Kruger Park: the ancient cratonic rocks to the west, and the much younger Jurassic rocks to the east. The Clarens Formation sandstone is Lower Jurassic in age, a mere 185 million years old or so.

The H14 crosses the Kaleka River after which the low ridge of Clarens Formation sandstone now lies on the left and road curves across the flat mopaneveld typical of the Jurassic rocks that lie above the Clarens sandstones. Two km after the Kaleka crossing the road curves southeast to reach the bridge over the Tsendze River. Here on the right side of the river crossing are exposures of Jurassic rocks that can be seen to slope ("dip") gently down to the east: this is typical of the Jurassic succession. The easterly dip means that as you drive eastward so you climb higher in the Jurassic rock succession. This is the law of superposition, with older rocks being covered progressively by younger ones:

*The study of … rock layers is known as "lithostratigraphy" and … it rests upon the fundamental premise that younger rocks are deposited upon older ones as horizontally and laterally continuous beds. The idea was expressed in the Dissertationis prodromus published in 1669 by the Danish scientist Nicolas Steno who is credited with being one of the first to elucidate several of the defining principles of the science of stratigraphy (*from The Ninth Tale (Montserrat) in http://barcelonatimetraveller.com/).

A pair of klipspringer antelope on Clarens Formation sandstone exposed east of the H14 just before the Kaleka River crossing. The monogamous klipspringer prefers rocky habitats where it is well camouflaged and lacks competitors, its adaptation to the geology providing an ecological advantage that has ensured this animal has not entered the endangered list.

Turn left into the H1-6 and drive 13km north across the Jurassic outcrop to the Mopani Rest Camp junction then left to enter the camp. At the rest camp we have returned down the east-dipping Jurassic succession to reach once again the Clarens Formation sandstone. The sandstones form a prominent ridge rising above the Pioneer Reservoir which lies on low ground underlain by basement gneiss. It is possible to stay in a bungalow overlooking the reservoir and with your own private exposure of Clarens sandstone.

Clarens sandstone exposure in Mopani base camp. Pink-weathering sandstones of the Clarens Formation preserving polygonal dessication cracks formed in a hot desert environment that covered much of Southern Africa in Lower Jurassic times 185 million years ago. The east-dipping, hard sandstones form a prominent west-facing escarpment that overlooks the lake produced by the Pioneer Dam below. The view is from Bungalow 101 (BD4V, Mopani Rest Camp) which not only has its own private Clarens Formation exposure but also extensive views over the lake and beyond over the flat, low ground underlain by cratonic basement gneisses to the west.

Day 2: Mopani to Punda Maria Rest Camp

We recommend starting the day with a pre-breakfast animal-spotting 6km drive to the Pioneer Dam Lookout. Drive back to the H1-6 then south for 2km to turn right onto the S142 which crosses the Tsendze River via a concrete causeway sometimes guarded by hungry crocodiles. To the left are gently dipping exposures of Jurassic basaltic rocks (Letaba Formation), but best not to leave the vehicle in order to examine them.

Causeway over the Tsendze River on S142 road, with adjacent crocodile waiting for breakfast. Basaltic rocks of the Letaba Formation crop out in low exposures behind and to the left of the car.

After crossing the river the road curves right to pass the Shipandani Hide and Lookout over the Tsendze River (right). In 200m pass a left fork and go straight on (west) for another 800m. Here the track passes from basaltic to quartzitic (Clarens sandstone) soils (seen as colour contrast on Google maps) and turns right at a sign to Pioneer Dam. In 100m you reach a fork where you stay left as the track loops clockwise and in 300m reaches the Pioneer Dam Hide, on the outcrop of the Clarens Formation sandstones. Here we are back close to the geological boundary between east (Jurassic) and west (cratonic) geological Kruger although, once again, the basement gneisses are not exposed. After visiting the hide, continue following the clockwise loop, with views north to the higher ground of the rest camp, and return by the outward route.

Zebra crossing on the drive back from Pioneer Dam to Mopane Rest Camp, looking east. Ahead lies the low, flat plain of mopaneveld growing on Jurassic basalt, beyond which rise the Lebombo Hills that are formed of harder, more resistant rocks overlying the basalt (and to be visited later on the journey).

The main drive of the day follows the H1-6 north from Mopani for 50km on a good road surface before entering the highlight: the 45km Red Rocks Loop on a dirt road (S52) that follows the Shingwedzi River and is usually full of wildlife (allow at least 3 hours for this loop). After this the route continues on good roads 30km north to Babalala picnic site then a further 42km northwest to the Punda Maria Rest Camp. Beware of speed traps, particularly in the last hour of the journey.

The H1-6 north initially passes a series of koppies (such as Bowkers Kop) as it runs northwest over the basaltic then sandstone outcrop back on to the cratonic basement, crossing the Tropic of Capricorn and passing a series of waterholes such as Olifantsbad Pan. At 37km north of Mopani the H1-6 passes the S144 (right), by now heading north close to the basement gneiss/Clarens Fm boundary. Eight km north of the S144 turn left on to the Red Rocks loop road (S52) then in 1km turn right (signposted Red Rocks 4km) to reach the Red Rocks viewpoint. From here one can see the dark basaltic rocks of the Letaba Formation underlain by the pink-red Clarens Formation sandstones.

View west from Red Rocks Lookout. The Shingwedzi River flows eastwards across the red outcrop of east-dipping Clarens Formation desert sandstones (top centre and right) and on to the overlying Letaba Formation basalts (brown rocks and soils on the left and foreground). The basalts were erupted from Jurassic volcanoes 182-3 million years ago, a moment in geological Deep Time when the desert environment of southeast Africa was transformed into a volcanic landscape which heralded the opening of the ocean between Africa and Antarctica. Riverbed potholes eroded into the Clarens sandstone have trapped sand particles containing heavy metals, leading to the discovery of alluvial gold here in the 1920's.

Continue driving south on the Red Rocks loop to a T junction with the S52 where you turn right and, after 1km, right again to cross the causeway over the Shingwedzi River. Here at last there are exposures of the ancient cratonic basement that underlies western Kruger.

View east from the causeway over the Shingwedzi River at Red Rocks. The grey rocks in the foreground immediately adjacent to the causeway form part of the cratonic basement of Africa and are over 3 billion years old. They are called the Groot Letaba gneisses, a "gneiss" being a rock that has been transformed into new mineral crystals by high temperature and pressure deep in the crust (a process called "metamorphism", a word derived from the Roman author Ovid's classic poem Metamorphoses which begins "Of bodies changed into new forms I speak").The most characteristic feature of such gneisses is that the newly recrystallized minerals have been aligned by the metamorphic pressures so that they form layers, as can be seen in this image (dipping steeply down to the left). In the background downstream are exposures of the overlying Jurassic Clarens Formation red sandstones. The break in time between the ancient gneissic basement and the Jurassic desert sandstones is over 2,800,000,000 years. Significant time gaps in rock sequences are known as "unconformities", and unconformities on Planet Earth don't get much bigger than this one at the Groot Letaba/Clarens boundary in the Shingwedzi river bed.

Drive back over the causeway to re-join the S52 and continue 9km further west on the south bank of the Shingwedzi River to cross the Tshanga River tributary where there are exposures of the Timbavati Gabbro (image below). Soon after this crossing turn left on to the road that runs south for 2km to the remote Tshanga Lookout for great views over the lowveld. There are exposures of the Timbavati Gabbro in the rocky ridge near the car park, but this is an unfenced area where predators are common, so fieldwork is discouraged.

The gravelly bed of the Tshanga River underlain by grey exposures of the Timbavati Gabbro, dated as just over 1 billion years old (around 1,111,000,000 years). Like the Phalaborwa Syenite 1 billion years before it, the Timbavati Gabbro is part of another huge igneous province, this one known as the Umkondo Province. Magmatic rocks of a similar age are found over an area of more than 2 million square kilometres in Southern Africa, and extend into North America (in those days Africa and America formed part of a supercontinent called Rodinia). A gabbro is similar to syenite in that it cooled slowly from molten magma, allowing crystals to grow that are large enough to be seen by the naked eye. However gabbro has a very different chemistry, richer in iron and magnesium and with more dark minerals such as pyroxenes. This chemistry is essentially the same as that of basalt so that the ecozone characteristic of the gabbro is similar to that found on the Jurassic basalts further east. Inset lower right: A close-up of the gabbroic texture in a rock from Tshanga Lookout. Gabbro (and basalt) mineralogy is dominated by crystals of black pyroxene and white feldspar.

Return to the S52 and, assuming the river is not in flood (the northeastern exit near the H1-6 junction involves another causeway river crossing), turn left and continue the loop clockwise to cross the river by another causeway (more Timbavati Gabbro) and then turn back east, following the north bank back east for 28km to rejoin the H1-6.

Warthogs on the S52 Red Rocks Loop

Following the S52 for 28km on the north side of the Shingwedzi River can be slow going….

Turn left on to the H1-6, pass the turnoff to the Shingwedzi Base Camp (to be visited on the return journey) and cross the Shingwedzi River, by now greatly broadened by the addition of the Mophongolo River flowing in from the northwest. Continue northwest for another 35km across the flat plain of the basaltic Letaba Formation outcrop to reach the comfort stop of Babalala on the left at the S56 junction. After this, continue north for a further 21km on the H1-7 to turn left into the H13-1, with the prominent hill of Dzundziwini rising to the south (left): we have by now left behind the monotonous basaltic soils and entered the different geology of this northwestern end of the park around Punda Maria. In a further 16km, turn right to reach Punda Maria Rest Camp in 4km. The rest camp is built on the southern slopes of a prominent east-west ridge (Dimbo Hill) which can be admired from the short "flycatcher" walking trail inside the camp. This ridge forms the eastern end of the Soutpansberg (Salt Pan Mountain) Range, an area famed for its reptile diversity.

The geology of the area around Punda Maria is dominated by sandstones belonging to the Soutpansberg Group. These sediments were deposited by rivers flowing around 1,900 million years ago across a fault-bounded basin and so they lie unconformably upon the >3-billion-year-old gneiss we have seen to the south in the Red Rocks loop. Despite the fact that the Soutpansberg sediments are so old, they are remarkably well preserved and commonly show original sedimentary structures such as ripple marks, many examples of which can be seen in the paving stones used around the camp.

Ancient ripple marks preserved in a paving stone used in the roadway leading to the Safari Tent site in Punda Maria. The ripples were produced by rivers draining an east-west orientated low-lying area ("Soutpansberg Basin") produced by fault movements in this area around 1,900 million years ago. They became preserved in the geological record during the later hardening (lithification) of the sandstone.

Today we have seen the Jurassic Clarens Formation sandstone (185 million years) lying unconformably above the Groot Letaba Gneiss (>3 billion years). The Clarens Formation was deposited across a huge desert area similar in size to the modern Sahara. It is curious how, around 1,700 million years *before* the Clarens desert, similar sandstones in another arid African sedimentary land basin were being deposited on the older gneissic basement (Soutpansberg Group on Groot Letaba Gneisses).This repetition of similar geological events is testimony to the incredible stability of the African craton and, of course, to the immensity of geological time:

…..In 1858 George Julius Poulett Scrope publishes his seminal work on the volcanoes of the Auvergne and yells to his readers the revelation of Deep Time: "The leading idea which is present in all our researches, and which accompanies every fresh observation, the sound of which to the ear of the student of Nature seems echoed from every part of her works, is—Time!—Time!—Time!"….. From: Barcelona Time Traveller: Twelve Tales

http://barcelonatimetraveller.com/

Day 3: Punda Maria to Pafuri

Today we visit the far north of Kruger National Park, including the geographic triple point on the Limpopo River at Crooks Corner where South Africa meets Zimbabwe and Mozambique. It is a remote drive across rolling mopane forest, less frequented by tourists than in the south of the park, and arrives at the sandy alluvial plain alongside the Luvuvhu and Lipopo rivers at Pafuri, a riverine area with abundant wildlife, before returning to Punda Maria.

Start the day with an early morning safari self-drive through the sandveld by following the 25km Mahonie Loop dirt road (allow at least 2 hours: alternatively do this at the end of the day, or even tomorrow morning). Shortly after exiting Punda Maria Rest Camp turn left on the S99 dirt track which loops anti-clockwise around the prominent ridge of Precambrian Soutpansberg Group sediments (for the stratigraphic enthusiast, these rocks belong to a subdivision of the Soutpansberg Group called the Wyllie's Poort Formation). The S99 soon turns northwest (left) as it runs through a broad valley with the Punda Maria east-west ridge of Soutpansberg Group sediments now to the south. There is no exposure of the underlying sandstones as the road heads west through the sandveld and leaves the stream system draining south into the Shingwedzi River to enter that which drains northeast into the great Limpopo River.

Around 10km from Punda Maria the track turns south through the gap in the hills offered by the north-draining Matukwala River (a tributary of the Luvuvhu River which defines the edge of Kruger Park as it drains northeast into the Limpopo). There are occasional exposures of the brown-weathering Wyllie's Poort quartzitic sandstone along the roadside as the track cuts south then turns back east to follow the southern side of the ridge leading to Punda Maria.

Exposures of brown-weathering Wyllie's Poort Formation sandstone alongside the S99 15km anticlockwise from Punda Maria Rest Camp. The layers ("beds") of brown-weathering sandstone dip gently to the north, a rock structure that favours the development of steep south-facing "scarp" slopes (such as that behind the rest camp) and gentler north-facing "dip" slopes. The sandy soils on these rocks are well drained and favour the growth of drought-resistant trees such as the corkwoods.

Fresher surfaces of the Wyllie's Poort sediments reveal white (quartz) and pink (iron oxides such as hematite) minerals cemented into a hard ferruginous, quartzitic sandstone. Note how the weathering is only skin deep, as expressed by the brown surfaces where the red iron oxide has altered to brown, hydrated iron oxide minerals (such as limonite and goethite).

Rejoin the H13-2 near the Punda Maria rest camp and (unless a comfort/breakfast break is needed back at the camp) turn right then left on to the H13-1 which runs southeast then east, with the Wyllie's Poort sandstone hill of Dzundzwini on the right (note that the S60 dirt road connecting the H13-2 to H1-8 offers a scenic shorter route but, in 2019 at least, the surface was so bad that it was much slower going). The H13-1 crosses back on to the Jurassic succession. At the T junction with the H1-7 and H1-8, by now back on the flat basaltic plains that characterise the Letaba Formation, turn left and head north for 13km to the S61 (left). Here we are close to the base of the Letaba Formation basalts, so by following the S61 west we cross back on to the Clarens Formation sandstone outcrop (apparent on the Google satellite map). Follow the S61 west for <1km to the Klopperfontein Dam area where the Shikuwa River drains northwest into the Luvuvhu River and a series of lookouts and loops offer good wildlife viewing on the Clarens sandstone outcrop. This scenic area, with its water supply and wild figs, was commonly used as a camping ground by the hunters following the "Ivory Trail" north from the Shingwedzi River into elephant hunting grounds.

Return to the H1-8 and continue north across flat basaltic mopaneveld. In this area, between Klopperfontein and the Mashikiri waterhole 8km further north, we are driving over basaltic-like rocks known as the "Mashikiri Nephelinites" which here lie beneath the Letaba Formation. For those who enjoy igneous mineralogy, a nephelinite is like basalt but with the feldspathoid mineral nepheline instead of the feldspar mineral plagioclase. The difference is simply a result of less silica in the magma: feldspathoids contain less silica than feldspars. In contrast the Letaba Formation rocks contain feldspar as well as being very rich in olivine, a type of basalt called "picrite" or "picrobasalt". All these rocks weather easily and are rarely exposed in Kruger away from roadcuts.

Elephant crossing the Clarens Formation sandstone outcrop on the way to the Klopperfontein waterhole. In the area between Punda Maria and Pafuri the Clarens sandstone features prominently to the west of the H1-8, in places forming koppies and river gorges.

Thirteen km from Klopperfontein turn left to visit the Nkovakulu waterhole outlook before returning to the H1-8. Over the next 10km the H1-8 runs north then northeast as it joins the western side of the Thambyi River valley, with the scenery becoming more undulating and forested as the road descends towards the Luvuvhu River, passing low exposures of weathered basalt. Two km before the H1-8 river crossing, the S64 ("Nyala Drive") dirt road leads off left (northwest) towards the historical site of Thulamela. The 5km drive to the south bank of the Luvuvhu River often reveals wildlife (such as nyala) but access to the Thulamela site must be booked in advance at Punda Maria as armed guard accompaniment is needed for protection against the carnivores. Upstream from here the Luvuvhu River snakes through the remote, inhospitable country of the Lanner Gorge.

The Thulamela stone citadel in northern Kruger lies on Clarens Formation desert sandstones overlooking a tributary gorge of the Luvuvhu River. It was reportedly occupied from c.1240-1700AD and at times contained an estimated 2000 people (including a royal enclosure) who smelted iron and traded in gold with merchants from the east coast. Photo from the exhibition at Pafuri Picnic Site.

Return to the H1-8 and continue north, passing the S63 (right) to reach the Luvuvhu River crossing. Geologically this area lies above the (unexposed) boundary between the Jurassic basalts and underlying Clarens sandstone: make a stop on the Luvuvhu Bridge where one can leave the vehicle to photograph the wildlife.

Buffalo in the Luvuvhu riverbed. In this northeastern corner of Kruger the Luvuvhu River runs over the Clarens Formaton outcrop then out across thick silt deposits that form a broad alluvial plain running east to the Limpopo River. The water supply and rich riverine forests, which include fever and mustard trees and the sycamore fig, support abundant wildlife.

From the Luvuvhu Bridge drive east through tropical woodland on the S63 dirt road to the Pafuri picnic site to enjoy your packed lunch (or braai) accompanied by vervet monkeys, views over the river, and an exhibition on the ecology and history of the area. The trees that line the Luvuvhu riverbank offer an excellent example of a "gallery forest". Such forests form corridors through less hospitable terrain and offer animals such as monkeys and baboons (as well as our hominid ancestors) better protection from predators. In the northeastern side of Kruger, along the border with Mozambique, have been found innumerable examples of stone tools made by hominids, starting with *Homo erectus* (who was also the first to use fire) around 1.5 million years ago, through to the introduction of more advanced stone tools by *Homo sapiens* around 250,000 years ago (Middle Stone Age). By 25,000 years ago, during the Late Stone Age, the origins of modernity in humans produced more complex toolkits and recognisably hunter-gatherer cultures, these becoming superseded by Iron Age, Bantu-speaking pastoralists after 2,000 years ago.

Vervet monkey hoping (unsuccessfully) that the human will break park rules and offer food or perhaps a beer. According to Wikipedia, vervet monkeys have been noted for having human-like characteristics, such as hypertension, anxiety, and social and dependent alcohol use. It has been only around 20 million years since our ancestral line split from that leading to the modern monkeys, a relatively short time in Earth history. Pafuri picnic site on the banks of the Luvuvhu River.

Continue east on the S63, looping through lush riverine forest to turn left at a T junction to reach Crooks Corner for extensive views over the Limpopo River. The huge arc of the Limpopo River runs over 1,700km, initially separating South Africa from Botswana and Zimbabwe before flowing into Mozambique here at Crooks Corner, one of Kruger's biodiversity hotspots.

The Limpopo River at Crooks Corner, on the lawless triple boundary between South Africa, Zimbabwe and Mozambique. The view is looking upstream across the river to Zimbabwe. The river varies dramatically in its water content, with huge floods during rainy season cyclonic events (such as that in February 2000) creating havoc and backing up along the Luvuvhu River to deposit silty sediment on the Parfuri floodplain.

From Crooks Corner drive south for 2km then west (right) along the paved S63 for 8km to pass roadside exposures of weathered Letaba Formation basalt. Resistant masses of basaltic rocks are gradually eaten away by physical weathering processes such as "onion skin" exfoliation, and chemical breakdown of minerals aided by water soaking through and evaporating within the soils and upper rock layers.

Rounded mass of spheroidally decomposing Jurassic basalt on the north side of the S63 shortly before the H1-8 junction. The top surface of this exposure demonstrates classic "onion-skin" physical weathering, also known as "exfoliation", a phenomenon typical of warm climates. Exposure to hot sun causes the rock surface repeatedly to expand then contract during the cooler night. Over time thin concentric layers of the damaged rock peel off, causing the parent rock mass to shrink in size. The chemical oxidation of the surface layers, favoured by a humid climate, is apparent from the brown colouration which indicates the presence of secondary iron oxides and hydroxides derived from primary iron-bearing minerals in the original basalt. The original grey colour of the fresher parent rock can be seen lower left.

Many of the exposures along this roadside display the effects of intense chemical weathering which causes the progressive destruction of fresh, dark, basaltic rocks. During such tropical weathering the primary igneous minerals (mostly pyroxenes, olivines and calcium feldspars) in the basalt chemically break down into soft clay minerals and the rock decomposes into soil and gravel, with calcium carbonate precipitating within and on top of the basalt to form criss-crossing veins and hard capping layers known as "calcretes". Such weathering is particularly intense in this northern end of Kruger Park where there is higher rainfall under a hot climate. The pervasive destruction of fresh rock by chemical weathering explains why there are very few natural exposures of bedrock across the basaltic mopaneveld savanna of Kruger.

Continue west to the H1-8 and return south to Punda Maria.

Day 4: Punda Maria to Shingwedzi

The route back south from Punda Maria to Shingwedzi rest camp is shorter than previous drives and highlights the splendid Mphongolo River loop on the S56 dirt road which is best taken very slowly in order to enjoy the scenery and wildlife. An early arrival in Shingwedzi allows time to explore the riverbank environment along the S50 downstream from the base camp.

Start the day with a brief visit to the Thulamela Hill viewpoint by driving back southeast from the PM Base Camp but then turn right on to the H13-1. After 2km turn right on to the S98 dirt road that leads northwest for 3km, climbing into the ridges of Wyllie's Poort Formation sandstone that characterise this corner of the Park. There is little rock exposure, but this is one of the few places in northwestern Kruger where you can drive to high ground with views, in this case over the low basaltic mopaneveld to the east and southeast and beyond to the Lebombo Hills at the Mozambique border. The western edge of Kruger Park lies less than one kilometre from here, whereas 10km to the south the outcrop of Soutspanberg Group Precambrian sediments (such as the Wyllie's Poort Formation) gives way to that of the underlying ancient basement gneisses.

Return to the H13-1 and turn left. The road initially runs northeast across the Soutpansberg Group outcrop but then curves southeast to cross ground underlain by much younger rocks: the Karoo Supergroup which, as Wikipedia will tell you, "is the most widespread stratigraphic unit in Africa south of the Kalahari Desert. The supergroup consists of a sequence of units, mostly of nonmarine origin, deposited between the Late Carboniferous and Early Jurassic, a period of about 120 million years". Unfortunately there is not much evidence in the flat land surface for this momentous change in geology beneath the lowveld forest.

Elsewhere in Kruger we have several times seen the Clarens Formation sandstones, which are the youngest sediments of the Karoo Supergroup and in central Kruger rest directly on the ancient gneiss basement. Here in the northernmost part of the Park, however, the Karoo Supergroup is much thicker and includes sediments lying below the Clarens Formation. These sediments in places include coal deposits and so are of economic interest (hence, the "Pafuri Coalfield"), leading to controversy in the 1970's when a state-owned steel company asked for permission to make a geological map of the area between Punda Maria and Pafuri in their search for coal deposits. Protests were raised, emphasising that the National Parks Act of 1976 prohibits prospecting in a national park, and subsequent coal mining activity was restricted to north of the Luvuvhu River (Tshikondeni Mine: 25km north of Punda Maria but just 3km from the park border).

After 14km on the H13-1 turn right into the S58 Dzundzwini Loop dirt road (5km) which follows the northern edge of Dzundzwini Hill at the eastern margin of the Soutpansberg Group outcrop. In 3km stop at the plaque and sausage tree (left) marking the site of the temporary resting camp set up in 1919 by Captain Johannes Jacobus ("Kat") Coetser, the first game ranger to be appointed to control the northern part of the park (Coetser moved on from here to set up the base camp at Punda Maria, which has a more reliable water supply). To the south across the road to the right rise exposures of pale sandstones which look like Wyllie's Poort Formation rocks but are inaccessible.

Exposures of pale sandstones on the north side of Dzundzwini Hill at the eastern edge of the Soutpansberg Group outcrop, across from the JJ Coetser temporary bush camp.

Continue on the S58, passing a turnoff for Dzundzwini Hill (a rough drive best done in a 4WD vehicle and not worth it geologically: another partial view over the basalt plain ahead), to reach the H1-7 where you turn right and drive 19km back south across the basaltic lowveld to the S56 junction (right). At this location the Letaba Formation basalts have been mapped as having erupted directly on Soutpansberg Group sediments (the Clarens Formation is absent here). There is no exposure visible from the road, which is a pity because this is the southernmost part of the Soutpansberg outcrop in Kruger.

The Babalala Picnic Site, with its thatched shelter built around an impressive sycamore fig, lies a short distance along the S56 west of the H1-7.

Elephants are commonly seen around Babalala, in this case providing entertainment for the children.

Elephant heading west from Babalala towards the confluence of the Mdungila and Shisha rivers which together flow into the Mphongolo River, forming an arterial network in the upper headwaters of the Shingwedzi drainage basin which attracts wildlife throughout the year.

The 33km loop along the S56 dirt road anticlockwise from Babalala follows the river systems flowing southeast to join the Shingwedzi River to the north of the Shingwedzi Rest Camp. Allow at least 2.5hrs to drive this loop, stopping frequently at the many lookouts on the way. The loop offers another example of abundant wildlife in a beautiful wooded riverine environment, with the additional attraction of occasional exposures of Precambian basement rocks.

The S56 initially runs southwest from Babalala, leaving behind the flat basaltic plain and moving on to more sandy terrain underlain by Soutenberg Group sandstones and underlying granites and gneisses as it follows the east bank of the Shisha River.

Spheroidally weathered remnants of quartz-rich and granitic Precambrian rocks form isolated exposures along the Mphongolo Loop.

Around 10km from Babalala the S56 passes the junction (right) to Sirheni Bushveld Camp, where the Mphongolo River flows in from the northwest. Over the next 6km keep visiting successive minor loops for views across this river, passing exposures of granitic basement rocks to reach the prominent outlook shown below:

Elephant herd enjoying the Mphongolo River, the banks of which expose east-dipping banded rocks attributed to the Groot Letaba gneisses which are overlain by Jurassic sediments and basaltic lavas as the S56 turns east.

Continue driving south then east, staying close to the river to enjoy the best of the riverine forest and wildlife.

Abundant wildlife within the lush riverine forest, sands and basaltic muds alongside the Mphongolo River.

Around 11km from the Sirheni junction ignore a junction to the left and continue southeast on the S56 which curves east to return to the Letaba Formation basalt outcrop after a further 6km. There are exposures of the basalts on the far riverbank and, by now 9km from the recent junction, one can view a vertical basaltic dyke cutting the deeply weathered and veined Letaba Formation basalts.

One for the dyke spotters with zoom lenses: exposure on the southern side of the Mphongolo River seen from the S56. A basaltic dyke cuts vertically through Letaba River Formation weathered basalt. Dykes like these were formed by sheets of magma rising through cracks, commonly feeding younger lava flows in fissure eruptions above. They solidified to form a massive grey rock more resistant to weathering than the surrounding older basalts which are criss-crossed by alteration veins.

In a further 3km the S56 reaches the H1-7. Turn right and drive 9km across basaltic mopaneveld, following the lower reaches of the Mphongolo River, to reach the confluence with the Shingwedzi River. Just after crossing the Shingwedzi (one can stop on the bridge) turn left and follow the western riverbank for 2km to the Shingwedzi Rest Camp. If there is time available after check-in, drive out of the eastern gate of the rest camp (not the main entrance) and turn right to follow the S50 for more wildlife viewing along the riverbank. The river initially runs south before turning east beyond the Kanniedood Dam. This area is geologically interesting because for the first time we have entered the outcrop of the Sabie River Basalt Formation (SRBFm) which lies above the Letaba Formation (LFm). All these basaltic lavas slope (dip) gently to the east so that the SRBFm lies above, and is therefore younger than, the LFm. It has been estimated that the SRBFm is up to 5km thick and was erupted over a period of less than half a million years.

Hippos in the Shingwedzi River from one of the many riverside lookouts southeast of the Shingwedzi Rest Camp. The northern bank of the river behind the herd exposes Sabie River Basalt Formation lavas, erupted 181 million years ago, a very, very long time before hippos evolved from the ancestors of whales, dolphins and porpoises.

Barging buffalo on the basaltic banks of the Shingwedzi River.

Day 5: Schingwedzi to Olifants RestCcamp

The journey from Shingwedzi to Olifants Rest Camp takes us back south along the H1-6, crossing from the Shingwedzi River drainage basin to that of the Letaba River. Geologically we follow the boundary between the mixed woodlands of the western Kruger old cratonic basement and the eastern Kruger Jurassic succession open savannah grasslands mostly on basalt. Around 50km south of Shingwedzi Rest Camp turn left on to the S144 dirt road (the "Tropic of Capricorn Loop"), to cross from the sandy, quartzitic soils of the basement gneisses and overlying Clarens Formation sandstone on to the basaltic soils of the Letaba Formation. The soils in this part of Kruger support grasslands rather than trees and the open scenery attracts a range of herbivores, often grazing together in mixed species to aid general alertness against the predators.

Lions resting in the early morning on the drive south along the H1-6 from Shingwedzi.

Just down the road from the lions the tsessebe and wildebeest stay alert on the basaltic soils…

While the nearby buffalo seems less perturbed as they graze the sweet grasses….

Just after 3km along the S144 make a stop at the N'wambu waterhole (right). Shortly after this turn right on to the S143, crossing the Tropic of Capricorn at the Tihongonyeni waterhole.

The unremitting barren flatness of the basaltic plain under big skies on the S143 Tropic of Capricorn Loop road.

The S143 runs southeast across the open basaltic plain through ostrich country with views east to the Lebombo Hills: the main geological objective of today's drive. At the junction with the S50 (Dipeni Road) turn left and drive 10km northeast, crossing back over the Tropic of Capricorn, to the track (right) leading to the Shibavantsengele Lookout, a popular bird-spotting site on the slopes of the Lebombo Hills.

View west from the Shibavantsengele Lookout road back over the basaltic plains that separate the mixed forests of western Kruger from the Lebombo Hills. The red-weathering boulders lying around are of a rock type called "granophyre", which is rich in quartz and feldspar (and therefore rhyolitic in chemical composition) and much more resistant to weathering than the underlying basalts. The granophyre lies at the top of the Sabie River Basalt Formation and here defines the edge of the Lebombo Hills (sometimes referred to more enthusiastically as "mountains").

The hill of Shibavantsengele (490m) rises to the south of the track and exposes the pale granophyre which forms a prominent outstanding ridge running north-south along the border with Mozambique. Granophyre is a type of finely crystalline granite that has managed to reach high levels in the crust, intruding its way slowly as it cools and solidifies. In this case the granophyre forms a sheet-like mass (called a "sill": think of a sill as horizontal and a dyke as vertical) that lies towards the top of the basaltic succession. All these rocks (basalts and rhyolitic granophyre) dip gently east, so by driving east we have moved up through successively younger rocks in the Jurassic succession.

Drive back south along the Dipeni Road (S50) and at the S143 junction continue south, following the Nshawu River to rejoin the H1-6 south of Mopane Rest Camp. Here consider a comfort stop at the Mooiplaas Picnic Site. Although this involves backtracking 8km north along the H1-6 it makes for an attractive break and the opportunity to stretch your legs.

Now continue south on the H1-6, with at times great views east and southeast to the Lebombo Hills, for over 30km across the basaltic lowveld to the bridge over the Letaba River. From the bridge there are extensive views downstream east across to the Lebombo Hills, with the added attraction of basaltic dykes well exposed in the river bank across to the right.

View east downstream from the Letaba River bridge. Exposures of the Sabie River Basalt Formation form low cliffs (right) and in the distance rise the Lebombo Hills which define the outcrop of younger granophyres and rhyolites that lie above the basalts.

Leaving the bridge, immediately on the left are exposures of a basalt flow upon a more weathered, older basaltic unit. Continue south on the H1-6 to visit the Letaba Rest Camp and its excellent elephant museum. One of the exhibits demonstrates how the ancestors of modern African elephants can be traced back over 40 million years through Eocene Palaeomastodons, Oligocene Gomphotheres, and Miocene Primelephas. It must have been quite a journey.

The next stop is Olifants Rest Camp via the H1-5 and H8, and accommodation check-in. The camp is built upon a ridge of hard rhyolitic rocks in a remote location and offers excellent views over the Lepelle (formerly Olifants) River gorge.

Vertical feeder dykes (centre left and extreme right) cutting the basaltic rocks exposed in the cliff banks upstream from the Letaba River bridge.

View looking downstream from the Olifants Rest Camp outlook across the Lepelle River. The hard "Olifants Beds" rhyolite on which the base camp is built continues on the other side of the river forming a prominent topographic feature with a west-facing steep scarp reflecting the easterly dip of the entire Jurassic succession.

The "Olifants Beds" rhyolite is packed full of crystals of pale feldspar set in a fine pink matrix. This rock was erupted around 181 million years ago as magma already full of crystals. Upon eruption the magma suddenly froze to form the fine pink matrix within which the crystals became embedded, a rock texture known as "porphyritic".

It is possible to get closer to the rhyolitic Lebombo Hills by driving out from the camp and taking the S93 north then almost immediately turning right on to the rather rough S44 east for 6km. Where the S44 turns left, take the track right that leads down to the lookout over the basaltic riverbed and rhyolitic ridge of the Lebombo Hills.

Track leading off the S44 to the lookout with views southeast into the Lepelle River valley 6km east of the base camp. The western edge of the Lebombo Hills is defined by prominent cliffs of rhyolite which deflect the river towards the southeast.

Close up of the Lebombo rhyolite cliff above the Lepelle River on the western edge of the Lebombo Hills. The rhyolitic lava is cut by horizontal and vertical fractures produced during cooling of this volcanic rock soon after eruption.

Marabou stork on S44 roadside near Olifants Rest Camp. Possibly the ugliest bird on the planet, the impressive pink gular sac is used for just that, to impress during the mating season.

Day 6: Olifants to Skukusa Rest Camp

This excursion visits a diverse range of ecozones, starting with a drive south across basaltic lowveld to Satara base camp then a splendid diversion up-stratigraphy eastwards almost to the Mozambique border before continuing south to Tshokane. From here the route moves southeast and down-stratigraphy to progressively older rocks, crossing from the Jurassic cover rocks back on to the ancient cratonic basement of western Kruger, with stops at Kruger Tablets and Orpen Rocks before bridging the Sand and Sabie rivers to reach Skukuza, the largest of the rest camps in Kruger.

From Olifants Rest Camp head back west to the H1-5 and turn south for a short distance to reach the N'wamanzi Lookout on the right for extensive views over the Lepelle River. Similar views can be enjoyed by stopping on the H1-5 where it crosses the river 5km further south. When the river bed is exposed one can see here low outcrops of Sabie River Basalt Formation partially covered by alluvial gravels, sands and mud. The H1-5 continues south, always still on the outcrop of the same basalt formation, to Satara Rest Camp.

Camouflaged Kudu grazing by the H1-5 roadside and, further down the road, a young male lion. The open savannah lands on the Jurassic basalt make for excellent wildlife viewing in this part of Kruger.

Black-backed jackal amid white-backed vultures close to the H1-5 roadside north of Satara. The basaltic savanna soils of the Satara area encourage the growth of more abundant grasslands as compared to most granitic areas (for example around Skukusa). The grass is appreciated by the herbivorous wildlife (and, as here, by their carnivorous predators) but more prone to higher intensity wildfires.

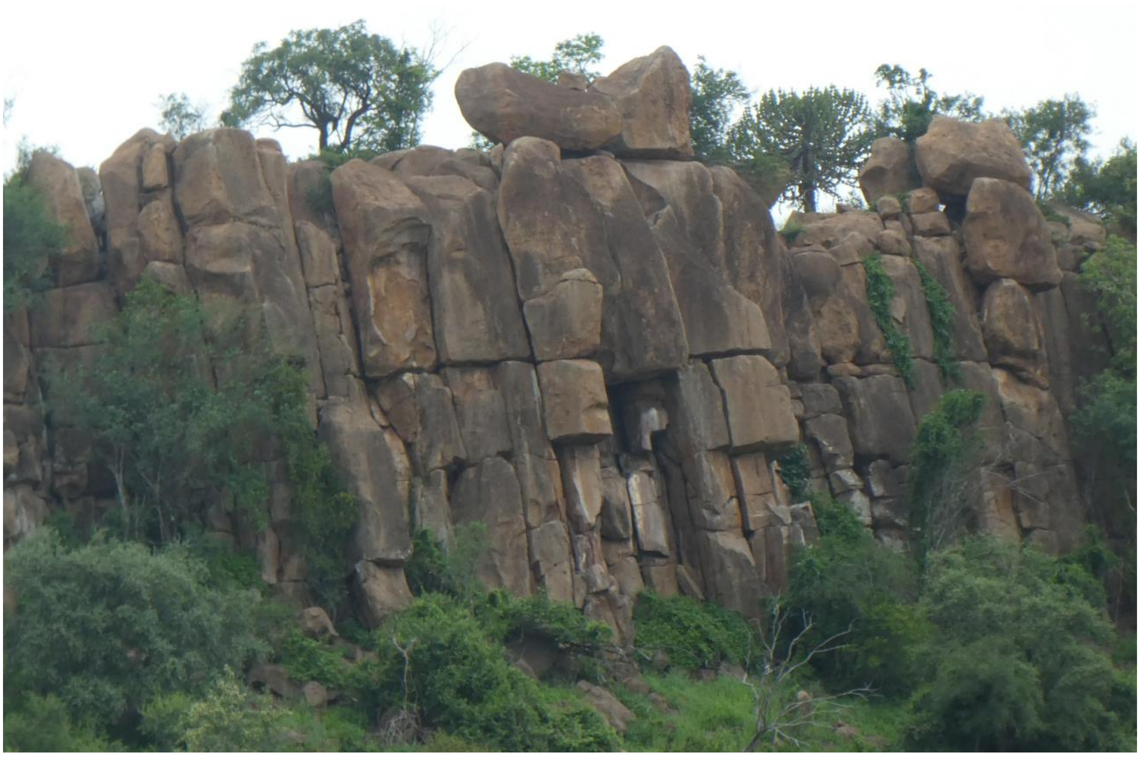
But even the savanna fires have their uses: in this case as a burnt lookout for vultures….

Continue for 5km south of Satara then turn left (east) into the H6 which runs for 20km to the Lebombo Hills. Initially this spectacular road crosses a particularly desolate stretch of basaltic lowveld. As the Lebombo Range gets closer the scenery becomes hillier and more vegetated as layers of hard rhyolite at the top of the Sabie River Formation make their mark on the topography. Pass the S37 (right) then S41 (left) to reach the turnoff (right) to the N'wanetsi Picnic Site where vehicles can be left at your own risk and there is a paved path (left) that leads up to a lookout over a natural dam in the Sweni River. As an added bonus here there are excellent exposures of rocks belonging to the Jozini Formation, these being Jurassic rhyolites that lie above the Sabie River Formation basalts. For the geologists amongst you, allow me to quote from a 2004 paper by Riley et al., "*The Jozini Formation crop out in a narrow belt (3–15 km wide) along the border with Mozambique … and comprise a thick sequence of largely high-temperature, anhydrous ignimbrites, interbedded with rare rhyolite lava flows. The majority of the rhyolites are porphyritic and contain phenocrysts of one or more of the following: plagioclase, clinopyroxene, magnetite, quartz and sanidine, plus accessory apatite and zircon*."
(see: http://www.largeigneousprovinces.org/sites/default/files/Riley_et_al_2.pdf).

Pathway leading up to the N'wanetsi Lookout, past exposures of Jozini rhyolite. The apparent layering shown by the rhyolite (dipping down from top right to lower left) is interpreted as due to flow of the hot rhyolite during eruption.

Close up of the flow fabric within the Jozini rhyolite. The porphyritic rock is packed full of small pale feldspar crystals and, just to the left of the finger, the fabric can be seen to define a curving fold interpreted as produced during viscous flow under gravity of the hot rhyolite away from the volcanic vent.

View south from the N'wanetsi Lookout across the Sweni River. To the left is the west-facing scarp cliff of the east-dipping Jozini rhyolite ridge which is more resistant to weathering than the flat, basaltic lowveld to the right.



Zoom close up of the tor-like Jozini Formation rhyolite cliff from the N'wanetsi Lookout, showing well developed near-vertical and horizontal fracturing ("jointing") produced during cooling after eruption on the Jurassic land surface. Note the great blocks of rhyolite left perched on the slowly eroding clifftop.

View west from N'wanetsi Lookout (The Traveller for scale) looking across from the red rhyolite outcrop over the basaltic lowveld of the Sabie River Basalt Formation below. Together the Jurassic basalts and rhyolites in Kruger and western Mozambique are around 12km thick, recording massive volcanism here in the Karoo Volcanic Province. These eruptions, first relatively gentle basaltic and then explosively rhyolitic, took place around 181 million years ago over a period of 1 or 2 million years. The eruption of these basalts and rhyolites occurred in extending crust as southeast Africa and Antactica split apart. The extension aided the rise of deep, hot mantle rocks and the basaltic magmas produced by their partial melting ("decompression melting": loss of pressure lowers the melting temperature of hot rock). By the time something like 7km of basalts had been erupted, the lower crust, overwhelmed by increasing amounts of magma rising from the extending mantle beneath, became hot enough to begin remelting of some of the early solidified basaltic rocks and it was this process that is thought to have produced most of the rhyolites.

Return to the H6 and take the S37 dirt road (left) 2km south to turn right into the Sweni Hide. Here, alongside the river, one is lower in the local geological succession and there are exposures of one of the rhyolitic units lying within the upper part of the Sabie River Basalt Formation. There are also good views eastwards from the hide across to the rhyolitic Lebombo escarpment south of the previous stop.

Return to the H6 and drive back west and down the geological succession across the barren, stunted basaltic plains to the H1-3 then turn south towards Tshokwane. In a little less than 10km the H1-3 leaves the basalts, crossing on to the outcrop of the underlying Clarens Formation sandstones, and the scenery becomes less severe as it passes several wildlife-rich watering holes, the S86 loop road along the N'waswitsontso River, and Mazithi Dam. Tshokwane offers a welcoming picnic or restaurant stop, although watch out for the pillaging monkeys: they are a real problem.

Nervously guarding food and coffee from the marauding monkeys at Tshokwane.

Now make one final return to the Lebombo Range and its rhyolitic geology by turning southeast into the H10, another route usually rich in wildlife sightings. The road crosses back up the basaltic succession and then climbs the Lebombo Hills to reach the Nkumbe View Site (right) 11km from Tshokwane.

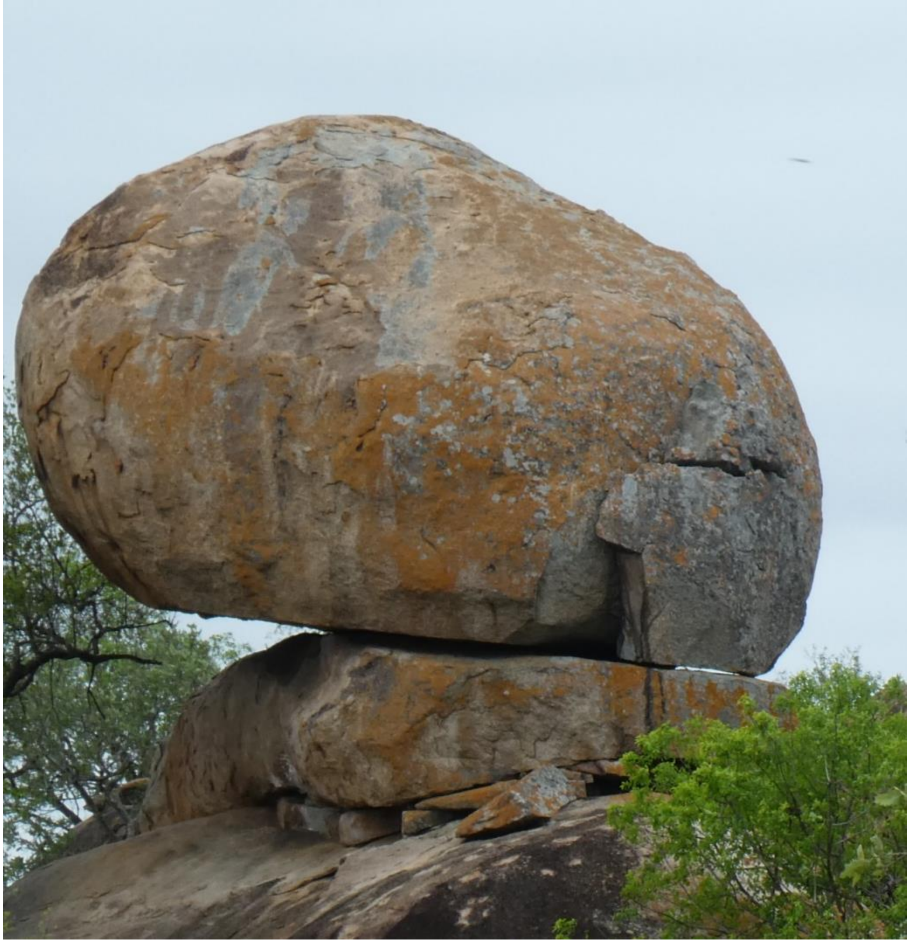
The Nkumbe Lookout westwards over the basaltic plains from the rhyolitic (granophyric) ridge of the Lebombo Hills.

Elephant and waterbuck on granophyre near Nkumbe Lookout

We now finish the day with an east-to-west traverse from the Lebombo Hills back across the basalts and Clarens sandstones to reach the ancient basement rocks of southwest Kruger. On the first part of this traverse, returning from Nkumbe to the Tshokawane junction, there are exceptional views northwards to the west-facing scarp of the Lebombo Hills.

Turn left into the H1-2 and head southeast for 10km across Jurassic sediments to a point where ahead lies the granitic koppies of the Kruger Tablets area: we are crossing from the Jurassic cover rocks to the Precambrian basement. From here southwards the geology is dominated by a unit called the Nelspruit Granite Suite, which comprises a range of basement rocks (mostly various types of granites and gneisses) over 3 billion years old.

The Kruger tablets, commemorating "the institution of national parks in the Union", are mounted on one of several huge granitic boulders resting on a flat exposure of granitic bedrock. These rocks, full of coarse feldspar crystals, outcrop as a series of granitic tors (sometimes called "castle koppies") in this part of the park. To view graphic examples of how such huge rounded granite boulders are formed, drive 1km further down the road to the Orpen Rocks (right) where the same suite of ancient granitic rocks is exposed in another koppie outcrop.



Balancing rock at Orpen Rocks, illustrating how these great rock masses very gradually become isolated by chemical weathering along horizontal and vertical cracks ("joints") and their rounded shapes are sculpted by physical exfoliation. Removal of soft weathering products such as clays along the joints, especially during the wet season, slowly makes the remaining rock mass increasingly unstable and liable to topple into lower ground. It is just a question of erosion and time.

Continue southwest for 18km on the H1-2 to the bridge over the Sand River where there are some of the best exposures of basement gneisses to be found in Kruger Park.

Archean gneisses exposed alongside the bridge over the Sand River show paler granitic areas and dark grey areas that have a different chemical, and therefore mineralogical, composition. Whereas the granitic areas are mostly composed of feldspar and quartz, the dark areas are richer in "mafic" (i.e. magnesium Mg- and iron Fe-rich) minerals such as biotite and hornblende.

Close-up of left side of previous image showing how the pale granitic component of the gneiss has intruded the darker mafic areas like a liquid. The grey gneisses are "metamorphic", i.e. formed under high heat and pressure deep within the Earth's crust, and they show a layering or banding which is typical of gneisses. They were once so hot that they began to melt, separating a semi-liquid, granitic fraction that became mobile. The more mafic parts of the gneiss have a higher melting temperature and so stayed solid (although hot enough to become soft and easily deformed) as the granitic component flowed through and around them. The exposure here demonstrates the complexity of the rock textures produced by such extreme metamorphism and deformation deep in the earth. Note also the thin black layer at the edge of the main granitic vein where dark, unmelted minerals in the granite have become separated from the molten granite. Such once-partially molten rocks are called "migmatites" and they are extremely common throughout the cratonic basement of western Kruger. They represent the transition from solid metamorphic rocks to liquid magma which later crystallises to form an igneous rock. If the process of melting continues so that little or none of the metamorphic rock is left then a granite will have been born. Later uplift and erosion of this granite will produce sediments which may become deposited and later buried, metamorphosed and perhaps melted again to continue the seemingly endless rock cycle: igneous-sedimentary-metamorphic-igneous-sedimentary…….

Another splendid exposure of basement gneisses in the Sand River, washed and polished by fluvial erosion. Once again the darker, more resistant mafic parts of the gneiss can be seen to have become isolated and drawn out as soft rounded masses immersed within a more mobile granitic component. There is no scale on the image (the crocodiles were a deterrent) but this is useful. The scale could be one metre or a vegetation-free landsat image a hundred km across of one of the ancient continental cratonic areas preserved at the Earth's surface. This is what much of Earth's lower crust looks like.

Water monitor resting on the granitic component of the migmatitic gneisses exposed in Sand River. Note the small area of mafic minerals preserved lower left.

The final stop of the day is the H1-2 bridge over the Sabie River 7km further southwest. Just before reaching the bridge a roadcut exposes banded gneisses cut by a dark basaltic dyke (right).

Brown weathered, quartz-veined migmatitic basement gneisses (right) intruded by a thick, grey, feldspar-porphyritic, basaltic dyke (left) in the roadcut on the north side of the H1-2 Sabie River bridge. The younger basaltic magma intruded, and froze solid against, the older metamorphic basement. The rock on the right is metamorphic, whereas that on the left is igneous. A textbook example.

Pot-holed gneisses in the Sabie River bed. Such holes excavated into the riverbed are produced by the swirling, grinding action of stones and other coarse sediment when the river is high.

Crocodile digesting peacefully alongside the Sabie River bridge crossing; a reminder not to leave the vehicle.

Continue on H1-2 and H4-1to Skukuza Rest Camp: it has been a long day.

Day 7: Skukuza to Berg-en-Dal Rest Camp

This final excursion runs from Skukusa to the southern border of the park and makes a leisurely end to the geotraverse, spending the final night in Berg-en-Dal Rest Camp. Start by heading south from Skukuza on the H1-1 for 10km to the prominent bare rock dome of the Mathekenyane “Granokop”. Turn left and drive to the top of this dome where you can leave the vehicle at your own risk. From here there are expansive views west over the forested lowveld to the great Drakensberg Escarpment and southwest to the hills in the far corner of Kruger Park. Underfoot are excellent exposures of migmatitic gneisses: a veritable field laboratory revealing the complex, polyphase history of these high-temperature metamorphic rocks.

View west from the smooth surface of Mathekenyane granitic gneiss koppie across the lowveld forest to the distant mountains of the northeastern Great Escarpment. The highveld west of the escarpment was uplifted during the 182 million-year old geological event that produced the Karoo basalts and rhyolites. A hot plume rising from the mantle caused Africa to bulge upwards and split apart to form rift valleys on either side that eventually opened to produce the early Atlantic and Indian oceans. Since that time the escarpment on this eastern side of Africa has slowly retreated westwards and the sedimentary products of its erosion have been spread across the lowveld and carried east by rivers to the ocean.

The rock exposed on Mathekenyane is a grey granitic gneiss cut by paler granite veins, interpreted as produced by partial melting of the hot gneiss complex during migmatisation. The above image shows how these veins vary greatly in their texture and mineral content: most of the veins are pink with relatively small crystals, although in places there are patches of coarse crystals of translucent grey quartz and pale feldspar (“pegmatite”: lower right), and areas rich in black biotite-mica (adjacent to and above the pegmatite). The deep brown staining (e.g. left of the sunglasses) is due to chemical weathering (oxidation) induced by surface water percolating through the cracks (joints).

Close up of the contact between porphritic granite gneiss (below) and a variably-textured granite vein (above). Note the large, rectangular crystals of white feldspar in the grey gneiss, giving it a porphyritic texture. Feldspar, like most minerals that form rocks on Earth, is a silicate, as well as being the commonest mineral in the Earth's crust.

The granitic veins intruding the Mathekenyane gneiss were not all produced at the same time. Older veins have been deformed into folds (lower centre) which are cut by younger, undeformed veins. This is a "polyphase intrusive and deformation history" and is typical of basement gneisses.

On Mathekenyane the various pale pink granitic veins, many of which run east-west across the exposure, are themselves cut by an even younger set of grey microgranite dykes which run northeast-southwest. In this image a pale pink granite vein (blue border) intruded into the porphyritic granite gneiss has been truncated and displaced top-to-the-left by a rather inconspicuous microgranite dyke (red border).

Close up of another example of a pale coarse granite vein (blue border) intruding darker porphyritic gneiss (again note the white feldspars). Both vein and gneiss are in turn cut a younger, more finely crystalline microgranite dyke (red border).The texture on the upper right (left and below the sunglasses) is somewhat obscured by the alteration effects of surface weathering.

Continue south on the H1-1 then turn left into the H3 towards Malelane. The road passes a number of granitic koppies with increasingly impressive views to the hilly, forested southwestern corner of Kruger. At 27km from the H1-1 junction turn left into the Afsaal Trader's Rest for a comfort stop.

Giraffes below one of many granitic koppies alongside the H3 in this verdant, well-forested and wildlife-rich corner of the park.

The road south of Afsaal initially becomes more barren and is reminiscent of the ecology above the soils of the Jurassic Karoo basalts seen the previous day. This is because in this area there is a narrow belt of Timbavati Gabbro (which we saw on the Red Rocks loop of Day 2) that can be traced all the way across the park from Phabeni Gate southeast to the Crocodile River at Biyamiti. Gabbro and basalt both have the same chemistry and so produce similar soils that in turn support a similar ecozone. The gabbroic belt is however narrow and we are soon back in undulating forested granite country more typical of this corner of the park, crossing the Mlambane River 8km south of Afsaal.

Elephants about to cross the H3 south of Afsaal in the hilly, granitic scenery of southwestern Kruger.

The Kruger Experience: wild animals roam freely while humans are confined to their vehicles. H3 14km south of Afsaal.

Rhino-spotting in southwestern Kruger. Location withheld for fear of poachers.

Crocodile River valley across the southern border of Kruger Park, looking south into the Makhonjwa (or Barberton) Mountain Range, which has yielded some of the oldest fossils on Earth.

The H3 begins the descent into the Crocodile River valley around 15km south of Afsaal, passing the S114, on the direct route to Malelane. However, if time allows we recommend instead a slow drive along the 20km Mlambane Loop: turn left into the S118 dirt road just after the Mlambane River bridge and follow it east along the river. This is an excellent area for wildlife and, as an added bonus, one can spot some unusual rocks after around 7km just before reaching the S114 junction. The exposures are on the opposite (north) side of the river and are shown below:

Zoom image of dark amphibolitic gneisses on the north side of the Mlambane River shot from the S118 near the S114 junction. These rocks are mafic (Mg- and Fe-rich) like the basalts seen in eastern Kruger. Here, however, they form part of the gneissic basement of western Kruger, and have been metamorphosed under high temperatures and pressures so that the original igneous minerals have recrystallized into metamorphic ones. They likely belong to the famous Barberton Greenstone Belt (BGB) which is mostly exposed in the mountains south of the Crocodile River but also occurs in this southernmost part of Kruger. The BGB is famous not only because it is very old (more than 3,500,000,000 years in places) but also because it contains traces of early life on the planet, not to mention the oldest known gold deposits. The BGB likely records the existence of an ancient ocean (oceanic crust is basaltic in chemical composition).

Upon reaching the S114 turn left to admire exposures of gneisses veined by pink granite in the bed of the Mlambane River, although getting out of the vehicle here is most definitely not recommended.

Grey gneisses cut by granite veins in the Mlambane River bed. Such rocks represent the "gneiss and granite" terranes (= continental crust) exposed on either side of the Barberton Greenstone Belt (= oceanic crust)

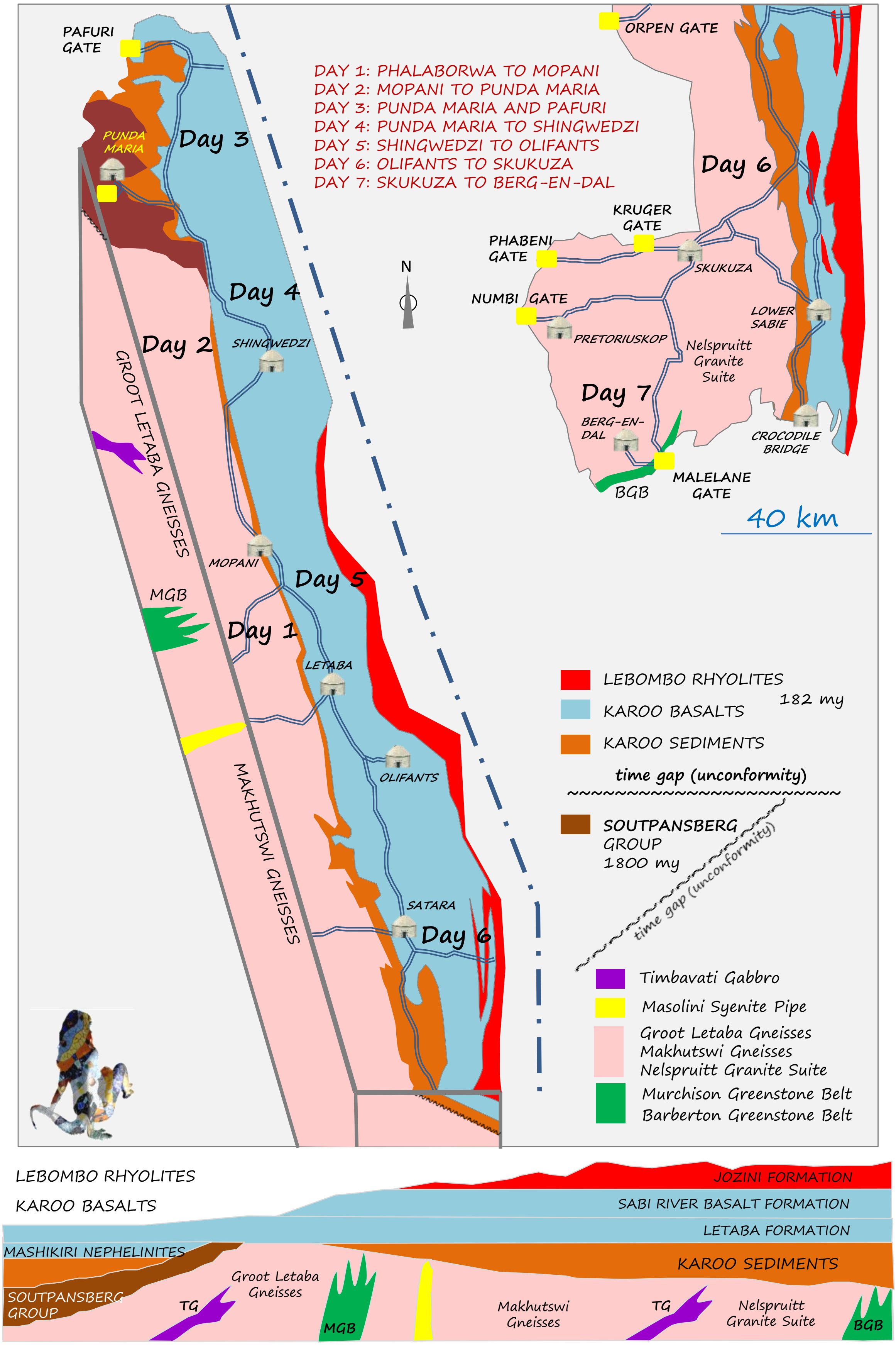
Now turn around, re-cross the bridge and drive southwest along the S114. In 4km the S25 Crocodile Bridge road comes in from the left and we merge into the wide, flat Crocodile River floodplain. In another 8km we re-join the H3: turn left, cross the Matjulu River then turn right into the S110 for the 10km drive to Berg-en-Dal Rest Camp. The drive takes us into the most mountainous part of the park: to the southwest rises the peak of Khandiwe which, at 839m is the highest point in Kruger. Park in the rest camp and walk the Rhino Trail which follows the perimeter fence.

View southeast from the Rhino Trail at the perimeter of Berg-en-Dal Rest Camp. Just behind and to the right of the dam are exposures of mafic basement gneisses.

Giraffe alongside the S114 on the Crocodile River floodplain, hosting a red-billed oxpecker feasting on ticks.

Close-up of gneisses by the dam in the image above. The dark areas are rich in the mineral amphibole and they are criss-crossed by feldspathic veins. This is a migmatitic amphibolitic gneiss. Examples of this dark, mafic gneiss can be admired in ornamental stones inside the camp.

Amphibolitic gneiss used as ornamental stone inside Berg-en-Dal camp. Note the contrast between the dark amphibole minerals (mostly black hornblende, with paler greenish actinolite top left) and the pale, feldspar-rich veins.



Simplified geological map and cross-section through Kruger Park. The lower diagram shows a cross section from north (left) to south and graphically demonstrates how across most of the park the Karoo sediments and overlying volcanic rocks (basalts and rhyolites) lie above the basement gneisses of the Kaapvaal Craton. In the north however the Soutpansberg Group lies between the old gneisses and Karoo sequence.

The Kruger Geological Big Five

Having completed the drive you will now appreciate the five great geological highlights offered by Kruger Park. From oldest to youngest these Kruger Geological Big Five (KGB5) are as follows:

1. **The Kaapvaal Craton: the oldest igneous and metamorphic rocks**. The geological deep roots of Southern Africa are known as the Kaapvaal Craton and in places they go back nearly 3.5 billion years and are therefore Archean in age (the Archean Eon lasted from 4 to 2.5 billion years ago). The western half of Kruger, west of a line from Babalala to the Crocodile River road west of Crocodile Bridge, is underlain by these ancient cratonic rocks. The Archean rocks (all >3 billion years old) are gneisses and granites and formed deep in the heat of the Earth's lower crust. In the south of the park they comprise the Nelspruitt Granite Suite (seen on days 6 and 7) and, along the extreme southwestern border, the Barberton Greenstone Belt (Day 7). In the central area of the park the basement rocks include the Makhutswi and Groot Letaba gneisses (the latter seen on Day 2 at Red Rocks). The ecological landscapes typically found on these rocks in western Kruger include mopane woodlands in the northwest (Day 1) and mixed broadleaf woodlands (for example the hills south of Skukusa: Day 7). Around Phalaborwa the basement gneisses are intruded by syenites dated as 2.06 billion years old and related to the Bushveld Complex exposed in the highveld west of Kruger (seen at Masorini on Day 1). Another important, although much younger, igneous event within the cratonic basement was the intrusion of the Timbavati Gabbro, 1.1 billion years ago (seen at Tshanga on Day 2 and crossed south of Afsaal on Day 7). The gabbro forms part of a huge area across which basaltic magmatism took place 1112-1006 million years ago across southern Africa, North America and Antarctica (before they split apart) and is known as the Umkondo LIP (Large Igneous Province).
2. **Soutpansberg Group: the oldest sedimentary rocks**. The eastern end of the Soutpansberg Mountain range enters the far northwestern corner of Kruger around Punda Maria where the hills are formed mostly from quartzitic sandstones deposited around 1.8 billion years ago. These sandstone lie within the Soutpansberg Group and are remarkable for having survived so long virtually unscathed and still preserving original sedimentary textures such as ripple marks. They were deposited by rivers in a valley that formed as a result of extensional fault movements north of the Kaapvaal Craton. They produce sandy, well drained soils that support a botanically diverse terrain known as the northern sandveld. Day 3 (Mahonie Loop) and Day 4 (Dzundzwini Loop).
3. **Karoo sediments: a Jurassic desert in Southern Africa.** For over 120 million years, from Late Carboniferous to Early Jurassic times, much of southern Africa formed a vast area known as the Karoo Basin. Sediments deposited in this basin form a thick sequence known as the Karoo Supergroup. In Kruger Park, Karoo sediments were deposited unconformably upon the Kaapvaal Craton and Soutpansberg Group Precambrian rocks and are mostly represented by the Clarens Formation sandstone, which was deposited in a Lower Jurassic desert environment similar to that of the Sahara today. On the map these Jurassic sediments with their overlying sandy soils and woodlands dip gently east and generally form a narrow outcrop running almost north-south, passing through Mopani and just west of Letaba in the middle of the park. In the far north around Pafuri, and in the southern park centre south of Satara the Karoo sediments are thicker and more widely exposed. Seen on Day 1 (Kaleka River), Day 2 (Red Rocks Loop), and Day 3 (Klopperfontein).
4. **Karoo basalts: Jurassic volcanoes burst upon the scene.** Around 182 million years ago in southern Africa the break-up of the supercontinent Gondwana was heralded by the eruption of basalts as Antarctica split away from the Kaapvaal Craton and the western Indian Ocean began to form. Hot, soft mantle rock began to melt as a result of decompression as it rose towards the Earth's surface along this line of gradual continental separation between Africa and Antarctica. The first magmas to be erupted were rich in olivine (and therefore relatively poor in silica) and are represented by the Mashikiri Formation nephelinites and overlying Letaba

Formation picrites (around 4km thick). As volcanism continued, the magma evolved to become less olivine-rich, producing the Sabie River Basalt Formation (around 4-5km thick; all erupted in less than half a million years). These basaltic lavas are tilted gently eastwards and underlie much of eastern Kruger. They strongly influence the soils, landscape and ecology, commonly forming open, flat savannah grassland plains and mopane shrubveld. The relatively poorly drained nature of the clay-rich soils on basalt aid water retention in the waterholes and so supports wildlife well into the dry season. Day 1 (Tsendze River), Day 2 (Tsendze River, Red Rocks), Day 3 (eastern Pafuri area), Day 4 (Shingwedzi River), Day 5 (Letaba River), Day 6 (Lepelle River).

5. **Lebombo rhyolites: the explosive volcanic climax.** Towards the end of the Sabie River basalt eruptions a new type of magma began to reach the surface. Rhyolites are viscous, slow-moving, rich in silica (around 70% SiO_2) and are very different from smooth-flowing, treacle-like black basalts (around 50% SiO_2). The reason why the rhyolites appeared is probably due to partial melting of older basaltic rocks in the lower crust: as the whole process of continental separation and volcanicity took place, more and more magma rising from partially melted mantle into the solid crust increased temperatures enough to begin to melt that crust. Small amounts of partial melting of basalt produces low-density silica-rich rhyolitic magma, which can then rise to explode at the surface. In places where the rhyolite magma approached the surface it sometimes failed to erupt, instead sending tongues which nosed their way into the top of the Sabie River basalt flows and solidified as granophyric sills (Day 5: Shibavantsengele Lookout). When eruptions did occur the rhyolite either oozed out as lava across the land surface, thick enough to form flow-folding, or else erupted explosively due to entrapped gases unable to escape through the viscous, almost solid magma. Up to 5km of these rhyolitic rocks lie above the Sabie River Basalt Formation and they are mostly explosive eruption deposits known as ignimbrites or tuffs. They record a spectacular climax to the Jurassic volcanism which all-in-all produced over 12km of lavas erupted in less than two million years. This volcanic event coincides in time with a global mass extinction event in the biosphere (the 7th largest so far recognised) which is likely to have been related to the massive Karoo eruptions and their effects on the atmosphere and ocean chemistry.

The lower part of the Lebombo rhyolites is known as the Jozini Formation which is found running north-south along the Mozambique border between the Shingwedzi and Crocodile rivers. These Jozini Formation rhyolitic rocks are much more resistant to chemical weathering than the basalts and so stand proud of the landscape to form the Lebombo Hills that define the eastern edge of Kruger Park. The gentle easterly dip of these pink-weathering volcanic strata bestows a distinctive scarp-and-dip profile to the hills, with steep, west-facing scarp slopes exposing tor-like koppies with vertical columns reflecting the cracks (joints) that developed as the rocks cooled (Day 5: Olifants Rest Camp and Lookout; Day 6: N'wanetsi and Nkumbe lookouts). This is one of the driest areas of Kruger and is chararacterised by shallow, stony soils with drought-resistant plants.

The End

Wes Gibbons 2019
http://barcelonatimetraveller.com/

Background to Holiday Geology Guides

The author and geologist Wes Gibbons has always had an interest in writing short geoguides aimed at inquisitive tourists, offering them the opportunity to learn about the landscapes and rocks of scenically attractive places. His argument is that there is so much more to know about rocks and Earth history than the superficial descriptions offered by tourist guidebooks, which rarely even scratch the surface of Deep Time.

His first attempt in this direction produced *The Rocks of Sark* (1975), published jointly with John Renouf of Manche Technical Supplies in Jersey, a venture that taught a youthful Wes to always be the one responsible for the final proof reading. In 1976 Wes moved from Sark to begin a PhD supervised by Greg Power (Portsmouth University) and Tony Reedman (British Geological Survey). Living in a former Post Office in the village of Greatham on the Hampshire-West Sussex border, Wes decided to pass his spare time preparing a guide to the geology of the Weald in southeast England. He sold the idea to the publishers Allen and Unwin who commissioned other authors to develop a mini-series: *The Weald* (1981), *Snowdonia* (1981), *Lake District* (1982), and *Peak District* (1982).

His next field-based guidebook surfaced in 1985, fruit of several years research work in Corsica (*Corsican Geology: a field guidebook* by Gibbons and Horák). Two years later Wes launched the Holiday Geology series, using a simple, inexpensive format later described as “a single A3 laminated sheet …. folded into three and (with).. six portrait panels … filled with a lively mix of colour photos, maps, sections and text” (review by Nigel Woodcock in Geological Magazine, 2000). The first two Holiday Geology guides were *Scenery and Geology around Beer and Seaton* (1987) and *Rocks and Fossils around Lyme Regis* (1988). The Holiday Geology concept attracted the attention of the British Geological Survey who went on to expand the series to over 20 titles.

Following his retirement in 2004 to live in Barcelona with Teresa Moreno, Wes maintained his interest in publishing field guides by writing the text to *Field Excursion from Central Chile to the Atacama Desert* (Gibbons and Moreno 2007), *The Geology of Barcelona: an Urban Excursion Guide* (Gibbons and Moreno 2012), and *Field Geotraverse, Geoparks and Geomuseums* (in central and southwest Japan: Gibbons, Moreno and Kojima 2016). His most recent publishing project, the most ambitious so far aimed at a general readership, has produced the book *Barcelona Time Traveller: Twelve Tales* (2016, Spanish translation 2017: Bimón Press Barcelona) and the resurgence of the Holiday Geology concept, although this time in virtual format linked to the *Barcelona Time Traveller* webpage.