The Witwatersrand and the Vredefort Dome

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The **Witwatersrand**(locally **die Rand** or **the Reef**), is a 56-kilometre-long (35 mi), north-facing scarpin South Africa. It consists of a hard, erosion-resistant quartzite metamorphic rock, over which several north-flowing rivers form waterfalls, which account for the name Witwatersrand, meaning "ridge of white waters" in Afrikaans.[1] This east-west-running scarp can be traced with only one short gap from Bedfordview(about 10 km [6 mi] west of O.R. Tambo International Airport) in the east, through Johannesburg and Roodepoort, to Krugersdorp in the west (see the diagram at left below).[2]

The scarp forms the northern edge of a 7-to-10-kilometre-wide (4–6 mi) plateau (or ridge) which rises about 200 m (660 ft) above the surrounding plains of the Highveld. The entire plateau-like structure is also often called the Witwatersrand. The plateau's elevation above sea-level is between 1700 and 1800 metres (5600–5900 ft).

The Witwatersrand plateau forms a continental divide, with the run-off to the north draining into the Indian Ocean via the Crocodile and Limpoporivers, while the run-off to the south drains via the Vaal into the Orange River and ultimately into the Atlantic Ocean.[2] [3]

Because of the extraordinary quantities of gold that have been extracted from the Witwatersrand rocks, the South African currency was named the Rand in 1961.

Geology of the Witwatersrand ridge

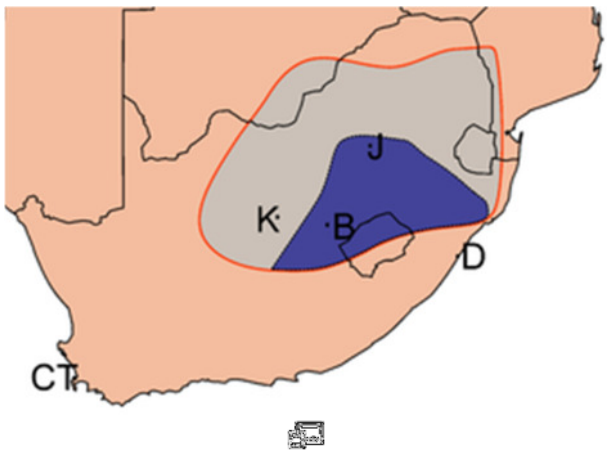
The Witwatersrand plateau consists of a 5000-to-7000-metre-thick (3.1–4.3 mi) layer of mainly sedimentary rocks laid down over a period of about 260 million years, starting approximately 2.97 billion years ago.[4] The entire series of rocks, known as the "Witwatersrand Supergroup," consists of very hard erosion resistant quartzites, banded ironstones and some marine lava deposits, interspersed with softer, more easily eroded tillites, mudstones and conglomerates. The oldest rocks (laid down 2.97 billion years ago) form the northern scarp of the Witwatersrand plateau; the youngest (laid down 2.71 billion years ago) are those that form the southern edge of the plateau.

Gold is found in the conglomerate strata of the younger members of the Supergroup, locally referred to as banket. The abundance of this gold is without equal anywhere else in the world. Over 50000 tonnes (55000short tons) have been mined from these rocks since this precious metal was first discovered here in 1886. This accounts for approximately 50% of all the gold ever mined on earth.[2]

Not all the conglomerates contain gold, and of those that do (known as “reefs” by the miners), the gold is not uniformly distributed throughout the layer, but tends to occur in streaks, where the pebbles that make up the conglomerate are larger than elsewhere. Here the gold is associated with other minerals, especially iron pyrite and uraninite, as well as carbon rich materials such as kerogen, or bitumen, which occurs in small balls less than 1 mm (0.04 in) in size, called “flyspeck carbon”, or as continuous layers about 10–20 mm (0.4–0.8 in) thick.[1] [4] The gold-bearing conglomerates occur chiefly in the upper, younger layers of the Witwatersrand Supergroup of rocks, on the southern side of the Witwatersrand plateau.

The Witwatersrand Supergroup strata which reach the surface in Johannesburg dip downwards to the south at an angle of about 30°.[2]From there on they are almost everywhere, with very few exceptions (see below), covered by younger rocks.[5] Gold mining in these buried portions of the Witwatersrand Supergroup is sometimes carried out at depths of 4 kilometres (2.5 mi) below the surface.[4] [6]

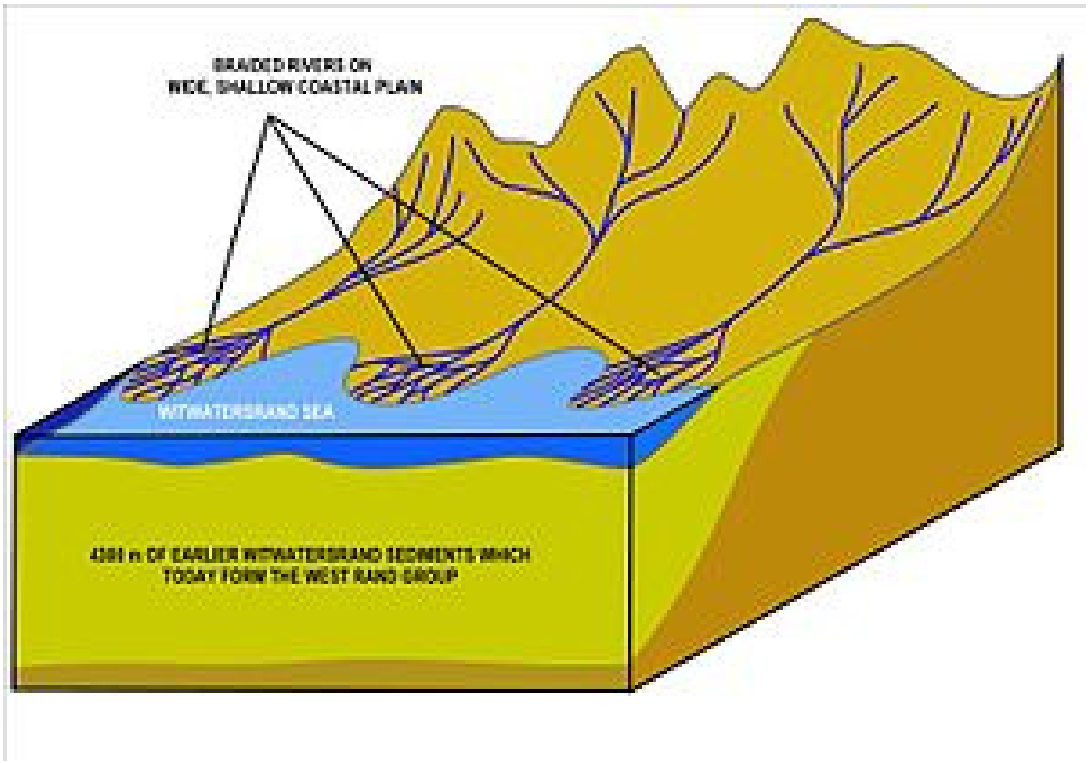
Geological origin



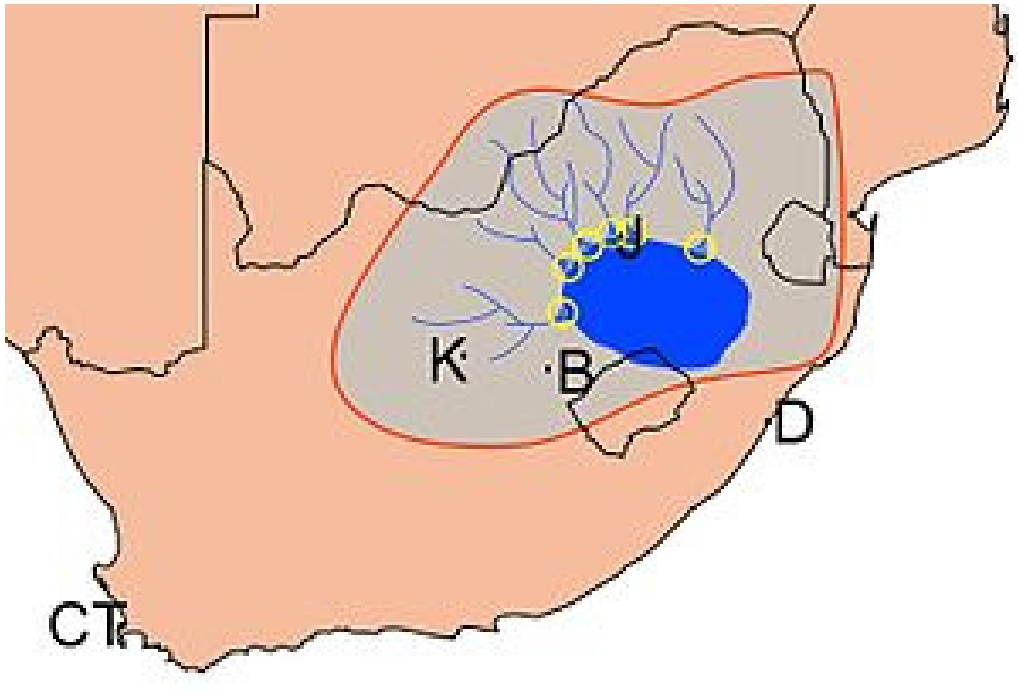
A diagrammatic representation of the position and size of the Kaapvaal Craton, outlined in red, in relation to present-day Southern Africa. The blue area depicts the portion of the cratonthat subsided below the “Witwatersrand Sea”, about 3000 million years ago. It is in this sea that the sediments accumulated that would ultimately form the “West Rand Group” portion of the “Witwatersrand Supergroup” of rocks. The younger “Central Rand Group” of rocks accumulated on the low, flat coastal plain (see the diagram below) after the Witwatersrand Sea had retreated southwards as a result of uplifting of the craton, especially in the north. **CT**indicates Cape Town, **D** Durban, **B**Bloemfontein, **J** Johannesburg, and **K**Kimberley.

An ashtray carved out of a soft form of banded ironstone. Note the alternating red and white layers that make up this rock. The red layers were laid down during the daylight hours when Archaean photosynthesizing cyanobacteria produced oxygen that immediately reacted with the dissolved iron in the water, to form insoluble iron oxide (rust). The white layers are sediments that settled during the night when there was no oxygen in the water. The earth’s atmosphere

was oxygen-free until about 2 billion years ago, when the rate of photosynthetic oxygen production began to exceed its rate of reaction with oxidizable materials (i.e. reducing agents).[7]



A diagrammatic presentation of the rivers that flowed into the Witwatersrand sea after 4300 m (14100 ft) of sediment had already been deposited in the basin. The fast flowing rivers cascading down the mountains to the north now flowed over a wide flat coastal plain to form broad deltas of sluggish braided rivers, where the heavy materials (cobbles, gold, uranium and iron pyrite etc.) carried down from the mountains settled out, to form the gold bearing "Central Rand Group" deposits. Today's gold ore is confined to the fossil river deltas.



The position of the Kaapvaal Craton (khaki coloured area) beneath the South African landscape, and the shrunken, shallow Witwatersrand Sea (light blue) at the time that gold was deposited in the broad, river deltas of six rivers that flowed into that sea, depositing all their heavier materials (cobbles, gold, uranium iron pyrite etc.) in the braided rivers of the deltas (see illustration on the left). Most of these gold deposits are deep under the South African surface, but form outcrops (exposures at the surface) along the length of the Witwatersrand ridge. The six gold fields thus established are, in order from the west, moving clockwise, to the northern shore of the Witwatersrand sea, Welkom, Klerksdorp, Carletonville, West Rand, East Rand and Evander.[1]

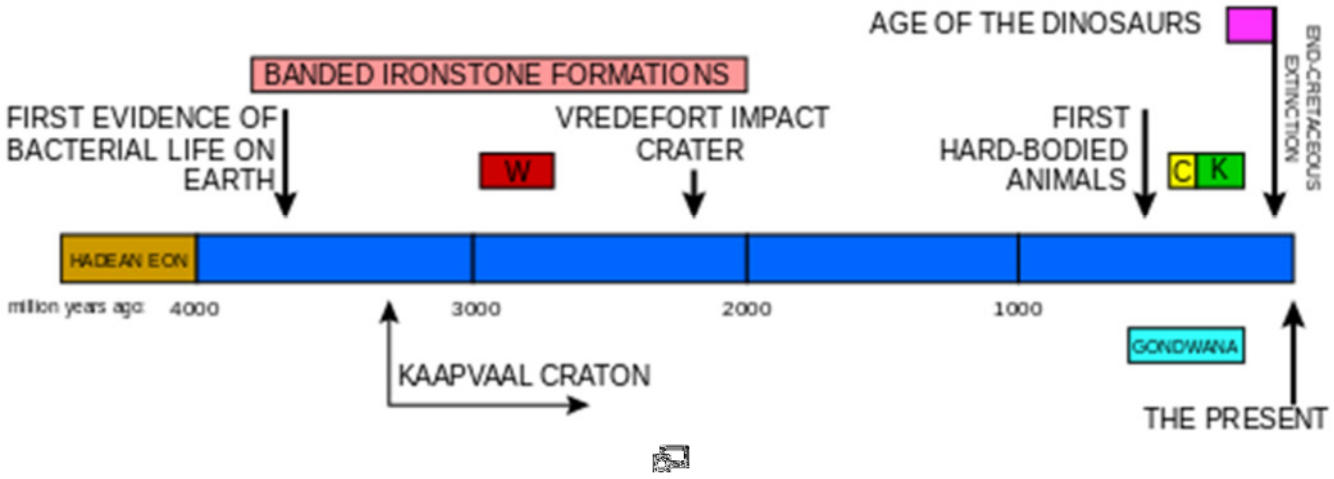
The Kaapvaal Craton, one of the first microcontinents to form on Earth through plate tectonics, was assembled about 3.9 billion years ago. Its size and position relative to Southern Africa today is indicated in the diagram on the left. About 3 billion years ago local cooling of the underlying asthenosphere caused subsidence of the south-eastern portion of this microcontinent

below sea level.[4] The floor of this newly formed “Witwatersrand sea” consisted of smoothly eroded granites. Sandy sediments brought in by rivers from the north started being deposited on the granite about 2.97 billion years ago. This sandy layer eventually became compressed to form the Orange Grove Quartzite, the lowermost layer of the Witwatersrand Supergroup. This quartzite formation forms the scarp from which the Witwatersrand derives its name (see above). As the sea deepened finer grained and muddy sediments accumulated.

There was no free oxygen in the Earth’s atmosphere till about 2 billion years ago, but there were photosynthesizing cyanobacteria.[7] The oxygen these microorganisms produced rapidly reacted with, amongst others, any dissolved iron compounds in the water, producing insoluble red iron oxide (rust), which precipitated out during the daylight hours. At night these reactions stopped. The result was alternating red and gray layers of mud which, when consolidated, became banded ironstones.[7]

Fluctuating sea levels resulted in the accumulation of a further variety of sediments, ranging from mud, to sand, to gravel, and banded ironstone. Tilliteдeposits, dating from 2.95 billion years ago, are indicative of the first glaciation episodes on earth.[4] [8] Within 60 million years, 4300 m (14100 ft) of sediment had accumulated on the granite base, to become the “West Rand Group” of rocks that contribute over 60% of the total thickness of the Witwatersrand Supergroup.[2] [4] [8]

Uplifting of the north of the Kaapvaal Craton, in addition to orogenesis(mountain formation), towards the end of the deposition of the “West Rand Group” of sediments caused the Witwatersrand sea to retreat. The area of the craton on top of which Johannesburg is now situated, became a vast riverine plain, which extended along the entire northern and western shoreline of the shrunken sea. The rivers formed braided deltas with many interlacing, slow flowing channels where all the heavy materials brought down from the mountains were deposited: large pebbles, and heavy minerals, such as gold, iron pyrite, and uraninite. The gold was in its elemental metal form. Cyanobacteria grew in relative abundance in these mineral rich waters.[2] [4] [8] The kerogen that is found in association with the gold deposits almost certainly represents what remains of these Archeanphotosynthesizing micro-organisms.[4]



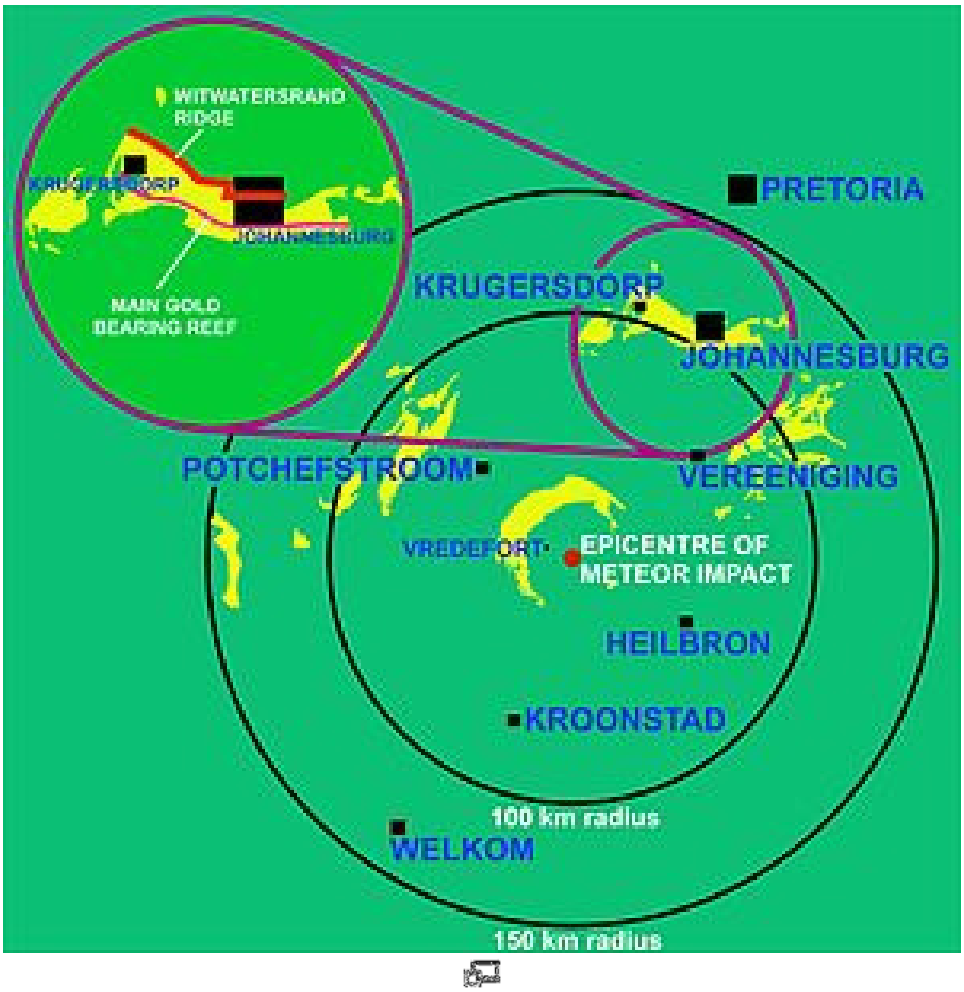
A timeline of the earth's geological history, with an emphasis on events in Southern Africa. **W** indicates when the Witwatersrand supergroup was laid down, **C** the Cape supergroup, and **K**the Karoo Supergroup. The graph also indicates the period during which banded ironstone formations were formed on earth, indicative of an oxygen-free atmosphere. The earth's crust was wholly or partially molten during the Hadean Eon; the oldest rocks on earth are therefore less than 4 billion years old. One of the first microcontinents to form was the Kaapvaal Craton.

It is clear that for the next 200 million years the flood plain was repeatedly inundated, sometimes eroded, and sediments re-deposited. The result was a 2500 m (8200 ft) thick layer of rock that is termed the “Central Rand Group”, which together with the “West Rand Group”, forms the “Witwatersrand Supergroup”. It is the younger Group of rocks that contains the gold bearing conglomerates that are today of great economic importance. The largely underground horizontal extent of the Witwatersrand Supergroup is known as the Witwatersrand Basin.

The ultimate source of the gold is unknown.[2] [4] But that it is restricted to the areas of the craton’s coastal plain where the rivers flowing into the Witwatersrand sea formed braided deltas,[1] indicates

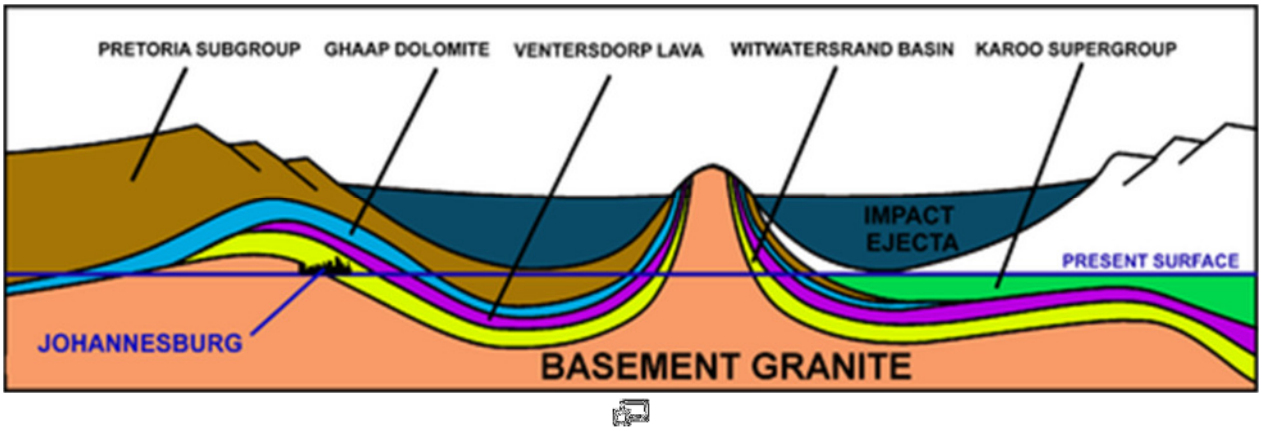
that the source was in the mountains to the north. The Welkom, Klerksdorp, Carletonville, West Rand, East Rand and Evander gold mines are all situated over these Archean fan deltas.

The “Central Rand Group” of deposits was brought to an abrupt end by massive outpourings of lava, which form the Ventersdorp lavas which erupted 2.714 billion years ago.[4] The cause of these lava outpourings is a matter of speculation. It might be related to the collision of the Kaapvaal craton with the Zimbabwe craton, eventually to become knitted together to form a single continental unit.



A schematic diagram of the area surrounding the Vredefort Dome, where a massive meteor created an impact crater 300 km (190 mi) in diameter 2.02 billion years ago. The red dot represents the epicenter of the impact. The outer circle has a radius of 150 km (93 mi), and indicates the approximate location of the crater rim. The inner circle marks the 100 km (62 mi) distance from the center. Note that the outcrops (exposure of the rocks on the surface) of Witwatersrand rocks (yellow areas) are located at 25 km (16 mi) from the epicenter of the impact and then again at about 80–120 km (50–75 mi) from the epicenter. The locations of important towns and cities in the region are indicate in the appropriate places. The red line in the detail of the Johannesburg region shows the location of the scarp/ridge that gave the "Witwatersrand" its name; the purple line the location where the main gold bearing reef is exposed at the surface, just south of Johannesburg .

A final event that had a major impact on the geology of the Witwatersrand Supergroup and its exposure in the Johannesburg region, was a massive meteor impact 110 km (68 mi) to the southwest of Johannesburg 2.02 billion years ago.[2] [4] The epicenter of the impact was close to the present village of Vredefort, which has given its name to the geological remnant of this immense event: the Vredefort Dome. Not only are the remains of this impact the second oldest on earth, but it is also the largest meteor impact that has left its imprint on the earth’s geology of today.[2] [4] A meteor 10–15 km (6–9 mi) across created a 300 km (190 mi) diameter crater, distorting all the rock strata within that circle. Johannesburg is just within the outer edge of this impact crater.



A schematic diagram of a NE (left) to SW (right) cross-section through the 2.02 billion-year-old Vredefort impact crater and how it distorted the contemporary geological structures. The present erosion level is shown. Johannesburg is located where the Witwatersrand Basin (yellow layer) is exposed at the "present surface" line, just inside the crater rim, on the left. Note the present exposure of the basement granite, known as the "Johannesburg Dome", belonging to the Kaapvaal craton, to the north of Johannesburg city center. Not to scale.

In the immediate vicinity of the impact all the subterranean strata were uplifted and upturned, so that Witwatersrand rocks are exposed in an arc 25 km (16 mi) away from the impact center. There are unfortunately no gold deposits in these outcrops. The meteor impact, however, lowered the Witwatersrand rocks within the crater. This protected them from erosion later on; but, possibly more importantly, bringing them to the surface close to the crater rim, near Johannesburg.[4] In fact, apart from the Witwatersrand outcrops (i.e. where the Witwatersrand rocks are exposed at the surface) in the immediate vicinity of the Vredefort Dome, virtually all the other outcrops occur in an arc approximately 80–120 km (50–70 mi) from the center of the impact crater, to the west, northwest, north and northeast.[5] Thus, it is possible that if it had not been for the Vredefort meteor strike 2 billion years ago, we would either have never discovered the rich gold deposits beneath the Southern African surface, or they would have been eroded away during the extensive removal of the surface of the Southern African Plateauduring the past 150 million, and more especially during the past 20 million years.[4]

Consequences of mining the ancient Witwatersrand rocks

Apart from the obvious hollowing out of the rocks below southern Johannesburg, causing unpredictable sinkholes, surface instabilities and earth tremors,[9] the bringing to the surface of rocks that had been laid down in oxygen-free conditions had unforeseen effects. Iron pyrite (FeS), which is relatively plentiful in the gold ores of the Witwatersrand, oxidisesto insoluble ferric oxide (FeO) and sulfuric acid (HSO). Thus, when mine waste comes into contact with oxygenated rainwater, sulfuric acid is released into the ground water. Acid mine drainage, as the phenomenon is called, has become a major ecological problem, because it dissolves many of the heavy elements, such as the uranium, cadmium, lead, zinc, copper, arsenic and mercury found in the mine dumps, facilitating their passage into surface water and ground water.[4] [9] [10] Sulfuric acid also erodes concrete and cement structures, resulting in structural damage to buildings and bridges.[9] [10]

History

The street entrance of George Harrison Park

Although gold had been discovered in various locations in South Africa, such as Barberton and Pilgrim's Rest, as well as at several sites near the Witwatersrand, these were alluvial concentrates in contemporary rivers, or in quartz veins, in the form that gold had always been found elsewhere on earth. When George Harrison, probably accompanied by George Walker, found gold on the farm Langlaagte, 5 km (3 mi) west of what would become the city of Johannesburg, in an outcrop of conglomerate rocks, in February 1886, they assumed that this was alluvial gold in an old riverbed, that had been tilted as a result of earth movements.[1] [2] However, when it was found that, traced downdip, the conglomerate was not merely developed for the narrow width of a river, but continued in depth, there came the realisation that this conglomeratic zone was part of a sedimentary succession.[1] Harrison had stumbled on the Main Reef conglomerate (part of the "Johannesburg Subgroup" of rocks — see illustration above). The conglomerate was quickly traced east and westward for a total continuous distance of 50 km (31 mi) to define what became known as the "Central Rand Gold Field".

Harrison declared his claim with the then-government of the Zuid Afrikaanse Republiek (ZAR), and in September 1886 President Paul Kruger issued a proclamation declaring nine farms public mining diggings, starting on 20 September 1886.[2] This heralded the historic Witwatersrand Gold Rush. Harrison is believed to have sold his claim for less than £10 before leaving the area, and he was never heard from again.

Harrison's original Zoekers' (in English: seekers', or prospectors') Claim No 19 was declared a national monument in 1944, and named Harrison's Park.[11] The park is on the busy Main Reef Road, immediately west of Nasrec Road.[2] In 1887 Cecil John Rhodes registered "The Gold Fields of South Africa" in London, South Africa's first mining house, with a capital of £250000. His brother Thomas was the first chairman.[2]

Gold production on the Witwatersrand 1898 to 1910[12] :134

Year	No. of mines	Gold output (fine ounces)	Value (million GB£)	Relative 2010 value (million GB£)[13]
1898	77	4295608	£15.14	£6910
1899 (Jan–Oct)	85	3946545	£14.05	£6300
1899 Nov – 1901 Apr	12	574043	£2.02	£908
1901 (May–Dec)	12	238994	£1.01	£441
1902	45	1690100	£7.18	£3090
1903	56	2859482	£12.15	£5220
1904	62	3658241	£15.54	£6640
1905	68	4706433	£19.99	£8490
1906	66	5559534	£23.62	£9890
1907	68	6220227	£26.42	£10800
1908	74	6782538	£28.81	£11700
1909	72	7039136	£29.90	£12200
1910	63	7228311	£30.70	£12400

See also

- Geography of South Africa
- Great Escarpment, Southern Africa
- Vredefort crater
- Witwatersrand basin
- List of mountain ranges of South Africa
- Pilanesberg

- Borakalalo Game Reserve

Further reading

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External links

- Relationships between the Vredefort structure and the Witwatersrand basin within the tectonic framework of the Kaapvaal craton as interpreted from regional gravity and aeromagnetic data
- Johannesburg Geology