The Bushveld Igneous Complex

THE GEOLOGY OF SOUTH AFRICA'S PLATINUM RESOURCES

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A vast composite body of plutonic and volcanic rocks in the central part of the Transvaal, the Bushveld igneous complex includes the platinum reef worked by Rustenburg Platinum Mines Limited and constituting the world's greatest reserve of the platinum metals. This article describes the geological and economic aspects of this unusually interesting formation.

In South Africa platinum occurs chiefly in the Merensky Reef, which itself forms part of the Bushveld igneous complex, an irregular oval area of some 15,000 square miles occupying a roughly central position in the province of the Transvaal. A geological map of the area, which provides the largest known example of this interesting type of formation, is shown on the facing page.

The complex rests upon a floor of sedimentary rocks of the Transvaal System. This floor is structurally in the form of an immense oval basin, three hundred miles long and a hundred miles broad. The sediments forming the floor have been extensively altered by thermal metamorphism, indicative of the high temperature of the molten igneous rocks which solidified to form the complex. These rocks consist of a vast body of basic, magnesium-rich rocks, the silica content of which gradually, although not regularly, increases upwards. Overlying this basic zone, whose predominant rock type is either norite or gabbro, lie sheets of the red Bushveld granite.

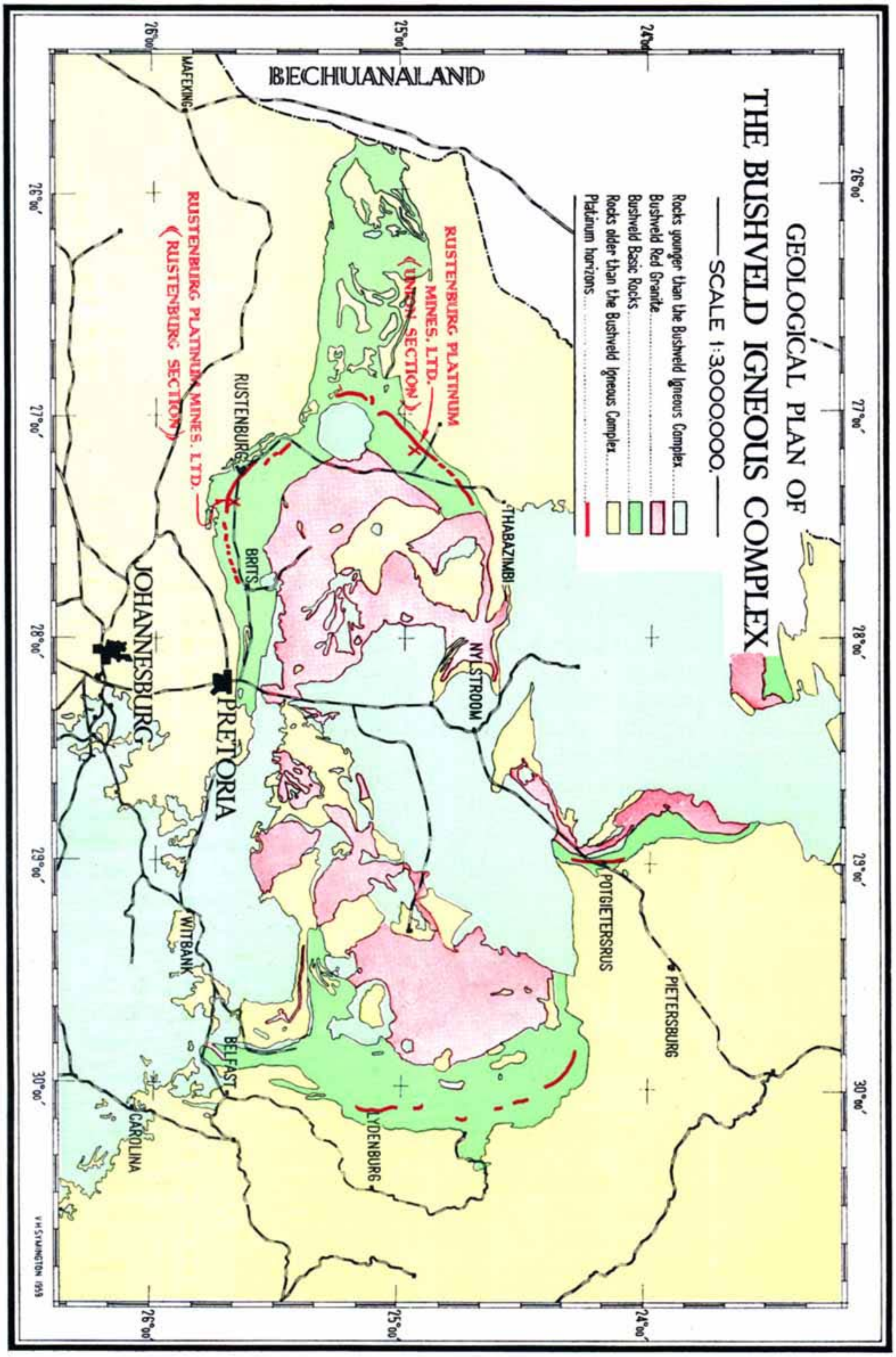
Both geological and economic interest centres around the mass of basic rocks. They have been the subject of intensive study by geologists from all over the world and present a number of fascinating problems, many of which are still unsolved.

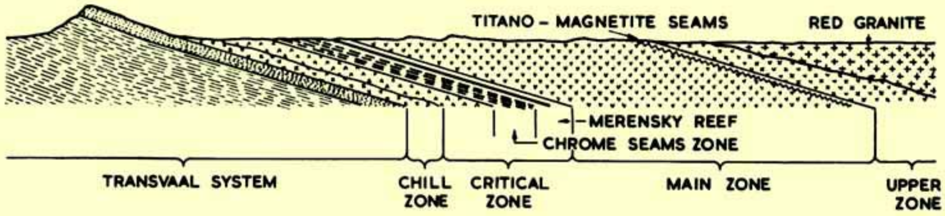
The basic rocks are exposed, as outcrops, in three areas covering over five thousand square miles. Two of these areas lie at the eastern and western ends of the Bushveld and form wide curved belts, trending parallel to the sedimentary rocks which they overlie, and dipping inwards towards the centre of the Bushveld at similar angles. The western belt has a flat sheet-like extension reaching the western boundary of the Transvaal. The third area extends northwards and cuts outside the sedimentary basin. Its exact relationship to the other outcrops within the basin has not as yet been solved.

As the eastern and western belts contain the more important economic zones, attention will be confined to these in this article. The two curved inward dipping belts have been estimated to reach fifteen to eighteen thousand feet in thickness. Geologists divide them into four main zones, namely the Chill Zone, the Critical Zone, the Main Zone and the Upper Zone. An ideal geological section is shown in the diagram on page 96.

The Chill Zone was formed by the earliest part of the igneous magma which came into contact with the sediments of the floor and was cooled rapidly. Its thickness is estimated to lie between five hundred and a thousand feet.

This Chill Zone grades into the Critical Zone, estimated to be from four to five thousand feet thick, in which the most valuable minerals are found. Within this zone


GEOLOGICAL PLAN OF
THE BUSHVELD IGNEOUS COMPLEX
SCALE 1:3,000,000.
Rocks younger than the Bushveld Igneous Complex
Bushveld Red Granite
Bushveld Basic Rocks
Rocks older than the Bushveld Igneous Complex
Platinum horizons
BECHUANALAND
MAFEKING
RUSTENBURG PLATINUM MINES, LTD. (UNION SECTION)
RUSTENBURG PLATINUM MINES, LTD. (RUSTENBURG SECTION)
RUSTENBURG
THABAZIMBI
BRITS
NYLSTROOM
PRETORIA
JOHANNESBURG
POTGIETERSRUS
PIETERSBURG
WITBANK
BELFAST
LYDENBURG
CAROLINA



An ideal geological section across the Bushveld Igneous Complex. The platinum-bearing Merensky Reef lies near the top of the Critical Zone

is a remarkable sequence of layered rocks which, although obviously igneous in origin, show all the characteristics of an unusually regular sedimentary series.

The rocks consist of alternations of pyroxenites (mainly magnesium-iron silicates), anorthosites (rocks consisting of almost pure felspar-sodium calcium aluminates) and norites (intermediate in composition between the pyroxenites and anorthosites). Layered within these rocks are regular seams of chrome ore, ranging in thickness from an inch to more than eight feet, while near the top of the zone occurs the platinum-carrying Merensky reef, named after Dr. Hans Merensky, the brilliant geologist responsible for its discovery.

A remarkable feature of the Critical Zone is that individual bands can be traced around the entire outcrop of the complex. The chrome seams and the Merensky reef retain their individuality with only minor variations wherever they have been prospected, and boreholes show them to continue unaltered in character down to depths of three thousand feet.

Above the Critical Zone, eight to ten thousand feet of norite (or gabbro) is met. This is known as the Main Zone. Here the remarkable layering of the Critical Zone becomes inconspicuous or absent. At the top of the zone, layering again reappears with bands of titano-magnetite, one to six feet thick, lying on white anorthosite. These bands appear to be just as persistent as those of the Critical Zone.

The Upper Zone, less than a thousand feet thick, forms the uppermost portion of the zone of basic rocks. In this zone the rocks become richer in quartz and poorer in pyroxene. Above this we find the Red Granite outcropping over five thousand square miles in the interior of the complex. This rock is responsible for tin mineralisation.

The area between the two zones of basic rock outcrops, both in the interior of the complex, and across its rim, is covered by sheets of the Bushveld granite and younger sedimentary rocks. In addition, outcrops of the Transvaal System rocks, which form the floor of the complex, are also found in the interior and their position has given rise to various interesting speculations.

The Merensky Reef

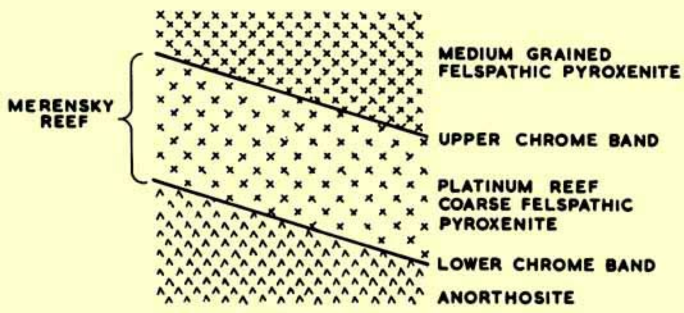
The platinum-carrying Merensky reef has been prospected over distances of 75 to 80 miles along both the eastern and western outcrop belts. Platinum values are persistent but in some areas values are consistently higher than in others.

It is this reef which is mined by Rustenburg Platinum Mines Limited at the two sections of its property, the Rustenburg section a few miles to the east of that town and the Union section some sixty miles to the north. The discovery of platinum in the Merensky reef in 1925 led to a considerable outburst of activity in platinum mining at a number of places where the reef outcropped, but this boom was short-lived and only two mining companies survived. These were merged in 1931 to form Rustenburg Platinum Mines Limited. In 1947 the Union Platinum Mining Company Limited was formed to work the

Charging a hole for blasting on the Merensky reef in the Rustenburg Platinum Mines. The white anorthosite footwall can be seen just level with the miner's knee. Above this lies a thin line of dark grey chromite with an undulating bottom contact. Then follows the coarse-grained pyroxenite of the Merensky reef almost to the roof of the stope, which consists of the less coarse-grained hanging wall pyroxenite

Merensky reef further north, but in 1949 this company was amalgamated with the Rustenburg company and now constitutes the Union section of Rustenburg Platinum Mines Limited. Over the intervening period the output from this source has grown very substantially, and Rustenburg now constitutes the world's largest producer of the platinum metals, and in fact the only major producer whose prime activity is the extraction of the platinum metals.

The platinum is not found in the pure state, but is a composite of platinum and the other five platinum group metals, their relative proportions showing variations from one area to another. Platinum is the predominant metal, followed by palladium, with smaller amounts of ruthenium, rhodium, osmium and iridium, together with traces of gold. A proportion of the platinum is present as "native" metal, invariably alloyed with iron (ferro-platinum), while the remainder



An ideal section across the Merensky Reef

A trainload of platinum ore being hauled from the workings at Rustenburg Platinum Mines

occurs as the arsenide and sulph-arsenide, sperrylite and cooperite. The ore invariably contains a few per cent of the sulphides of iron, nickel and copper. The nickel and copper are extracted as a by-product from the platinum concentrates, adding appreciably to the value of the ore.

The Merensky reef in its typical section, shown on page 97, is a coarsely crystalline aggregate of pyroxene and felspar, with sulphide mineralisation. It underlies a finer grained bank of a similar rock and rests with an extremely sharp contact on a band of white anorthosite. Thin seams of chrome ore, usually less than an inch thick, are found on both the top and bottom contacts. In some areas, however, one of these chrome seams may be absent. The ore within or adjacent to these chrome bands is generally the richest in platinum. A feature of the reef, which makes for easy mining, is its regularity in dip and strike, the evenness of its values and its constancy in thickness.

Dykes and faults are rare in the two mines controlled by Rustenburg Platinum Mines Limited. The only underground complication is the occasional occurrence of what are known as "potholes". These are roughly elliptical areas in which the reef suddenly becomes displaced into the footwall and is often somewhat disturbed and broken. The reef can however be mined out in a considerable proportion of potholes. Their origin is still a mystery.

The reef has been proved by drilling down dip on the Rustenburg and Union mines and their potential ore reserves are very considerable.

Economic Resources of the Complex

In addition to the platinum content of the Merensky reef, which represents the world's greatest reserve of this metal and its sister elements, nickel and copper are being extracted as valuable by-products.

The chrome seams of the Bushveld, while of lower grade than the Rhodesian or Turkish ores, form the major proportion of the total known chrome reserves of the world. Their continuity in thick seams over scores of miles of strike and their persistence in depth as proved by deep drilling, make for easy and cheap mining.

The titano-magnetite seams of the Main Zone show the same persistency and continuity, but have not been exploited to date. Titanium is now assuming importance in metallurgy and there is little doubt that treatment of these ores will be attempted in the future. Contained in the titano-magnetite ore is a persistent fractional percentage of vanadium. The total reserves of titanium and vanadium in these iron ores must be very large.

It is obvious, therefore, that the ores of the Bushveld igneous complex occupy a prominent place in the world's mineral resources.

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Synthesis of Fluoroaromatic Polymers

INTERMEDIATES FOR HIGH-TEMPERATURE PLASTICS

A research programme on the synthesis of fluorocarbon polymers for possible use in high-speed aircraft, ordnance equipment and other types of high-temperature application has recently been carried out at the National Bureau of Standards. Most plastic materials at present available are not capable of withstanding high-temperature conditions but it is thought that polymers derived from completely fluorinated aromatic compounds should have considerably improved resistance to temperature and also to radiation.

Hexafluorobenzene provides a convenient starting point for the synthesis of such polymers and the discovery of a method for its synthesis in reasonable yields and quantities (M. Hellman, E. Peters, W. J. Pummer and L. A. Wall, *J. Amer. Chem. Soc.*, 1957, **79**, 5654–5656) has greatly accelerated their development. Hexafluorobenzene is obtained by pyrolysis of tribromofluoromethane in a platinum tube 80 cm long, 1 cm wide and about 1 mm thick packed with platinum gauze. The best yields, 55 per cent, were obtained at 540–550°C under a nitrogen pressure of 4.5 atm.

Pentafluorophenol, one of the most useful compounds obtained from hexafluorobenzene, is prepared by the addition of solid potassium hydroxide to its pyridine solution. The hydrogenation of hexafluorobenzene using a platinum-on-carbon catalyst at 300°C gives a high yield, 40 per cent, of the monohydro derivative, pentafluorobenzene, together with 10 per cent tetrafluorobenzenes (R. E. Florin, W. J. Pummer and L. A. Wall, *J. Res. Nat. Bureau Standards*, 1959, **62**, (March), 119–121). The catalyst maintains its activity for long periods. The main products of the reduction can be brominated to pentafluorobromobenzene and dibromotetrafluorobenzene or iodinated to the analogous iodides. The presence of the reactive bromine or iodine atoms makes such compounds invaluable intermediates for the preparation of further fluorocarbons and their polymers.

So far successful attempts to prepare polymers have been made using sodium pentafluorophenolate, diiodotetrafluorobenzene and pentafluorobromobenzene as starting materials. It is expected that such polymers will possess the combination of properties necessary to give both high thermal stability and plasticity.