Ground-Water Provinces of Southern Rhodesia

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1757-D

Prepared in cooperation with the Southern Rhodesia Division of Irrigation and Lands under the auspices of the U.S. Agency for International Development

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By P. ELDON DENNIS *and* L. L. HINDSON

CONTRIBUTIONS TO THE HYDROLOGY OF AFRICA AND THE MEDITERRANEAN REGION

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GROUND-WATER PROVINCES OF SOUTHERN RHODESIA

By P. ELDON DENNIS and L. L. HINDSON

ABSTRACT

Ground-water development, utilization, and occurrence in nine ground-water provinces of Southern Rhodesia are summarized in this report.

Water obtained from drilled wells for domestic and stock use has played an important part in the social and economic development of Southern Rhodesia from the beginnings of European settlement to the present. Most of the wells obtain water from fractures and weathered zones in crystalline rocks. More recently, there has been an interest in the possibility of obtaining water for irrigation from wells. Studies of the authors indicate that quantities of water sufficient for irrigation can be obtained from alluvial sediments in the Sabi Valley, from Kalahari sands in the western part of the country, and perhaps from aquifers in other areas.

The ground-water provinces fall into two groups—those in the crystalline rocks and those in the noncrystalline rocks. Historically, the wells in crystalline rocks, especially the Gold belts province and the Intrusive granites province, have played a major role in supplying water for the needs of man. These provinces, together with two other less important crystalline rock provinces, form the broad arch which constitutes the central core of the country. The noncrystalline rocks overlie and flank the crystalline rocks to the southeast, northwest, and north. The noncrystalline rock provinces, especially the Alluvium-Kalahari province, contain the most productive or potentially productive ground-water reservoirs in Southern Rhodesia and offer promise of supplying water for irrigation and for other purposes.

INTRODUCTION

The field investigation of the ground-water resources of Southern Rhodesia, on which the present report is based, was made between May and October 1959 as a part of the technical assistance program of the U.S. Agency for International Development (formerly the International Cooperation Administration) in behalf of the Government of Southern Rhodesia. The senior author, of the U.S. Geological Survey, was assigned to the project with his Rhodesian counterpart, L. L. Hindson, of the Division of Irrigation and Lands, Government of Southern Rhodesia. The investigation was planned to evaluate the possibilities of developing appreciable additional water supplies from stream deposits of the Sabi Valley and to make a reconnaissance evaluation of the ground-water resources of the entire country.

The investigation was undertaken by the authors with the assistance of many persons engaged in geologic and hydrologic work, not all of whom can be acknowledged here. Maps, reports, data, and discussions were freely given by several members of the Division of Irrigation and Lands; Mr. J. C. Ferguson, Director of the Geological Department, and members of his staff; Dr. Geoffrey Bond of the National Museum at Bulawayo; and Mr. D. MacDonald, Water-Supply Engineer for Rhodesia Railways.

GEOGRAPHY

Southern Rhodesia, which has an area of about 150,000 square miles, lies between lat 15°30′ and 22°30′ S. and long 25° and 33° E. in southern Africa (fig. 1). It is mainly an interior plateau, the greater part of which lies between altitudes of 1,000 and 8,000 feet. A broad arch, having an altitude of 4,000 to 5,000 feet above sea level, extends across the central part of the country from southwest to northeast, becoming wider to the northeast. This higher part of the plateau is known as the high veld. A range of mountains whose peaks reach altitudes of more than 8,000 feet forms part of the eastern boundary with Mozambique. The arch forms the drainage divide between streams flowing northwestward and northward to the Zambezi River and those flowing southward and southeastward to the Sabi-Lundi and Limpopo Rivers. The low-lying plains bordering these river systems are known as the low veld.

Although Southern Rhodesia lies in the tropics, much of the country has a relatively temperate climate owing to the high altitude. Some regions receive as much as 48 inches of rainfall a year, but other regions receive as little as 12 inches. Rainfall is seasonal occurring largely between November and April. The winter months from May through October are dry. Many of the larger towns and cities now (1964) obtain municipal water supplies from surface reservoirs, but most of the rural inhabitants and many smaller communities depend upon wells.

Southern Rhodesia is a youthful and vigorously growing country. In the past, it has been chiefly known for its mineral exports of gold, chrome, and asbestos. In recent years, however, its exports of tobacco have exceeded any other single product, and the growing importance of agriculture to the economy is indicated by a yield of 3,000 pounds per acre of long staple cotton under irrigation in the Sabi Valley. Citrus fruits, avocados, and pineapple grow exceptionally well; in fact, there are few crops that cannot be grown successfully in the country. The climate is such that two and three crops can be grown in many areas each year. Scarcity of water, however, is the chief factor in

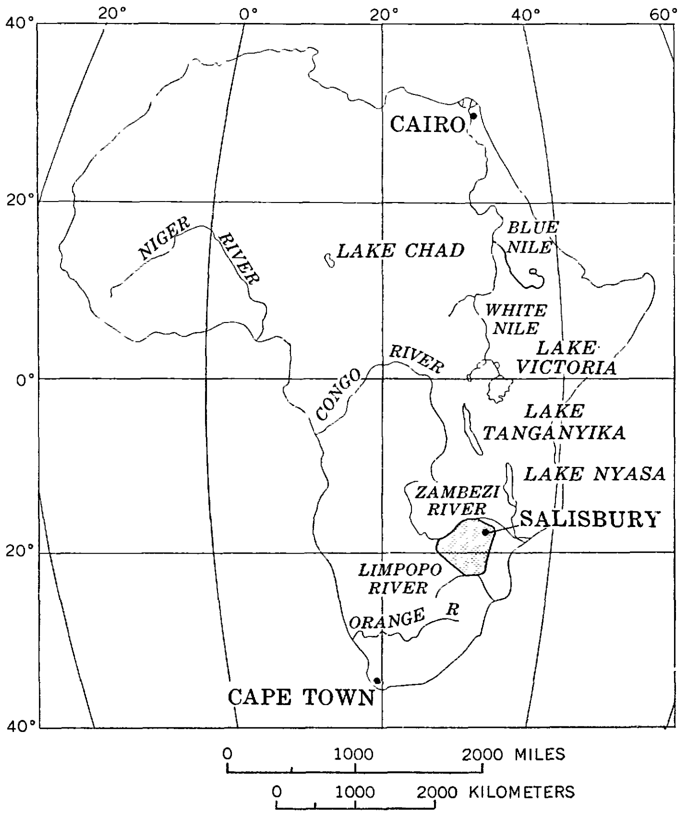

FIGURE 1.—Index map of Africa showing location of southern Rhodesia.

limiting the agricultural potential of the country, for in the low veld most crops can be grown only under irrigation, and in the high veld some supplemental irrigation is highly beneficial. The industrial potential is also large, but again the limiting factor is the availability of an adequate water supply.

GROUND-WATER DEVELOPMENT AND UTILIZATION

The development of domestic- and stock-water supplies from boreholes (drilled wells) and to a lesser extent from dug wells has been an important factor in the economic growth of Southern Rhodesia from the beginnings of European settlement to the present. The long dry winter season and the lack of a perennial flow of water in all but a very few rivers and streams make ground water the only dependable source of supply in most of the country. Fortunately, there are relatively few extensive areas where boreholes cannot be constructed to obtain from a hundred to a few thousand gallons of water per hour.

In Southern Rhodesia most boreholes are constructed by the Boring Section of the Division of Irrigation and Lands. The drilling machine commonly used is the cable-tool (percussion) type rig, generally supplemented by core drilling with steel shot and water where the rock is very hard. The coring equipment is mounted as an auxilary device on the standard cable-tool rig. This combination type of drilling has generally proved effective in most of the crystalline rocks. An average of 5 to 20 feet per day is drilled with the "jumper" and 3 to 8 feet per day with the "shot." In the completed hole, a 5- or 6-inch screw-joint steel casing is commonly set in soft or caving surficial material, and the lower part is left "open hole." Where unconsolidated material occurs in the water-bearing zone, the lower joints of casing are slotted so that water can enter through the slots and (or) through the open end of the casing. In the native reserves, piston-type hand pumps (bush pumps) are installed, except where the water level is very deep. On European farms, jet pumps and other types of power-driven pumps are used.

Borehole site selection in Southern Rhodesia and throughout much of South Africa has chiefly been based on electrical resistivity probes. A brief description of the method is given by MacDonald (1958). The method has been useful in locating fractures and weathered zones in the crystalline rocks, but generally it cannot be used to locate aquifers in thick sedimentary sequences.

Dug wells were used by the native Africans as a source of water supply before the advent of the European settlers. Wells as much as 100 feet deep or more were dug in soft materials such as the alluvium of the Sabi Valley, but the most common type of well was a simple pit put down in the sandy beds of ephemeral streams to tap underflow. Such wells were excavated each year after surface runoff had ceased, and as the dry season advanced, the pits had to be deepened. This type of dug well is still widely used by the Africans in all dry riverbeds where the thickness of sand is sufficient to sustain an underflow. The European settlers also have made some use of this simple means of extracting water. For example, near the Beitbridge a farmer has excavated a large pit in the sand of the Limpopo River channel and pumps water for irrigation. Some years ago, a similar pumping scheme was in operation in the sand of the Sabi River channel, a few miles south of the Sabi Experiment Station.

Another method of extracting water from the shallow sand is by means of the "sand point" or "well point," which consists of an intake screen with a drive point generally 1¼ to 4 inches in diameter and 2 to 6 feet long. This point is driven into the sand below the water table and is attached by piping to some kind of a suction pump.

A battery of several points can be connected to a manifold and pumped with a single pump. Only little use has been made of this simple type of well, but it is proving very successful in the sandy beds of the Umzingwane, Semokwe, and Shashani Rivers.

The thermal and mineral springs of Southern Rhodesia have been described by Maufe (1933) who gives pertinent geologic and hydrologic data on 32 springs. Maufe points out that there are two distinct groups of springs, the larger group extending in a northeast-southwest direction along the Zambezi Valley and the smaller group extending in a north-south direction along the eastern highlands parallel to the Sabi and Odzi Rivers. The springs of both groups probably rise along post-Karroo basalt faults.

More recently, Bond (1953) has studied the temperature relations of thermal waters issuing as springs or found in boreholes in the Middle Zambezi Valley. He found that plotting temperature of the artesian water in relation to the depth from which the flow issued in the boreholes gave a straight-line relationship, indicating a geothermic step of 31.3 feet per degree Fahrenheit for the shale and coal beds of the Lower Karroo. For sandstone, the step is larger, about 60 feet per degree Fahrenheit. Using these step figures and the known thickness of the Karroo and Sijarira Formations, respectively, he calculated that the expected temperature of springs issuing from the base of the Sijarira Formation would be about 202°F, which is near the temperature of the hottest springs so far recorded in the area.

Although the importance of nonthermal springs in supporting the dry-weather flow of the streams of Southern Rhodesia is recognized, no systematic study has been made of their geologic and hydrologic characteristics. Furthermore, very few attempts have been made to develop springs as sources of water supply. Many small springs have no central discharge point but issue from seeps dispersed over a large area. Such seepage gives rise to marshes or bogs, which are of little use to native game and of even less use as sources of water for stock and domestic purposes. Springs might be more profitably developed in areas where it is difficult to obtain satisfactory water supplies from boreholes.

The utilization of both surface water and ground water by the European settlers was for domestic, municipal and stock purposes, but only recently has water from the perennial streams been used for irrigation. The first settlements were on the broad central arch, where the "gold belts" rest upon the granite (pl. 1). The arch (or high veld) is relatively cooler and receives more rainfall than the lower plains (low veld) along the Zambezi River to the north and along the Sabi and Limpopo Rivers to the south. For these reasons, European settlement and systematic utilization of available water resources were largely confined to the high veld until recent years. Mining was the principal occupation of the early settlers. Agriculture developed slowly: at first, only dryland crops were grown on the high veld; later, these crops were supplemented by irrigation on the high veld; and finally, irrigation farming was initiated on the low veld. Much of the low flow of the Sabi River in the winter season is now used to irrigate a variety of crops including citrus fruits, bananas, cotton, beans, and wheat. The yield of many crops under irrigation in the low veld has been phenomenal, and efforts are being made to make more water available for irrigation in these areas by impounding the wet-season runoff in surface reservoirs and by developing ground water. The largest ground-water reservoirs occur in the Alluvium-Kalahari province, which is chiefly in the low veld.

GROUND-WATER PROVINCES

Ground water in Southern Rhodesia occurs in two types of rocks, crystalline and noncrystalline, and thus the ground-water provinces naturally fall into two major groups. The crystalline rocks, of intrusive igneous and metamorphic origin, are much more widespread than the noncrystalline sedimentary rocks containing associated interbedded lavas. The water-bearing capability of the rocks is chiefly determined by the nature of the interstices—the voids, or pores, in the rocks in which the ground water occurs. The voids in the noncrystalline sedimentary rocks are chiefly primary, that is, they are the original pore spaces between the grains and particles of rock as it was deposited. These voids are likely to be interconnected over considerable distances, the aquifers (water-yielding beds) are commonly sheetlike and extensive, and a general water table or other piezometric surface is likely to exist over a considerable area. On the other hand, the openings in the crystalline rocks are chiefly secondary; that is, they are fractures and weathered zones generally along such fractures. The pore spaces are likely to be interconnected over relatively short distances and rarely in more than one direction, the aquifers are commonly irregular in form and not extensive, and a general water table is not likely to occur; thus great variation can occur in the water levels of even closely spaced boreholes.

NONCRYSTALLINE ROCK GROUP

The ground-water provinces in the noncrystalline sedimentary group comprise the youngest rocks in the country. They include stream alluvium, Kalahari beds, Cretaceous rocks, and rocks of the Karroo system. The Jurassic lavas are grouped with the sedimentary rocks because they are interbedded with them and occur in the same geographic region. On the map (pl. 1) the sedimentary formations and associated volcanics are seen to be largely confined to the west, north, and south margins of Southern Rhodesia.

ALLUVIUM-KALAHARI PROVINCE

Broad stretches of stream alluvium are not present in Southern Rhodesia; the largest alluvial deposits in the country occur in the Sabi Valley, at the confluence of the Sabi and Lundi Rivers, on the Nuanetsi River near its confluence with the Limpopo, and at several places along the Zambezi River. Stream alluvium has also been found to overlie Triassic rocks in part of the Mzarabani area and similar relatively thin mantles of older stream alluvium may occur elsewhere. Locally, as at Marandellas, the weathered material covering the crystalline rocks on the old erosion surface contains rounded stream pebbles at its base. Generally, however, the locations of such old stream deposits have yet to be determined. The most recent stream alluvium consists of sand in the river channels, a part of which is shifted by stream action in flood stage.

The character of the older stream alluvium is but little known and has been studied only in the Sabi Valley, where the alluvial deposits consist of interbedded clay and sand which are intercalated with gravel and scree near escarpments. The clay is commonly very silty and sandy and may contain coarse sand and small pebbles. Concretions of calcium carbonate are abundant in places. The sand seems to have been largely arkosic and the decay of the feldspar grains makes it clayey. The sand grains are not well rounded, and some are so poorly rounded as to be more properly called grit.

The sandy beds in the older alluvium are commonly water-bearing but have low transmissibilities, 2,500 to 12,000 gpd per ft (gallons per day per foot). Although not as permeable as many stream deposits in other parts of the world, these older alluvial deposits are important ground-water reservoirs, and most drilled wells in the Sabi Valley yield quantities of water sufficient for irrigation.

The sand in the river channels is also arkosic, one-quarter to one-half of the grains consisting of feldspar. The grains, however, are unweathered and the transmissibilities are comparatively high (about 150,000 gpd per ft). The depth of sand in the river channels ranges from 0 to about 50 feet. Much larger water yields can generally be obtained from wells and boreholes in the deeper sections of these channels.

The Kalahari beds cover a large part of the country northwest of Bulawayo. They overlie the Jurassic basalt in the west, but to the east they first overlap the Triassic sandstone, and then the granite and other crystalline rocks. Patches of the Kalahari beds extend eastward beyond the Great Dyke around the margins of the Manesi Range and east of Umvuma. Beyond Southern Rhodesia, the beds extend westward and southward across Bechuanaland and far into South West Africa and Angola, and northwards over large areas in Zambia, Angola, the two Congo Republics, and Gabon. The Kalahari beds cover about one-fourth of Africa south of the equator and were probably removed by erosion from much larger areas.

The origin of the beds is described by MacGregor and Tyndale-Biscoe (1959) as follows:

> The Kalahari Sand was undoubtedly deposited by wind, but the unbedded and unsorted nature may indicate that the conditions were not strictly arid, and that the grains were held where they fell in grass or other vegetation. The source of the great volume of blown sand, which may amount to 20,000 cubic miles south of the equator, in spite of considerable erosion in recent times, can only be the sea floor exposed by a recession of the waters caused by the uplift of the continent and later by the accumulation of ice at the polar regions during the Great Pleistocene Ice Age. It seems probable to the writer that the Rhodesia Kalahari Sand was brought in by trade winds from the east, and was deposited over hill and dale as large wind-way dunes or "siefs."

At the surface, the sands are commonly fine and well sorted. Unlike the arkosic river sands, they largely consist of well-rounded quartz grains and are white or light reddish brown in color. Locally, as at the Main Camp of the Wankie Game Reserve, a limestone occurs in the sands at or near the surface. It is a secondary limestone deposited by ground water and is descriptively called vlei limestone or calcrete. In the Gwaai area, the lower part of the Kalahari beds are commonly indurated and rest upon basalt. Much of this indurated sand, called pipe sandstone, appears to have contained a calcareous cement some of which was replaced by silica and the rest leached out along vertical joints and (or) root openings and insect burrows. Locally, silification has given rise to a dense, relatively impermeable rock called silcrete, which occurs most commonly at the very base of the Kalahari beds.

Boreholes in the pipe sandstone drilled by Rhodesia Railways at Intundhla and elsewhere, yield as much as 315 gpm (gallons per minute). Great difficulty has been experienced by drillers in completing boreholes in the unconsolidated fine sand, which they describe as "quicksand" or "running sand." Nearly all the boreholes that have been successful in obtaining water from the Kalahari beds go through the fine water-bearing sand, which is cased off, and draw water from the sandstone below. Where the sandstone is too tightly cemented to yield water, no water has been obtained from the Kalahari beds.

The Kalahari beds likely contain the largest ground-water reservoirs in Southern Rhodesia. Their porous nature permits water from rainfall to seep into them, and streams of considerable size flowing across them are said to completely disappear by infiltration.

CRETACEOUS PROVINCE

Rocks probably of Cretaceous age occur in the Zambezi valley north of Mount Darwin. The apparent thickness is about 2,300 feet and the beds are conglomeratic throughout. In a stretch some 20 to 30 miles wide along the Mozambique border between the Sabi and Limpopo Rivers are coarse grits and conglomerates which are probably the estuarine continuation of marine Cretaceous beds farther south.

The only information available on the water-bearing characteristics of the Cretaceous rocks comes from a number of boreholes drilled by Rhodesia Railways along its line to Lourenço Marques. Yields of 7 to 24 gpm were obtained from individual wells. Chemical quality ranged from 735 to 2,400 ppm (parts per million) of total dissolved solids.

JURASSIC LAVA PROVINCE

The rocks of the Jurassic lava province are generally poor water producers. The lavas—chiefly olivine basalt, pyroxene andesite, and nepheline basalt—cover wide areas in the southern and in the northwestern parts of the country. The lava overlies the Upper Karroo sandstone in the Sabi Valley area and underlies the Cretaceous rocks between the Lundi and Limpopo Rivers. The Kalahari beds overlie the Jurassic lavas in much of the northwestern part of the country.

In the southern part, artesian water was found in sandstone beneath 376 feet of basalt in borehole 14 near Chidumo. The flow was reported at 33 gpm containing 1,184 ppm dissolved solids. A few wells have obtained small yields of water from fractures in the lavas at shallow depth but generally only after many attempts which ended in dry holes.

In the Gwaai area near Tjolotjo, ground water is present in fractures in the basalt, but water is more commonly found in the Forest Sandstone, which is interbedded with the basalt. A borehole about 16 miles northwest of Tjolotjo penetrated 597 feet of basalt and found no water.

KARROO PROVINCE

The provinces which comprise rocks of the Karroo System in Southern Rhodesia are divided into the Lower Karroo subprovince with rocks of early Permian age and Upper Karroo subprovince with rocks of Late Triassic age, respectively. The division is based on the difference in age and the common separation of the rocks of the two subprovinces by an unconformity. The rocks of the two subprovinces have distinctly different hydrologic characteristics. In both subprovinces the rocks were deposited in the basinlike depressions on either side of the broad central arch in the region now occupied by the drainages of the Zambezi and Limpopo Rivers. Because the basins were almost filled with sediments by Late Triassic time, the Triassic rocks transgressed far beyond the limits of the Permian rocks. In the northwestern part of the country, the Permian rocks crop out in the Wankie and Sebungwe regions, and in the southeastern part, in comparatively narrow belts in the Beitbridge and Nuanetsi regions. The Triassic rocks are exposed in the same regions but cover much larger areas along the Zambezi drainage system. According to Watson (1959), about 80 percent of the Karroo succession in the Wankie coal field is generally argillaceous and impermeable.

UPPER KARROO SUBPROVINCE

The Forest Sandstone and Escarpment Grit are the important aquifers in the Upper Karroo subprovince. As can be seen in plate 1, the subprovince covers a much larger area than any other of the noncrystalline rock provinces except the Alluvium-Kalahari province. The rocks consist of a basal conglomerate, fine-grained red marly sandstone, pebbly arkose, and generally fine-grained aeolian sandstone. Except for the aeolian sandstone, the rocks commonly are poorly sorted and the grains are angular. The rocks cap many flat-topped buttes and plateaus in the Sebungwe region, and seeps and small springs occur along the escarpments where more permeable beds are underlain by less permeable ones. In the Sebungwe region northeast of Gokwe and in parts of the Shangani region, boreholes have been uniformly successful in obtaining water supplies from the Escarpment Grit. Water supplies up to 250 gpm have been obtained by Rhodesia Railways from individual boreholes in the Triassic rocks at Nyamandhlovu, Igusi, Sawmills, and Intundhla. On the other hand, in the Mzarabani region the rocks to a depth of about 400 feet in the Upper Karroo province proved to be too fine grained to yield water to boreholes.

LOWER KARROO SUBPROVINCE

The rocks constituting the Lower Karroo subprovince are of Early Permian age. They consist chiefly of mudstone, carbonaceous shale, and coal. In the Wankie region, they contain the Upper and Lower Wankie sandstones and in the Sabi region the shales are interbedded with grit and sandstone.

The Madumabisa Mudstone contains thin sandy beds that have yielded small supplies of water to shallow (±200 ft) boreholes in the Sebungwe region, but most of the water is too highly mineralized for use. Watson (1959) reports that one borehole in this region struck a strong flow of highly mineralized water in the Madumabisa Mudstone.

The Wankie Sandstones are reported to be generally fine grained and moderately to well cemented. Their potential value as fresh-water aquifers is largely unknown. The Upper Wankie Sandstone supplies the Rhodesia Railways borehole near the Entuba Siding, and several of the test holes drilled for coal in the Sebungwe region struck artesian water in this formation. The water from the deeper boreholes, however, is brackish to salty.

CRYSTALLINE ROCK GROUP

A popular notion that the crystalline rocks of Southern Rhodesia beneath the red-soil areas are more likely to yield ground water than the lighter gray soil areas is not unfounded. The rocks composing the Gold belts province are commonly mantled by red soils and generally contain more fractures and weathered zones than the younger intrusive granites, which are covered by gray soils. The rocks of the Gold belts province are therefore generally more productive than those of the Intrusive granites province.

Not included in either the Gold belts or Intrusive granites provinces are younger, metamorphosed sedimentary rocks of the Umkondo and Lomagundi systems, whose soils range in color from a deep red derived from the basalt of the Umkondo to very light-colored soils from the quartzites and arkoses of both systems. In neither the Umkondo province nor the Lomagundi province is the soil color indicative of the water-bearing characteristics of the underlying rocks.

The areas of crystalline rock are commonly covered with an eluvial or alluvial soil mantle. This regolith appears to be thickest, as much as 150 feet or more, in an area referred to by King (1951) as the Gondwana peneplain of the central arch, where it has not yet been eroded away. The regolith is thin or absent in the areas of active erosion, between the peneplain surfaces and the valley plains of the low veld. Although many boreholes have penetrated the regolith, little is known of its character or which parts are transported alluvium and which parts are eluvial—products of rock weathering formed in place. Where the regolith is derived from the granite and granite gneiss, the upper part of the regolith is commonly a white, pink, or light-gray angular arkosic sand. Where it is derived from greenstone, dolerite, epidiorite, and other rocks that contain mafic minerals, the regolith is commonly more clayey and red to brown in color.

Much of the regolith in Southern Rhodesia is permeable and plays an important role in absorbing and retaining part of the rainfall;

part of this absorbed rainfall seeps down to the water table. A part or all of the ground water from many of the boreholes in the crystalline rocks comes from a saturated zone at the base of the regolith. In other areas where the water is in fractures beneath the weathered zone, the weathered material serves as a retaining blanket from which the water is slowly released to the underlying fractures.

UMKONDO PROVINCE

In the southeastern part of the country, the Umkondo province comprises rocks of the Umkondo system that rest unconformably on granite and gneiss. These rocks form the highlands around Chipinga and Melsetter and downfaulted masses west of the Sabi River. Rocks of the system are also present west of Salisbury, in Urungwe, and a small patch is preserved in the Inyanga highlands. In the Chipinga highlands, the system is generally composed of quartzites containing interbedded lenses of limestone. Arkose forms the basal bed in places, and basalt caps the system. Dolerite sills are present at several horizons. Very little is known of the groundwater potential in these areas. Surface water is abundant in most of the Umkondo province, and for this reason only a negligible amount of drilling has been done. A few springs, however, rise from rocks of the Umkondo system on the escarpment face west of Chipinga. As the system consists of little decomposed, extremely hard rocks, ground water occurs chiefly in joints and fractures.

Several boreholes have been drilled in the downfaulted Umkondo rocks of the Maranka area, where the rocks are composed of limestone, marl, quartzite, and basalt. Drilling was largely unsuccessful in the southeastern part of the area, where deep faults are suspected of draining the ground water to lower levels. Domestic supplies are obtained from shallow wells in the west, where the marl overlies the granite. Water also is obtained from fractured quartzites in the central part of the area. Water is generally present in the quartzite and limestone and commonly within 100 feet of the land surface.

LOMAGUNDI PROVINCE

This province comprises rocks of the Lomagundi system, a thick series of sedimentary formations forming a well-defined escarpment stretching from the base of the Mafungabusi Hills northeastward to the vicinity of Sinoia and thence towards the Zambezi Valley.

The Lomagundi rocks consist of a lower arenaceous group of dolomite, quartzite, and slate, and an upper argillaceous group of quartzite, slate, and grit. At the north end of the Hunyani Range, boreholes, 150 to 200 feet deep, in the fractured slate produce as much as 16 gpm for domestic supplies. In the Magondi area, the ground water is also obtained solely from fractured zones in slate. Quartz veins are common in the slate, and water is commonly obtained from such veins, probably because the veins occur only where the slate has been fractured. Drilling in the quartzites has been less successful than in the slates; owing to technical difficulties, drilling stopped while the holes were still at shallow depth, and it is not known if water is present at greater depth. The arkose is considered to be a tight formation, and only small supplies are present in zones of decomposition. Few boreholes have been drilled in the dolomites north of Sinoia, but the presence of solution channels and caves in this area suggests that large supplies can be developed where such solution features transect the zone of saturation.

INTRUSIVE GRANITES PROVINCE

The Intrusive granites province occupies more than half of Southern Rhodesia. The rocks of this province form parts of intrusive bodies of several different geologic ages. East of Que Que, the granite is probably older than the Bulawayan Greenstone, whereas near Bulawayo granites of three distinct ages are recognized, all of them younger than the greenstone. In the Mount Darwin area four types of granite have been recognized. Not all the granites are old, for there are granites of post-Lomagundi and post-Karroo age. Chemical analyses of Rhodesian granites indicate that the soda granites predominate over the potash granites.

The granite underlies much of the high veld agricultural area of Southern Rhodesia. An analysis by Lange[1] of borehole records has shown that the granite is the least favorable rock type for the development of ground water. In the main, these rocks are reliable water bearers only in the fractured and decomposed contact zones containing the rocks of the Gold belts province and other intrusive rocks. In the absence of a contact zone, any water present is likely to be found in the joints. Commonly, the joints are in three sets—one is horizontal and the other two, vertical and perpendicular to each other. Weathering and erosion along the joints produces the attractive "castle kopjes" so common in the Rhodesian landscape. However, jointing becomes less pronounced with depth, as the joint openings become more narrow or become filled with secondary limestone or other impervious material.

Granite in the Marandellas area contains many dikes of dolerite, which have fractured the granite and produced weathered zones along the contacts. Such decomposed zones are easily located by electrical resistivity methods, and water is usually obtained from

[1] Lange, H. E., 1952, Borehole water resources in Southern Rhodesia: Master of Science thesis, Natal Univ.

them. On the surface, red soils and the presence of quartz, dolerite, and banded ironstone rubble are indicative of a fractured or decomposed zone and worthy of geophysical investigation.

North of Marandellas, erosion of the granite has produced "ruware," hills of massive granite containing very few joints, in marked contrast to the "castle kopjes." Ground water is found only at the contacts with dolerite dikes and sills or at shallow depth in the decomposed zones of the larger dikes and sills. South of Marandellas, the regolith is shallow, and even small yields are difficult to obtain from fractured zones in the granite at depths from 150 to 200 feet.

The Gutu and Ndanga areas lie in broken, hilly country where active erosion is now in progress; the granite surfaces are swept clean by the swiftly flowing streams. The rainfall runs off the bare rocks into the streams; so, the percentage of the precipitation which actually becomes ground water is very small. Wells of small yield can be obtained locally in fractured zones near dolerite intrusions.

Westward in the Enkeldoorn and Umvuma areas where a large remnant of the Gondwana surface still exists, the regolith is sufficiently deep to yield water. The country is rolling and thickly covered with grass. The soil is absorbent and helps to retain much of the precipitation, which percolates down to the water table.

West of Salisbury in the vicinity of the Great Dyke, the granite yields moderate supplies of water to wells. Successful boreholes have been drilled near Lydiate, Kutama, and Makwiro, where the granites have been fractured by dolerite intrusions, most probably associated with the Great Dyke itself. Farther west in Gadzema, Zwimba, and Trelawney, where the granite is largely unjointed and unfractured, there is little ground water.

GOLD BELTS PROVINCE

The Gold belts province consists of elongated erosion remnants of metamorphic rocks resting on the granite. The rocks of the province have been divided into three systems: the Shamvian, Bulawayan, and Sebakwian. The Bulawayan system is most important hydrologically.

The rocks of the Shamvian system consist of metasediments—chiefly arkose, graywacke, and conglomerate. The rocks do not readily decompose, and water is usually found in fractured zones. The location of suitable borehole sites is more difficult than in the greenstones of the Bulawayan system, and well yields are generally small.

The rocks of the Bulawayan system are extensively exposed in most of the Gold belts. They consist of basaltic lavas, tuff, and agglomerate metamorphosed to greenstone and interbedded with metasediments. The metasediments are banded ironstone, metamorphosed arkose and graywacke, quartzite, phyllite, and marble. In general, the greenstone readily yields ground water to wells. In Arcturus, east of Salisbury, the deep regolith in the valleys between the greenstone hills and ridges is an exceptional aquifer. Several boreholes have potential yields greater than 30 to 50 gpm. One owner who investigated the capacity of a borehole drilled on his property discovered that the yield was 250 gpm.

The rocks of the Sebakwian system underlie the Bulawayan Greenstone. They include highly metamorphosed sediments and magnesian rocks, probably derived by metamorphism from ultramafic igneous rocks. The composition of the sediments is very near that of granite, and the magnesian rocks have been altered to serpentine, actinolite, or tremolite schist. Information concerning the water-bearing character of the rocks of the Sebakwian system is not presently available.

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