The uranium deposits of the Tete district, Mozambique

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Geological Survey of Great Britain.[1]

Introduction.

EARLY in 1947 an unusual mineral deposit was discovered at Mavuzi in the Tete district of Mozambique. The discovery was made by native boys searching for corundum on behalf of Senhor Mario Canuto de Carvalho, a Goanese prospector who had for some years been associated with primitive gold and corundum operations on the north bank of the Zambesi. The dominant ore-mineral in the new deposit was superficially similar to the pegmatitic samarskite found in small quantities in the mica-mining districts of the Alto Ligonha in eastern Mozambique; and when exposure of the mineral to a photographic plate confirmed that it was radioactive, the identification as samarskite was accepted both by local prospectors and by most of the field geologists who later worked on the deposits. The presence of uranium in the ore was first proven in a chemical analysis by the Southern Rhodesian Geological Survey.

Within a few months of the first discovery, on which concession rights were granted by the Portuguese Colonial Government, some 50 tons of concentrated mineral assaying between 7·5 and 8·0 % U_3O_8 had been recovered from the principal prospect. A year later more than 300 claims, each a kilometre in radius, had been staked for uranium. Options on the main properties were taken up jointly by the British South Africa Company, New Consolidated Gold Fields Ltd., and Gold Fields Rhodesian Development Co., Ltd., and exploratory development was actively pursued.

In June and July 1947 specimens of the ore were submitted to the Geological Survey in London by the Southern Rhodesian Geological Survey, by various London dealers in rare minerals, and by certain British mining houses. The first specimens received were analysed for uranium only, giving values of from 7 to 10 % U_3O_8; and from its appearance the mineral was assumed to be a euxenite or samarskite as was reported by the senders. Samarskite is of frequent occurrence

[1] Communicated by permission of the Director.

in the Mozambique pegmatites, no less than eleven mining concessions taken out from 1935 to 1939 mentioning this mineral by name; but as the output had hitherto been insignificant the new occurrence did not arouse as much interest as it might have done had the true nature of the mineral been recognized earlier. Not until a reliable chemical analysis became available, showing very high titanium and a complete absence of niobium and tantalum, was it realized that the mineral was almost a unique species. It has approximately the composition of an ilmenite with some 8 % urania. Investigations by Dr. F. A. Bannister of the British Museum (Natural History) and by Mr. J. E. T. Horne of the Geological Survey, already published in the *Mineralogical Magazine* (1950), have shown that the mineral is essentially identical with davidite, a species which occurs in very sparse amounts at the Radium Hill uranium workings, South Australia. In Mozambique a few crystals of this hitherto very rare mineral have been found weighing as much as 40 or 50 lb.

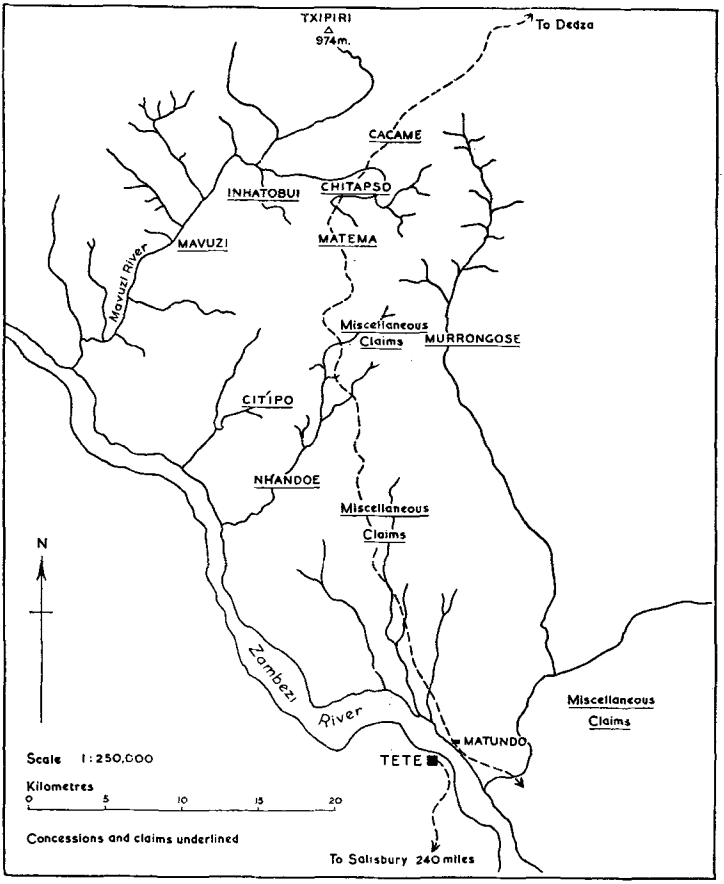
Following this preliminary mineralogical work the authors were invited by the British South Africa Company to make a brief field study of the deposits, and in June–July 1948 a full investigation of the various prospects was undertaken in conjunction with Dr. R. A. Pelletier (Chief Geologist) and Mr. A. T. M. Mehliss (Resident Geologist) of New Consolidated Gold Fields. It was found that the uranium complex was of a completely new geological type, but that the extent and importance of the deposits had been greatly exaggerated, the reserves of economically workable ore being quite insignificant viewed from the strategic and supply aspects. The British control of the deposits was allowed to lapse in August 1948. Since then close on another 100 tons of davidite has been produced by Portuguese operators at a high cost, principally from float and hand-cobbed surface ore, and has found a market in France.

The present paper presents a brief description of the geology and mineralogy of the occurrences. In the course of the field studies the authors had the benefit of constant consultation with Dr. Pelletier and Mr. Mehliss, and without the collaboration and assistance of these gentlemen this report could not have been produced.

Topography, Climate, and Vegetation.

The Discovery Concession is situated on the Mavuzi river, a tributary joining the Zambesi on its north bank at a distance of about 30 miles from Tete, the administrative centre of this part of Portuguese East Africa. The Mavuzi mine is reached from Tete by ferry across the

Zambesi to Matundo, thence by the main all-weather road for 21 miles to Matema, and thence by a 9-mile bush road.



SKETCH MAP OF URANIUM CLAIMS, TETE DISTRICT, MOZAMBIQUE.

FIG. 1.

According to official climatic maps the Mavuzi district is the hottest spot in Africa south of the equator. The mean annual temperature observed in 1947–48 was 83° F., occasionally falling to under 40° F. at night in winter and in the summer rising to 110° F. Rainfall averaged some 34 inches in the year. The climate is not healthy and malaria is endemic.

The region is part of the Zambesi valley, and is topographically a maturely dissected peneplain which has suffered recent rejuvenation of

drainage. The mineralized country is rugged, being cut by innumerable steep-sided ravines, some of which contain perennial streams. Although over 300 miles from the coast, the altitude is only about 350 feet above sea-level. Bed-rock is not well exposed and the considerable depth of rock-decomposition products is a serious handicap to geological studies. The vegetation consists of grass up to 6 feet high and open mopani bush, the latter providing a fair reserve of mine timber. Occasional baobab trees are a striking feature of the landscape.

Geology.

Prior to the present investigation, practically no regional geological work had been carried out in the Mavuzi district. The only map available (Borges, 1946) is a geological sketch on a scale of 1 : 1,000,000, which indicates that the principal feature of the district is a roughly oval-shaped intrusion of gabbroic composition some 80 miles long by 30 miles broad. This is overlain by sediments of Karroo age except on its north-west side, where gneisses and granites are said to occur. Apart from frequent basic dikes of roughly east–west trend and probably of Tertiary (Rift Valley) age, the basic igneous masses are all of pre-Karroo age and are probably all pre-Cambrian. So far as is known, the radioactive minerals are only found within the outcrop of the gabbro mass.

The gabbro is of noritic type, akin to a basic charnockite, the constituent minerals being dominantly labradorite and hypersthene. The grain-size varies greatly and is often very coarse. Anorthositic phases consisting essentially of labradorite felspar are frequent and are usually coarse in grain. This complex was intruded by northerly-trending basic dikes, the emplacement of which was followed by intensive shearing in a north–south direction. Later acid intrusions, including syenitic dikes and quartz veins, are accompanied by some larger masses of syenitic rock occurring typically in dike-like and lenticular forms. Coarse-grained pegmatites of quartz and potash-felspar also penetrate the basic complex, and are sometimes injected in lit-par-lit fashion into sheared epidioritic modifications of the norite. The final igneous activity in the district is seen in the dikes of east–west trend that are clearly much later than the rest of the complex. No true granites were seen anywhere in the region; they are absent from the assembly of boulders in the bed of the Mavuzi river which, since good exposures of fresh rock are lacking over much of the area, provides the best representation of the local lithology.

A number of what are apparently roof-pendants and enclaves of an ancient sedimentary complex are found within the norite-anorthosite mass. These include principally limestones and more rarely pelitic and psammitic schists, the schistose rocks sometimes containing lit-par-lit injections of granite-pegmatite. The most notable of these enclaves, seen at the Matema lime quarry, 9 miles east of Mavuzi, is a pendant or xenolith of crystalline limestone about 200 yards wide by over a mile long. The limestone is relatively pure and free from calc-silicates, exhibiting only a little scapolite, phlogopite and albite arranged in well-defined bands. No traces of uranium mineralization were detected in Geiger-counter investigations over this well-exposed body of limestone.

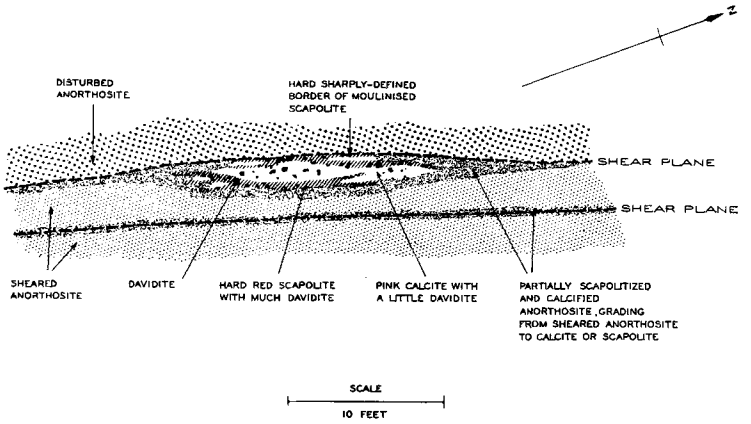
Mineralization.

The uranium mineralization is patchily distributed over an area of about 300 square miles, but the wide extent of this distribution is no indication of the amount of mineral involved. Throughout this region claims were staked with the utmost liberality wherever scattered mineral float or a mineralized outcrop was encountered, entirely without regard to the prospects of mineralization continuing in depth. Some of the properties contain no more than traces of davidite, a fair proportion of the mineral collected by some claim-holders being magnetite. At the time of our visit in mid-1948 all the claims had been prospected on a very limited scale by trenching—probably upwards of 500 trenches in all, mostly sited at random without reference to the geological structure. Only at the Mavuzi property worked by the British companies had any scientific development been carried out. The concession of Inhatobui adjoining Mavuzi to the north-east, on which some 250 exploratory trenches had been dug, and the Citipo claims some 10 miles south-east of Mavuzi, both proved to be of mineralogical interest.

The associations of the radioactive mineral davidite show considerable variety, but four different and distinctive types of gangue are found. These consist of scapolite, calcite, pyroxene, and a 'felsitic' rock. The mineralization is for the most part intimately associated with shear zones, the largest of which (at Mavuzi) is about half a mile in length, with a width of from 5 to over 40 feet. The shears have converted the noritic country-rocks to strongly-foliated epidiorites, frequently exhibiting augen structure, in which there has been very extensive scapolitization of the felspar.

Following the consolidation of the basic rocks the complex was locally subjected to intense shearing stresses, the finer-grained norites being

transformed to epidiorites and the coarser rocks to streaky hornblende-gneisses of basic composition, often with a well-developed augen structure. A typical epidiorite shows in thin section sheaves of hornblende prisms in a matrix of granular scapolite, associated with a varying



TYPICAL OCCURRENCE OF DAVIDITE
IN ASSOCIATION WITH CALCITE AND SCAPOLITE
MAVUZI, TETE, MOZAMBIQUE.

FIG. 2.

quantity of granular zoisite and some epidote. As was to be expected, the earliest sign of shearing stress is alteration of the pyroxene to amphibole; but the transformation of felspar to scapolite, dating from the time of shearing or possibly a little later, is even more widespread. The Mavuzi rocks show more widespread regional scapolitization than any other igneous complex known to the writers. Scarcely a single specimen from the anorthosite-norite suite can be found that is altogether free from scapolite; and extensive shear zones, assumed in the field to consist of saussurite, have been found on laboratory study to be formed of pure scapolite rock or of scapolite-calcite rock, often with relict structures of the original norite. This extensive scapolitization extends to the deepest mine workings (110 feet) and presumably continues in depth. It is characteristic of all the ore-bearing zones and is attributed to the hypogene ore-bearing solutions. At the surface the scapolite weathers to a white clay which is commonly rich in calcite, the calcite sometimes giving rise to a pan of secondary calcrete a foot or two beneath the ground level.

The scapolite-calcite type of mineralization.—The scapolite-calcite

mineralization is the commonest development at the Mavuzi mine. Early in the mineral sequence massive white quartz seems to have been injected into the shear zones, and must have formed veins up to 2 or 3 feet wide. Disrupting the quartz, and sometimes combining with it to form a massive diopside, a high-temperature dolomite-calcite is found. Bodies of calcite and/or dolomite are rather common, up to 50 feet long and 3 feet wide; but whether these are all of metasomatic origin or whether some may represent enclaves of sedimentary rock is uncertain. Locally they are relatively free from pyroxene and quartz, locally pyroxene is seen enclosing some remnants of quartz, and elsewhere quartz blocks up to 2 feet wide are to be seen, each surrounded by a reaction band of diopside. Occasionally a little cinnamon-brown chalybite is present. Certainly much if not all of the carbonate is metasomatic, for a calcifying invasion has extensively attacked the neighbouring sheared gabbros, the anorthositic phases being particularly affected. The calcite is accompanied by a very great deal of scapolite. All stages from incipient to complete scapolitization of gabbros and anorthosites, followed by partial to complete calcification, are evident at more than half a dozen localities. Pyroxene remnants are marked by cloudy chlorite and thus form palimpsests of the original rock structures.

During the emplacement of the calcite and scapolite a number of sulphides and oxides were introduced. These include pyrite, pyrrhotite, chalcopyrite, and rather frequent molybdenite, with rutile, davidite, magnetite, ilmenite, and a little tourmaline. Some golden-brown apatite is locally associated with the oxides, particularly with davidite. The highest concentrations of davidite occur in the more intensely scapolitized portions of the altered basic rocks, although a considerable amount occurs scattered throughout the massive calcite which represents the advanced stage of the emplacement process.

The scapolite-rich bands are typically narrow, seldom exceeding 2 feet in width, and they may persist in length and depth up to 50 feet, although they are usually of much smaller extent. Several narrow bands may occur grouped over a width of rock of 20 feet or so. The presence of davidite is invariably marked by pink to deep red staining, forming an aureole round the typically plum-size particles of radioactive mineral. Where the latter are abundant the whole rock assumes this red colour. Local staining is generally absent when the mineral is embedded in calcite, though the latter may also have an overall pink colour.

Subsequent to the mineralization, renewed movements gave rise to local shearing of the scapolite zones and plastic flow of the calcite. As

a result, the molybdenite flakes are oriented parallel to the direction of movement and the davidite and rutile crystals are typically shattered to pieces, often with evidence of having been dragged along to form parallel trains. Good crystal forms are therefore of rare occurrence. In field appearance the scapolite zones often have a davidite-rich core, suggesting that the scapolite-forming and davidite-bearing liquors were introduced through narrow fissures, scapolite mineralization permeating the neighbouring rocks and davidite being deposited near the fissures. The identity of these structures is sometimes preserved in the massive calcite, but elsewhere is represented by strings of scapolite remnants and davidite, and often by strings of davidite only.

Subsequent to these phases late quartz was introduced, usually in small stringers which are seen to cut both scapolite and calcite masses and break through crystals of davidite, rutile, magnetite, and apatite. The late quartz is sometimes drusy and is frequently smoky in appearance. It is associated with specular haematite, magnetite, and pyrrhotine, the decomposition of which results in locally intense iron staining. Unlike the early quartz it does not give rise to the formation of pyroxene in contact with carbonate. Very locally, late silicification has been sufficiently intense to replace completely the scapolite and calcite within an inch or so of the borders of the veinlets, thus providing the rare spectacle of davidite embedded in quartz. Late stringer veining of the altered gabbros by fibrous calcite and red stilbite is also fairly common.

The pyroxenic type of mineralization.—In this type of occurrence the davidite is associated with coarse-grained pyroxenic rocks that have the superficial appearance of basic pegmatites. Like the calcite and scapolite bodies they are lenticular in shape, up to some tens of feet in length and a few feet in width. They commonly occupy shear zones little affected by subsequent movements. This pyroxene association is well developed in the Inhatobui area, adjacent to the Mavuzi claims.

Several features indicate that the origin of these bodies is different from that of true pyroxene pegmatites. The latter may be observed elsewhere throughout the norite-anorthosite complex to consist of massive coarse hypersthene, sometimes grading into coarse hypersthene-labradorite rock. In the rocks under discussion the pyroxene is not a hypersthene but a green diopside. Crystal individuals range from an inch or so to a foot across and comprise the bulk of the rock. Subsequent movements and metasomatism have caused incipient alteration to a dark tremolite-like amphibole. Red and pink scapolite, generally mas-

sive and granular but occasionally in prismatic crystals up to an inch in length, occurs intergrown with the pyroxene. This mineral is rarely present in important quantity within the pyroxene bodies, where it usually occurs in vague, vein-like bands, but marginal concentrations are fairly common. The pyroxene-davidite assemblages are invariably accompanied by an aureole of scapolitization of the neighbouring country rock, extending for several feet on either side and decreasing in intensity outwards. In these aureoles the ferromagnesian minerals are represented by black hornblende and some tourmaline, biotite, and apatite. Another feature of this type of occurrence is the presence of late veinlets and stringers of vermiculite running parallel with the pyroxene bodies, often along their margins.

Mingled with these pyroxene bodies at Inhatobui are many small davidite-bearing scapolite—or more rarely calcite—deposits of the type previously described. Occasionally the massive pyroxene is seen to have a core of white quartz or to contain occasional blebs of quartz throughout its mass. Elsewhere white quartz seems to have entered as a late injection. Again, some pyroxene bodies were observed to have a core of massive calcite with a little scapolite round which the pyroxene forms an obvious crust.

The davidite occurs in the scapolitic phases marginal to and enclosed within the pyroxenic bodies. As before, the scapolite is invariably stained pink or red where in contact with the davidite. The mineral also occurs marginally in the infrequent massive calcite, the latter apparently derived from calcification of scapolitic zones. Davidite crystals in these associations are typically imperfect and have grain sizes varying from microscopic to rare individuals about 4 inches across.

Davidite also occurs in the vermiculite veinlets. The mica is brown biotite occurring in closely packed books up to two inches across. The veinlets vary in width from an inch to 4 inches. Scapolite is usually absent. The radioactive mineral forms grains of various sizes, exceptionally giving individual crystals 3 or 4 inches across which occupy the whole width of the veinlet.

In addition to these associations davidite occurs less frequently embedded in the massive pyroxene, usually marginally in large pyroxene individuals.

The 'felsitic' type of mineralization.—A further type of davidite occurrence is especially well developed at the Citipo claims, where the radioactive mineral is found in a hard pink-coloured rock which was termed 'felsite' in the field. Patchy developments of the same

character have been seen at Mavuzi. Microscopic examination shows that this 'felsitic' rock consists essentially of sodic plagioclase intimately associated with davidite-bearing carbonate, the davidite crystals being surrounded by the usual red staining. Quartz is absent or present in minute quantity only.

The 'felsite' or soda-plagioclase rock is of relatively late date since it is commonly found in veins (up to a foot in width) intruding the mineralized shear zones in scapolitized norite. The not infrequent occurrence of prisms of tourmaline in the felspathic rock suggests a link with the scapolitizing fluids and a possible derivation from the labradorite of the gabbro. It is noteworthy that the total amount of sodic plagioclase in these 'felsites' is never great. The larger bodies contain a considerable proportion of calcite, but in smaller masses the albite may be preponderant and thin veins of a relatively pure albite rock are found traversing masses of metasomatic limestone. All these 'felsite' bodies are characteristically impersistent, being seldom more than 20 feet in length. Grains of davidite, occasionally found scattered sporadically throughout and sometimes only of marginal distribution, may have been picked up from pre-existing rock; but they may equally well be contemporaneous with the albite-rock, which clearly marks a late phase of the pneumatolytic alteration of the norites and anorthosites and is not to be regarded as of true igneous origin.

Sequence of mineralization.—The following is a reconstruction of the history of the Mavuzi complex in so far as we have been able to decipher the sequence of mineralization from field examination and from petrographic and mineragraphic study.

(1) The norites and anorthosites were sheared to epidiorite and possibly to saussurite rock, the shear-zones forming the most likely channels for later mineralizing fluids.

(2) Massive quartz was introduced into the shear zones in irregular blows. Most of this quartz was shattered by later movement.

(3) Progressive alteration to scapolite and carbonate in the shear rock took place through the influence of the mineralizing fluids, producing scapolitized epidiorites and a massive scapolite-calcite facies. The white quartz of phase (2) is found embedded in irregular masses of dolomitic calcite, each fragment having a reaction rim of diopside (now partly or wholly transformed to tremolite). All stages can be seen up to the complete replacement of the quartz by massive pyroxene.

(4) The scapolite-calcite and scapolite-dolomite associations so formed range from wide masses of carbonate rock to somewhat narrower bodies

of pure scapolite rock, with all possible intermediate associations of scapolite and calcite. These assemblages carry davidite, rutile, sphene, magnetite, ilmenite, apatite, and molybdenite, the phases rich in scapolite being particularly favourable to davidite, usually with biotite (vermiculite) in small flakes, grains of tourmaline, and less commonly sphene and rutile. The davidite concentrations are typically narrow, probably representing deposition in the immediate vicinity of a fissure. In massive calcite davidite occurs typically in bands and stringers of individual crystals, suggesting that it was formed primarily in a narrow concentration of scapolite which was later completely calcified. Tourmaline has not been seen in the massive calcite and vermiculite occurs but rarely, though rutile and less often sphene may be found in crystals up to a few inches in length. Magnetite and ilmenite are commonly associated with the davidite, not infrequently in composite aggregates. Molybdenite occurs as scattered flakes, usually where apatite is abundant. The apatite forms stringers of small prisms as well as larger irregular crystals of a reddish-golden colour, the largest crystal met with reaching over a foot in length.

(5) There is some evidence that, at this stage, white or pinkish quartz was locally intruded into the calcite bodies. The quartz ramifies through the calcite, but forms no pyroxene or amphibole by interaction. There is, apparently, no contemporaneous mineralization except possibly some albite and apatite. Later deformation, during which the calcite underwent plastic flow, caused shearing of this quartz, giving a granular crush matrix of quartz and calcite in which quartz blocks are oriented in stringers with their long axes parallel to the direction of flow. The davidite and rutile crystals were shattered and drawn out in small trains, along which the matrix is coloured a bright red. Molybdenite flakes are also oriented parallel to the flow, while diopside crystals were crushed and transformed to tremolite.

(6) A further stage is seen in the introduction of permeation zones and stringers of translucent white quartz, associated with pyrite, haematite, and apatite. This quartz invades the crushed calcite producing locally a haematitic calcite-quartz rock, usually containing some apatite. Elsewhere stringers of haematite and apatite penetrate the masses of amphibole and pyroxene. The apatite crystallizes in abundant well-formed prisms within the quartz and sometimes contains well-defined zones of haematite where it grows in association with that mineral.

(7) Later movements have resulted in a local brecciation of these silicified zones, the breccia being cemented by thin veinlets of late white

quartz, sometimes occurring in druses with the smoky pyramids of quartz overgrown with specular haematite.

Conclusion.

The present generalized account of the davidite deposits purposely omits any detailed description of the workings or of the mine geology. It will suffice to say that the Discovery Concession at Mavuzi, which is more richly mineralized than any other known property in the district, must originally have been most spectacular. The mineral occurred here as rich streaky disseminations of crystalline masses, blocks of brecciated davidite veined with calcite and scapolite seldom weighing less than several pounds. An open-cast quarry in scapolitized norite and anorthosite, 180 feet long and locally attaining a depth of 40 feet, yielded 53 tons of hand-cobbed mineral. Many of the individual crystals, all of which unfortunately were broken up, exceeded a foot in diameter.

Towards the bottom of the quarry the mineralization weakened, and the ore encountered underground on the 100-foot level all proved to be of unpayable grade. Many other shows throughout the Mavuzi district, with promising mineralization at the surface, were found to die out underground within a few feet or a few tens of feet. The distribution of davidite along the shears is clearly very patchy indeed; and the loose and running nature of the ground is a serious handicap to mining, for the extent of mineralization underground tends to vary directly with the degree of brecciation, scapolitization, and incoherence of the bedrock.

The claims staked at localities other than Mavuzi—at Inhatobui, Nhandoe, Citipo, Cacame, Chitapso, Matema, Murrongose, and elsewhere—call for little additional comment. At their worst they contain no more than a few particles of davidite in float, at the best their mineralization is not much richer than that seen in a field of uraniferous pegmatites. Near Matema, 5 miles west of the main road, the rock quarried in an exploration trench is a coarse-grained limestone resembling a skarn ore, with much granular magnetite and a good deal of well-crystallized tourmaline in the matrix. One davidite crystal was found pseudomorphing tourmaline, and well-crystallized plates of allanite up to an inch across are present in quantity. Adjoining trenches show decomposed anorthosite-norite veined by scapolite and calcite-magnetite rock; and the skarn-like limestone is therefore again assumed to be a product of the metasomatism of anorthosite.

No uranium deposit strictly comparable to the davidite occurrences

of the Tete district is known to us. The davidite of Olary in South Australia occurs in pegmatitic lodes consisting of quartz, biotite, ilmenite, and rutile, cutting paragneisses that include scapolite-schists and amphibolites (Mawson, 1944). The country rocks are in process of granitization, and a sheared aplitic soda-granite, with which the pegmatites are genetically connected, sometimes forms the wall-rock of the lodes. The intense scapolitization and carbonatization typical of Mavuzi is not found here. The only other uranium mineralization where scapolitic alteration of the wall rock has been reported (Sandberger, 1885) is found in the mesothermal pitchblende lodes of Jáchymov in Czechoslovakia; but according to Stěp and Becke (1904) the reputed scapolite is a misidentification of oligoclase-albite.

A 'titano-magnetite' uranium mineral, possibly akin to davidite, has been recorded from pegmatites in the *High Pamir of Central Asia* (Golubkova, 1930), but no particulars of the geology of this occurrence seem to have been published. That davidite is of more widespread distribution than hitherto realized is, however, suggested by a study of samples recently received by the Geological Survey from a pegmatite 65 miles east of Swakopmund in South-West Africa. These have been found to be rich in titanium and iron, with about 9 % urania, and to be relatively free from niobium and tantalum; after heating to destroy their metamict nature they give X-ray powder photographs closely resembling but not identical with those of the mineral from Mozambique.

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