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15. GEOLOGICAL INVESTIGATIONS, SAMPLING AND DIAMOND DRILLING AT MANYEGHI HELIUM-BEARING HOT SPRINGS, SINGIDA DISTRICT

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I. Introduction

A number of the hot springs in the Mponde River area emit gas containing from 5 to 10 per cent. helium. The gas with the highest percentage of helium comes from the Mponde Springs but the much more extensive springs at Manyeghi about 15 miles to the north were considered more suitable for the detailed investigation which it had been decided to undertake as part of a campaign to develop a Commonwealth source of helium for the U.K. atomic power programme.

The object of the investigation, some aspects of which are summarized in this report, was to ascertain whether an increased flow of helium could be obtained over and above that naturally escaping from the spring vents.

Most of the work was done during the period May to December, 1958. The investigation included the drawing up of a detailed topographic map (G.S. 1276, in pocket) of the area of the springs; an examination of the geology of the area immediately adjacent to the springs; an appraisal of the structure of the area by means of air photographs; a search for hitherto undiscovered spring vents; an extensive programme of pitting which supplied information on weathering, bedrock geology and ground-water conditions; detailed measurement of the brine and gas flow from the spring vents and a study of variations in these factors; and various other measurements, including sub-surface temperatures in the spring vents, radio-activity associated with the spring vents, and the effect of changes in hydrostatic pressure on gas and brine flow. Six diamond-drill holes totalling 1,043 feet were drilled under Vents 3 and 4 in an attempt to find out the nature and orientation of the structure which channels the flow of gas and brine. Some magnetometer traverses were also done.

II. Location and Access

Manyeghi Springs are situated on the eastern side of the Mponde River valley, about 85 miles north-west of Dodoma and about 4,000 feet above sea-level. The springs are about 3 miles south of the Kwa Mtoro-Singida road, from which they can be reached by a turn-off about 2 miles south-east of the village of Msughaa.

III. Geology of the Manyeghi Area

(a) Regional Setting

The Mponde Valley is a south-south-east-trending trough about two miles wide. It represents the downthrown block to the east of a strong rift-fault system (the southward extension of the western boundary fault of the Kenya Rift Valley) which forms a prominent scarp rising about 700 feet above the valley-floor along its western side. No comparable topographic feature occurs on the eastern side of the valley, but a low scarp marks a zone of fracturing which may be an antithetic fault system dipping to the west and making connection at depth with the main rift fault. Manyeghi Springs extend over a stretch of about a mile and a half of this zone of presumed antithetic faulting.

(b) Rock Types

The area around Manyeghi Springs is part of a Precambrian migmatite complex in which granitic material greatly predominates over the unmigmatized, metamorphic host rock. Four main components of the migmatite complex can be distinguished in the field:

(i) Foliated biotite gneiss, often with large, oriented feldspar porphyroblasts.
(ii) Medium-grained migmatitic granite with a noticeable content of biotite.
(iii) Leucocratic migmatitic granite, apparently without biotite.
(iv) Pegmatites and aplites.

The outcrops in an area of about one square mile immediately to the east of the springs have been examined in some detail and the following sequence of events is suggested as a possible explanation of the field relationships observed in that small area.

The biotite gneiss (i) is thought to represent a member of a suite of ancient, regionally metamorphosed rocks. These rocks were subjected to a period of migmatization during which large feldspar porphyroblasts were developed parallel to the foliation (about 260 degrees) of the biotite gneiss, much of which was completely made over to biotitic migmatitic granite (ii). At some later stage a resurgence of migmatization affected the area and much of the earlier migmatitic granite and almost all of the remaining host rock remnants were replaced by the leucocratic migmatitic granite (iii). This phase of migmatization was more intense than the earlier one and was accompanied by local mobilization of granitic material. Much of this mobilized material recrystallized more or less in place to form large masses of coarse-grained pegmatite pervading the leucocratic migmatitic granite, but some was injected along planes of weakness in the earlier migmatitic granite and the remnants of biotite gneiss, forming veins of pegmatite and aplite.

Basic dykes also occur in the area. They follow various strike directions and are almost certainly later than the migmatites. The original pyroxene of these rocks has been converted to hornblende, actinolite or epidote, indicating that a relatively mild regional metamorphism has affected the area at some time since the emplacement of the basic dykes.

(c) Structure

The salient structural feature of the area is a system of strong south-south-east-trending rift faults with a downthrow to the east. A zone of faulting, probably antithetic to the main rift faults, runs parallel to the major rift scarp about two miles to the east, forming the eastern boundary of the broad, flat Mponde Rift Valley.

The rift faulting cuts ancient migmatites which exhibit a well-marked system of pre-rift structural lines (joints, dykes and fractured zones) which have, in many cases, been the loci of renewed movement during the later faulting.

The joint system in the migmatites can be tentatively interpreted as indicating a more or less east-west compressive state which may have caused a gradual gentle doming of the area. The sudden release of this stress may have been the cause of the large-scale normal faulting of the rift episode.

A rather unexpected feature shown up by the air photographs is that the predominant structural directions in the areas to the east and to the west of the rift fault do not appear to be the same. The dissimilarities in the structural pattern on either side of the fault may possibly indicate that the two areas have behaved differently and independently since very ancient times on account of some fundamental tectonic difference, since emphasized by the formation of the rift faulting along the boundary.

The faulting which produced the main rift scarp in the Manyeghi area strikes between 340 and 360 degrees, the latter trend probably being the earlier one. To the north of Manyeghi Springs the main rift becomes more variable in strike and splits into two or more parallel systems. This area is considered by Gherardi (Unpubl. rep., 1958) to typify a moderate-dipping, normal fault system with its step and splay faults. The character of the rifting changes further south to more or less straight, uninterrupted lines with sudden offsets along old fractures; this Gherardi considers to be characteristic of true collapse structure and implies a very steeply-dipping fault. The character of the rift directly opposite Manyeghi Springs is intermediate between these two extremes.

The structure of the eastern boundary of the rift valley appears to be that of antithetic faulting resulting from east-west tension brought on by the major downfaulting further to the west.

To the south of the springs the antithetic faults strike mainly at 340 to 360 degrees (parallel with the main rift fault) but in the area of the springs and for a few miles to the north the adjustment seems also to have taken place along old lines of weakness striking at 310 and 290 degrees, giving a zone of faulted blocks which has no doubt been the main localizing feature of the hot springs. To the north of the Singida road the main rift trend comes in strongly again on a strike of 350 degrees.

IV. GENERAL CHARACTERISTICS OF THE SPRING VENTS

Warm dilute brine with bubbles of gas containing just over five per cent. helium are emitted at intervals along a stretch of about a mile and a half of the eastern side of the Mponde Rift Valley. The outflow from these springs, Manyeghi Springs, runs southwestwards towards the Mponde River, forming a large swamp some two miles long by half a mile wide in the floor of the valley. The ground waterlogged by the brine is characterized here, as at other helium spring localities, by a lush growth of round-stemmed green reeds (*Cyperus rotundus*, or "Ndagu").

The appearance of the spring vents is nearly always similar, the brine escaping from the top or flanks of low, humped-up areas of mud and sand covered with a growth of Ndagu reeds. In some cases the natural vents were dug out to form artificial pools of clear water in order to facilitate measurements of gas and brine flow.

The sand filling the vents is coarse, in some cases grading downwards into an aggregate of angular rock fragments as much as two inches across.

The volume of brine emitted from the different vents varies enormously, ranging from flows in the region of 10,000 gallons per hour from each of the two most active groups of vents to scarcely perceptible seepages in the case of some of the dying vents. In all, 35 points of emission of brine are known, of which 11 are strongly active.

The temperature of the brine varies considerably from vent to vent, being generally higher (90 to 100 degrees F.) in the more active vents. Some of the feebler old vents are quite cold (60 to 70 degrees F.).

In most cases the flow of gas from the vents is roughly proportional to the rate of emission of brine.

V. DIAMOND-DRILLING

Six diamond-drill holes totalling 1,047 feet were drilled under Vents 3 and 4.

The purpose of the drill-holes was primarily to investigate the nature and disposition of the structure up which the gas and brine is supplied to the springs, though at the same time it was hoped to obtain interesting information about variations in brine temperature, composition, pressure, gas content, etc., with depth. If a clear picture of the structure could be obtained it was hoped to site a deep hole to intersect this structure at a depth where a marked increase in the rate of flow of gas and brine could be expected.

At the start of the drilling programme it had been thought that the brine channels below certain groups of springs where the points of emission of gas and brine showed a marked linear distribution (e.g., Vents 3 and 4 and Vents 7 and 8) might be in the form of more or less simple planar structures which could be positively identified in a borehole. If such a structure could have been intersected in three points at succeedingly greater depths, it might have been possible to predict its downward extension by normal geometrical methods.

The first hole, G.S. 10, was drilled at an inclination of 45 degrees on a bearing normal to the line of gas/brine emissions in Vents 3 and 4, and actually served to confirm the general impression of the structure as stated above. It tapped a large flow of hot brine at 180 feet below surface just to the south-west of the spring, the increase in flow occurring almost entirely within a 20-foot stretch of the hole. There had been no appreciable brine flow up to this point, and although the hole was extended another 75 feet beyond it, no further increase was obtained. This seemed to indicate a well-defined structure dipping steeply to the south-west, so a second hole, G.S. 11, was drilled from the same site and on the same line, but at an inclination of 70 degrees, in an attempt to intersect the assumed structure at [illegible] feet below surface. Unfortunately, this hole (300 feet inclined depth) did nothing to confirm the idea of a simple, constant-dipping planar structure and it was necessary to drill a third hole (G.S. 12, 275 feet inclined depth) from the other side of the spring to see if the main structure perhaps dipped to the north-east rather than to the south-west. Although these second and third holes both intersected strong flows of hot brine with gas, the inflows occurred at several points in each hole and there seemed to be no logical correlation in space between the brine-bearing channels intersected in the three holes.

It had originally been intended to drill below Vents 7 and 8 as well as 3 and 4, but, as sub-surface conditions were likely to be essentially similar for both groups and no clear picture had emerged from drilling at Vents 3 and 4, it seemed unlikely that definite information would be obtained at Vents 7 and 8 either. It was thus decided instead to drill directly beneath the main area of gas and brine emission in Vent 3 in the hope of intersecting the feeder channel within 40 or 50 feet of the surface.

Three short, inclined holes, G.S. 13, 14 and 15, mutually at right angles, were drilled under this area of gas bubbles and *not one* intersected the main gas/brine channel(s) although all developed moderate flows of gas and brine which increased gradually with depth. This makes it fairly clear that no definite planar structure exists (at least near surface), and that the brine flow follows a zig-zag path within a fairly wide zone of intersecting fissures. The path of the brine probably changes continually as certain fissures become plugged with the green bentonitic clay which is so characteristic of the vent areas.

It was found impossible to interpret the detailed upward path of the gas and brine from the drilling results. The brine channels intersected in the different holes may or may not be directly connected; certainly in no case was the flow from one hole affected by changes in flow from the others, and, even when the first three holes were flowing at a total of about [illegible],000 gallons per hour, the flow from the spring itself was only slightly affected.

Brine issued from the three deeper boreholes under considerable pressure. Daily measurements made by screwing a pressure gauge on the top of the casings showed average pressures of 9½ pounds per square inch for boreholes G.S. 10 and 11, and 6 pounds per square inch for G.S. 12. These pressures are equivalent to heads of about 22 and 14 feet of water respectively (the difference between these two figures being approximately that of the difference in height of the two borehole sites). These figures were found in all cases to check almost exactly with direct measurements of the height to which water rose in the casing when it was pulled.

The small flows of water from the short holes G.S. 14 and 15 rose respectively 9½ and 7 feet (vertical height) in the casings.

VI. The Gas and Brine Flowing from the Springs

(a) Measurement of Brine Flow

The rates of flow of brine from most of the principal spring vents were measured by noting the height of water in a 90 degrees V-notch set in the outlet stream. The figures obtained may be slightly too low owing to loss by lateral seepage under the impounding earth walls of the pools.

The flow varies somewhat from time to time and the figures quoted below are the maxima and minima of the normal range.

RATE OF FLOW OF BRINE FROM PRINCIPAL SPRING VENTS, MANYEGHI

Vent No. 1	3,140	to	3,580 gallons per hour
Vents Nos. 3 and 4* ...	10,700†	to	11,700 gallons per hour
Vents Nos. 7 and 8* ...	8,175	to	8,745 gallons per hour
Vent No. 9	3,250	to	3,930 gallons per hour
Borehole G.S. 10	3,275	to	3,335 gallons per hour
Borehole G.S. 11	2,900	to	3,275 gallons per hour
Borehole G.S. 12	2,730	to	2,860 gallons per hour

*Combined flow for both vents. †Flow from spring when Boreholes G.S. 10, 11 and 12 all flowing free.

The physical characteristics of the other major vents made it impossible to install V-notches but it is estimated that they flow at from 2,000 to 5,000 gallons per hour each.

The total volume of brine being emitted from the known points of emission at Manyeghi is estimated at about 50,000 gallons per hour.

(b) Measurement of Gas Flow

The gas was collected by displacement of brine in a two-foot-square perspex box graduated in fractions of a cubic foot. Each vent was pegged out into two-foot squares and each square where there was any observable flow of gas was measured a sufficient number of times to ensure a reasonable average figure (three to five times in the case of those squares where the gas flow was relatively large), each measurement being of the gas evolved during a 30-minute period. The average rates of emission for each individual position were then summed to obtain the total flow from each vent.

In the case of the deeper boreholes no visible bubbles of gas issued with the brine, which gushed out under pressure from the top of the casing. Gas only appeared when the brine was led through a hose into a large pond and allowed to flow gently away; under these conditions the water in the pond became clouded with innumerable minute gas bubbles which caused a sparkling as they escaped from the water surface. The gas emission over the whole surface of the pond was determined by a large number of individual measurements with the perspex box as described above, and the figure obtained, plus a correction to compensate for the small amount of gas which may still have escaped after the brine had left the tank, is believed to be a fair estimate of the available gas associated with the borehole brine flows.

The gas-flows from the major vents range between 11 and 24 cubic feet per hour and the deeper boreholes yielded about 8 cubic feet per hour. The estimated total flow of gas from known points of emission at Manyeghi is about 130 cubic feet per hour, representing about 7 cubic feet of helium per hour.

(c) Composition of the Brines

All known points of brine emission, active and dying, were sampled and the samples were analysed in the Geological Survey Laboratories.

The Manyeghi waters have a composition unlike that of the majority of thermal waters from other areas. Their characteristic feature is the presence of the three anions chloride, bicarbonate and sulphate, all in considerable amounts. The relative proportions vary considerably, but a typical average sample would contain chloride, bicarbonate and sulphate in the ratio 700:500:350. The pH of the brines varies from 7·5 to 9·5, i.e., slightly alkaline. The metallic ions consist almost entirely of sodium, with only very small amounts of potassium, magnesium and calcium. Total dissolved solids make up between 2,000 and 3,000 parts per million.

The other helium-bearing springs in the locality, e.g., Mponde and Takwa, emit waters of a somewhat different composition, where chloride is much more the predominant anion and the relative abundance of the subordinate anions is reversed, sulphate being greater than bicarbonate.

The general composition of the brines from the various vents at Manyeghi is sufficiently similar to indicate that all are supplied from the same system of uprising mineralized waters, and the slight differences in composition are probably a relatively near-surface effect brought about by variations in temperature, pressure and degree of dilution dependent on the permeability of the feeder channels, and by differences in reactivity of the wall rocks. The fissures in the strongly-fractured, near-surface zone are probably filled with static or slowly-dispersing brine which has percolated laterally from the main channel-ways and cooled off. The main uprising flow of brine may thus be contaminated to a varying extent with cooler, near-surface brine which could, by virtue of the different physico-chemical conditions, be of a somewhat different composition from the main flow. In this way, differences in temperature and composition at the different vents could be produced.

The composition of the brines from the three deeper boreholes differs considerably, particularly in the Cl/SO_4 ratio, although all three draw from fissures not far removed in space. These holes obviously tap fissures in the heterogeneous zone of mixing, which accounts for the fact that the temperature at this depth (150 feet or less) was not significantly higher than that at surface. A borehole which intersected the main channel-way of uprising brine below this zone of mixing would most probably show much higher temperatures.

(d) Composition of the Gases

Analyses of gases from ten different points of emission at Manyeghi are reported below. Figures are given as percentage by volume.

Vent	He	N_2	A	H_2S	CO_2	CH_4	O_2	H_2
1*	5·2	91·6	1·2	0·5	1·3	0·2	Nil	Nil
2*	5·4	90·0	1·2	0·6	1·8	0·4	0·3	0·3
3*	5·1	91·4	1·4	0·2	1·3	0·2	0·4	—
3†	5·5	90·3	1·5	0·2	1·4	—	0·1	0·8
8†	5·1	92·2	1·5	Nil	1·0	0·2	Nil	0·02
9†	5·5	92·3	1·5	Nil	0·5	0·2	Nil	0·04
G.S. 10†	6·7	89·3	1·6	0·1	1·4	—	0·01	0·7
G.S. 11†	6·7	90·2	1·6	0·02	1·2	—	0·01	0·01
G.S. 12†	5·2	92·1	1·6	Nil	0·9	0·2	Nil	0·03
O.V. 3†	4·4	93·0	1·6	Nil	0·8	0·2	Nil	0·02
O.V. 6†	5·4	92·4	1·5	Nil	0·6	0·01	Nil	0·1

*Analyses: December, 1957; Government Chemist, London.

†Analyses: September, 1958 and January, 1959; Atomic Energy Research Establishment, Harwell.

It will be seen from the above analyses that the composition of the gas varies very little. Nitrogen always makes up about 90 per cent. of the gas, helium composes a little over half the remainder and argon and carbon dioxide together contribute about another 3 per cent. The remaining 1 per cent. or so is divided up amongst hydrogen sulphide, hydrogen, oxygen and methane in differing proportions.

A close similarity in composition is found in helium-nitrogen natural gases from springs in other parts of Tanganyika. Where the helium content is higher (up to nearly 18 per cent. in some cases) the nitrogen content drops proportionally, the content of the other constituents almost always being in the same order as in the Manyeghi gases. In a few gases of this type the carbon dioxide content is as much as 3 or 4 per cent. and in such cases the helium content is lower in proportion. Argon content seems to show little variation with changing helium content.

Measurements of isotopic ratios in the gases from the hot springs in the Maji Moto area of Musoma District show that the nitrogen possesses a ratio identical to that of atmospheric nitrogen but that the argon has a ratio very different from atmospheric argon. This implies that the nitrogen in the gas is probably atmospheric but that much of the argon may be radiogenic or original. No such measurements have been made on the Manyeghi gases, but the close similarity in environment and general composition of the gases from the two areas makes it likely that the same thing is true.

At Manyeghi, gas from Vent 3 contained 5·5 per cent. helium and 90·3 per cent. nitrogen, whilst gas from borehole G.S. 10, from an inflow of brine at about 130 feet below surface, contained 6·7 per cent. helium and 89·3 per cent. nitrogen.* It thus seems likely that the nitrogen in the gases is of atmospheric origin and that it decreases in depth, probably to the extent that, if gas could be tapped from great depth (below the point where it is picked up by the circulating waters) it would contain virtually no nitrogen.

The relative proportions of nitrogen and helium in the gases from different vents are remarkably constant. The most likely explanation of this is that meteoric waters circulate to depth carrying a fixed proportion of nitrogen and oxygen from dissolved air. That part of the water following fissures which extend to the greatest depths meets an uprising mixture of super-heated magmatic steam, alkali halides, helium, carbon dioxide, hydrogen sulphide and possibly other gases, and returns to surface as heated saline water carrying nitrogen and helium; the oxygen in the circulating waters will be used up in oxidising hydrogen sulphide to sulphate and in various reactions with wall-rocks. Variations in the relative proportions of helium and nitrogen will probably be fairly small in the zone of circulating ground-water, being caused merely by dilution of the deepest, helium-carrying water with less deeply circulating water containing nitrogen only.

(c) Relationship Between the Gas and Brine

The helium-bearing gas typically appears with brine in the spring vents. It is considered unlikely that significant volumes of gas are being evolved in places other than the spring vents, although a gentle emission of gas over large areas of the swamp could easily be taking place unnoticed. Gas rising from a deep source through crystalline rocks must travel up some sort of fissure system, and, in all probability, any fissure system which is capable of channelling a flow of gas will, in this area of circulating thermal waters, already be utilized by a flow of brine. Thus the gas will normally follow the same path as the brine right up to its point of issue at the spring vents.

At depths greater than about 50 feet below surface the association of gas and brine is thought to be fundamental, the gas being transported *in solution* in the brine.

The flow of brine from the deeper boreholes (G.S. 10, 11 and 12) contained no visible bubbles of gas; gas only appeared when the brine was allowed to come into equilibrium with the atmosphere by relatively slow outflow from a reservoir, indicating that the gas was in solution in the brine under conditions of increased pressure at the points of inflow to the boreholes (between 80 and 280 feet below surface) and that the escape of gas in response to the reduced pressure at surface requires some time to take complete effect. By contrast, the gas in the spring vents rises from the sand as definite, well-formed bubbles because the brine, percolating slowly upwards by devious paths in the near-surface zone, has time to adjust itself to the lowered pressure and a separation of gas starts to occur some distance (probably 50 feet or so) below surface. The small flows of brine from boreholes G.S. 11, 14 and 15 entered the holes mainly at depths of less than 50 feet and the gas associated with them rose up the holes as definite, small bubbles.

Measurement of gas and brine flow from Vents 3 and 4 and boreholes G.S. 10 and 11 gave a similar figure in all three cases for the volume of gas emitted per unit volume of brine, (about 0·015). These were the first points of emission to be measured accurately and it was expected that the same constant gas/brine relationship would be found to apply at the other main vents. This, however, was not so. In the case of Vent 1 and Vents 7 and 8, the gas/brine ratio was almost twice as much, while Vent 9 gave an intermediate figure.

A probable explanation of these differences is that a part of the main upward flow of brine from depth may be diverted laterally away from the main channel through side fissures, especially in the broken, weathered zone very near surface. Gas which bubbles off from

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*At Maji Moto, Musoma District, gas from the natural spring vent contained 13·2 per cent. helium and 86·3 per cent. nitrogen, while gas entering the borehole at not greater than 400 feet below surface contained 17·5 per cent. helium and 78·0 per cent. nitrogen.

the brine in response to lowered pressure in the near surface zone, being of low density, will tend to rise vertically and appear in the actual spring vents along with only a part of the brine which had held it in solution, the remainder of the gas-depleted brine flowing away laterally below surface to appear at a lower topographic level out in the swamp. This process is exemplified by Vent 9, where laterally-diverted gas-poor brine appears in Vents 9c, 9d, 9e and 9f out in the swamp, several hundred feet to the west of the main point of emission of gas in Vent 9 itself.

VII. Rock Alteration and Weathering Associated with the Springs

(a) Alteration in Hard Bedrock

Microscopic study of thin sections of Manyeghi rocks indicates that almost all the rocks of the area have suffered some degree of alteration. The degree of alteration is perhaps rather greater in the case of rocks known to be more or less intimately associated with the uprising hot brines, although the type of alteration does not seem particularly distinctive.

The brines, as they appear at surface, have a particularly low K/Na ratio (about 1:100). If, as seems likely, the alkalis are supplied from a deep magmatic source in which the K/Na ratio is higher, the paucity of potassium in the brines at surface is probably the result of fixation of potassium in the rocks traversed by the uprising brines. This could be effected by such processes as sericitization of soda-feldspar, though fixation of potash in certain clay minerals is probably more important.

(b) Green Bentonitic Clay

A very characteristic feature of the rocks near Vents 3 and 4 is a green clay found in fissures in both weathered and undecomposed bedrock.

The clay is a soft, wax-like material, blue-green when wet, grey-green when dry. On drying it develops symmetrical shrinkage cracks and finally curls up into flaky crusts. It absorbs a very large volume of water to form a thixotropic gel and is certainly one of the montmorillonite group of clays.

This clay was encountered commonly in the boreholes, both as fragments, up to an inch or more across, brought up in the water flush and apparently derived from banded or layered masses filling large fissures, and also as adherent coatings, often mixed with sand and rock fragments, in many small joint fissures, especially fairly near the surface. The same green clay occurs in fissures in the zone of deeply rotted bedrock to the east of Vents 3 and 4.

Neither in the drill core nor in the pits does the green clay appear to be confined to any particular rock type and it would seem that the clay has been brought in by circulating waters and deposited on the walls of the fissures, rather than having been formed *in situ* by alteration of the wall-rocks.

The origin of the clay is not known with certainty. It is unlikely to have been derived from the normal quartz-feldspar migmatite, but may have been formed by the decomposition under alkaline conditions of biotite-rich rocks or basic dykes at a depth where the brine is at higher temperatures than at surface, and carried in suspension in the uprising waters as minute, probably colloidal, particles.

(c) Rock Weathering at Surface

The 91 pits dug in the region of the spring vents gave interesting information as to the depth and nature of weathering in the area.

Three main types of weathered ground occur:—

(i) Grey or brown, sandy clay without coarse rock fragments. This is redeposited material and is characteristic of the fairly shallow pits on the sand flats along the edge of the swamp.

(ii) Grey, yellow or red, sandy clay, full of more or less rotted fragments of assorted rock types. This heterogeneous type of weathered mantle can be considered normal for the area.

(iii) Completely decayed bed-rock retaining the textural character of the rock from which it was derived, i.e., a decomposition *in situ.*

This third type of weathered ground, which seems to be more or less confined to the area east of Vents 3 and 4, may possibly be produced where the rocks have been extensively broken and exposed to processes of hydrothermal alteration, thus rendering them particularly susceptible to deep weathering from the surface. The presence of fissures filled with the green bentonitic clay may indicate that the rocks have at some time been affected by flows of brine.

(d) Weathered Rock below the Spring Vents

The diamond-drilling at Vents 3 and 4 provided useful information about the depth and nature of weathering in the immediate area of that group of springs.

Weathered rock was found down to 50 feet below surface on the north-east side of the spring and to 85 feet on the south-west side. The biotite gneiss is the most easily weathered rock type, the migmatitic granite is less so and the coarse-grained pegmatite is the most resistant. Thus, in boreholes close to the spring, patches of unweathered pegmatite were found only about 15 feet from surface, whereas the first appearance of coherent, fresh, biotite gneiss more or less marks the lower limit of weathered rock.

Further interesting information was provided when a 4-inch diameter open pipe was driven 18 feet into the bed of Vent 3 by water-jetting. The material brought up consisted of angular, flat-sided fragments of quartz-feldspar migmatite, often up to a couple of inches across, and much green clay. This seems to indicate that the spring vent is underlain near the surface by a breccia zone (partly of tectonic origin and partly broken up by intense weathering), up through which the brine percolates by a tortuous path, following those fissures which are the least clogged with green clay.

VIII. VARIATIONS IN PHYSICAL CONDITIONS AT THE SPRING VENTS

(a) Day-to-Day Variations

Daily measurements of brine flow, brine temperature, radio-activity, air temperature (wet and dry) and barometric pressure were made at each of the main spring vents over a period of about four and a half months. The three deeper boreholes, G.S. 10, 11 and 12, all flowed free for about six weeks and daily measurements of brine flow, temperature and pressure were made on them during this period.

Brine temperature and rate of flow vary from day to day, more erratically and over a wider range in some springs than others. Changes in air temperature, humidity and barometric pressure appear to have no consistent effect on these variations.

Erratic changes in temperature are presumably due either to a non-constant supply of hot brine to the vents, or to variations in the relative proportions of cool surface water and deeper hot brine. It is significant that the most erratic figures were obtained in the most feebly active vents, where the channel ways are obviously thoroughly choked and likely to favour an inconstant rate of supply of brine. It might be expected that vents closely adjacent on the ground, such as 3 and 4; 5a and 5b; 6 and 6a, would show similar rises and falls of temperature, but this was found not to be so.

Changes in the rate of flow of brine occurred in the main vents at about the same time, although the smaller fluctuations may be merely the result of observational error in reading the V-notch. A main period of erratic changes in flow affected all the vents during May and early June.

There appears to be no seasonal change in the rate of flow from the springs. Apart from minor fluctuations, the V-notch readings remained the same throughout the dry season of 1958 and continued thus through the rainy season months of January and February 1959. The body of ground-water supplying the springs would appear to be a very large one and is possibly subject to considerable recirculation.

(b) Diurnal Variations

The data discussed below were obtained during a 48-hour session at Vents 3 and 4. Measurements were made every 30 minutes of gas flow, brine flow, brine temperature, radio-activity, air temperature (wet and dry) and barometric pressure.

The figures for the rate of flow of gas were obtained with the gas box kept in a constant position over an area of active gas emission in Vent 3. Variations in the gas flow in this one position can probably be taken as a fair indication of the shape and magnitude of variations in the total gas emission from the spring. The flow varied continuously between [illegible] and 3½ cubic feet per hour with no particular period of high or low readings.

The temperature of the brine in Vent 3 showed extremes of 94 and 98 degrees F. There were continuous fluctuations of a degree or so and certain periods of altered average temperature could be distinguished. In general, brine temperatures seemed to be slightly higher during the day than at night.

Brine temperature in Vent 4 ranged between 90 and 96 degrees F., but most of the time was very constant at 92 degrees F. A sudden anomalous rise of 4 degrees during the period 12.30 p.m. to 4.00 p.m. on the second day seems to be real as it occurred also at Vent 3 and in the temperature of the outlet stream. It presumably indicates a period of inflow of hotter brine, though it should be noted that no increase in the rates of flow of gas or brine seemed to occur with it.

The fact that both Vents 3 and 4 showed this sudden increase in temperature seems to imply a close connection between them. They are less than 100 feet apart at the surface yet the brine emitted from them is at quite different average temperatures (97 and 92 degrees F.); this is thought to indicate that, at depth, the two vents draw from the same uprising flow of brine but that, nearer surface, the channels divide and one branch suffers greater cooling than the other, either through following a less direct path or through greater admixture with cold, near-surface waters.

The rate of flow of brine remained quite constant throughout the 48-hour period of measurements.

Changes in air temperature, humidity and barometric pressure seemed to have no definite effect on the behaviour of the springs.

IX. GENESIS OF THE GAS AND BRINE

In the following paragraphs certain suggestions are made as to the fundamental aspects of the supply of gas and hot brine to the springs. Some of these ideas are well supported by the evidence obtained in the investigations, while others are suggested merely as likely possibilities.

(a) Location and Mechanism of the Springs

Manyeghi Springs are located on a zone of fracturing (probably an antithetic fault system) to the east of a major rift fault. Spring vents occur at various points in this zone over a strike length of more than a mile and a half.

There seems little doubt that the zone of presumed antithetic faulting provides the main locus of uprising thermal waters. The actual spring vents may be located at points of excessive fracturing in this zone, perhaps at points of intersection with other zones of weakness, their positions in detail probably being influenced by local variations in permeability in the surface material.

The localization of the springs within a small section of the antithetic fault zone is considered to be an indication of the existence in the Manyeghi area of especially well developed and deeply-extending fissure systems which make connection with a source of heat and magmatic emanations at depth.

Gherardi (1958) has explained the occurrence of the springs on the antithetic fault zone rather than at the base of the main rift scarp by the fact that the main rift fault is now a zone of compression and will consist mainly of tight fractures, whereas the antithetic fault zone is a region of tension and, hence, of open fissures and brecciation, which provides a convenient channel-way for the passage of large flows of water.

(b) Source of the Spring Water

The large volume of water emitted from the springs and its comparatively low temperature and concentration of dissolved solids are indications that the water is mainly of meteoric origin.

The springs are thought to be of artesian type, the main source of the circulating water being precipitation on the high ground of the main rift scarp and further to the west. Water percolates downward through fissured ground associated with the rift faulting and is also introduced into fissures below the clays in the floor of the rift valley through alluvial fans at the base of the scarp. The ground-water moves through the joints and fissures below the impermeable clays, partly penetrating to considerable depths, and, on entering the easily permeable, antithetic fault zone, rises through open fissures to find outlet at the springs. It emerges under a hydrostatic head resulting from the difference in height between the water-table in the fault scarp area and the ground at the springs. The effect of heat and addition of gas to the circulating water at depth may also aid in causing it to issue under pressure.

A very small proportion of the spring water is probably derived from the magmatic emanations by the condensation of superheated steam.

(c) Source of Heat

The heat supplied to the Manyeghi hot springs is considered most likely to be of volcanic (magmatic) origin.

Some of the reasons for this supposition are as follows:

(a) Recent volcanic rocks appear at the surface not very far away (at Hanang, 65 miles to the north-east) and in the same rift-faulting association. Hot springs, some of which emit helium-bearing gas, occur in probable genetic association with such recent volcanicity in a number of places, e.g., Golai, Lake Balangida (James, 1953).

(b) A high-temperature volatile phase given off from a body of magma, besides being a likely source of heat, constitutes at the same time a convenient explanation of the source of the dissolved material in the hot waters.

(c) The presence of a plug of magma pushing its way upwards along the deep extension of the rift fault below the general area of Manyeghi provides a partial explanation of the localization of the springs in that area.

(d) Source of the Dissolved Salts

High-density magmatic steam carrying alkali halides in solution, along with carbon dioxide, hydrogen sulphide and other minor constituents, is considered by White (1957) to be the original material which gives rise, by mixing with circulating meteoric water and undergoing various pressure and temperature changes and reactions with wall-rocks, to the various types of warm mineral waters found in hot springs of volcanic origin.

At Manyeghi such uprising high-temperature magmatic emanations probably first come into contact with deeply circulating ground-water somewhere near the junction of the antithetic and main rift-fault systems (at a depth estimated to be in the order of 5,000 feet below surface). The ground-water becomes heated and charged with dissolved material and rises through the open fissures of the antithetic fault system to emerge at the spring vents.

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The waters described by White often contain relatively high proportions of silica, boron and lithium, and he considers that these constitute criteria for the volcanic origin of the waters. In the Manyeghi waters these constituents are all very scarce and the K/Na ratio is exceptionally low, but this may well be due to the special character of the source magma. The volcanic rocks of the Central Rift Valley are essentially an under-saturated, soda-rich, alkaline group (phonolites, nephelinites and, exceptionally, carbonatites) which would be expected to give off a silica-poor volatile phase. Insufficient analytical data are available to say what sort of boron and lithium content would be expected in emanations from such a magma, but a fairly low K/Na ratio might be expected.

(e) Source of the Helium-Bearing Gas

It has been suggested in an earlier section of this report that the essential non-reactive constituents of the gas at great depth may be helium and argon only, and that the nitrogen which makes up the bulk of the gas at surface is atmospheric nitrogen from air dissolved in the circulating meteoric waters.

The helium and argon are most probably original trace constituents of the high-pressure, high-temperature magmatic emanations. The main gaseous constituents of the emanations, probably carbon dioxide and hydrogen sulphide, will dissolve in the cold ground-water and give rise to various chemical reactions, whilst the superheated steam will condense and become part of the uprising stream of heated ground-water. The inert gases helium and argon alone will remain unchanged.

Helium is known in volcanic (fumarole) gases from various parts of the world, but usually occurs only in small proportions, seldom exceeding 0·01 per cent. of the dry constituents.

The quantity of helium being emitted in the gas from the Manyeghi spring vents appears to be large, but a simple calculation will show that it is by no means exceptional. The total volume of brine being emitted at Manyeghi is roughly 50,000 gallons per hour, containing about 350 p.p.m. SO_4 and 500 p.p.m. HCO_3. If these constituents are considered to be derived entirely from H_2S and CO_2 in the magmatic emanations, then it can be calculated that the total weight of H_2S and CO_2 being supplied per hour (ignoring any recirculation) is more than 100,000 grams. The total flow of helium from the springs is not more than 7 cubic feet per hour, or about 35 grams; thus helium can have composed only about 0·0035 per cent. of the dry gases in the magmatic emanations.

Normally gaseous emanations from depth, helium-bearing or otherwise, become dissipated on their journey upwards and the unreactive constituents are lost unnoticed from a large area of the earth's surface. The unusual feature at Manyeghi is not that an excessive amount of helium is contained in the source gases, but the fortuitous way in which the helium has entered a system of circulating waters and been transported upwards to a localized point of issue at surface.

Many volcanic gases contain virtually no helium and it is probably the nature of the source magma which determines whether or not helium is present. Helium is the end-product of various processes of radio-active decay taking place throughout the earth's crust and is continuously being given off into the atmosphere in very small quantities. Magmatic emanations relatively enriched in helium may well be derived, therefore, from magmas which are particularly rich in radio-active constituents. The Central Rift Valley volcanic province is typified by anomalous radio-activity, present in primary form in carbonatite bodies and their associated pyroclastics, and in a number of secondary or unexplained forms such as surface-coatings, phosphate rocks, strontianite, etc. Thus the idea that Manyeghi is underlain by a sub-outcropping magma unusually rich in radio-active constituents is not entirely without foundation.

X. CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER WORK

It is estimated that the total amount of helium being given off naturally from the spring vents at Manyeghi is about 7 cubic feet per hour, or almost 68,000 cubic feet per year. The helium is believed to be transported from depth in solution in the spring waters and it is unlikely that significant quantities of helium are being given off anywhere other than from the spring vents.

By building simple collecting domes over the seven main vents a continuous gentle flow of helium-bearing gas containing about 5 cubic feet of helium per hour could be obtained; with 100 per cent. separation this would yield 43,000 cubic feet of helium per year. When installation and running costs of an extraction plant and the cost of transportation of cylinders of helium to U.K. are considered, this natural output is clearly quite uneconomic. It is estimated that the flow would have to be increased at least one hundredfold to make the prospect anything like an economic proposition.

In view of the apparent absence of any reservoir structure, the rate at which helium is being given off from the spring vents must be the same rate at which helium is being supplied to the system from its deep magmatic source. It is thus highly unlikely that there is any way of artificially increasing the output of helium, and almost certain that this cannot be done by near-surface work. The shallow drill-holes produced a small amount of helium, but only as much as was contained in solution in the brine which flowed from them. If more than a relatively small number of such holes were drilled to tap the brine supply below the springs, the flow from the springs themselves must begin to fall off and the total yield of helium would not be increased significantly above the present figure.

The possibilities suggested for the source of heat and gases in the springs and the mechanism by which they reach the surface are largely hypothetical. The only possible way in which these ideas can be confirmed or disproved is to drill a large-diameter, deep borehole into a zone several thousand feet below surface, where conditions of temperature, pressure and chemical state can be expected to be markedly different from surface.

It has been suggested that the rate of supply of helium from the source is slowed down by the back-pressure resulting from the path of escape of the gas being, not a simple open channel, but a system of narrow, imperfectly connected fissures which permit only a limited rate of flow of fluids. If the main stream of uprising emanations could be intersected by a large-diameter borehole, the free path so provided would remove the restraint which had previously been operating on the system and might cause an accelerated evolution of magmatic emanations; thus, although the necessary borehole would be very expensive and the chances are, in fact, against it paying for itself in terms of helium it would certainly provide invaluable information as to the mechanism of Manyeghi and other hot spring systems; moreover, until such a hole is drilled, Manyeghi can never be definitely written off as a potential source of helium.

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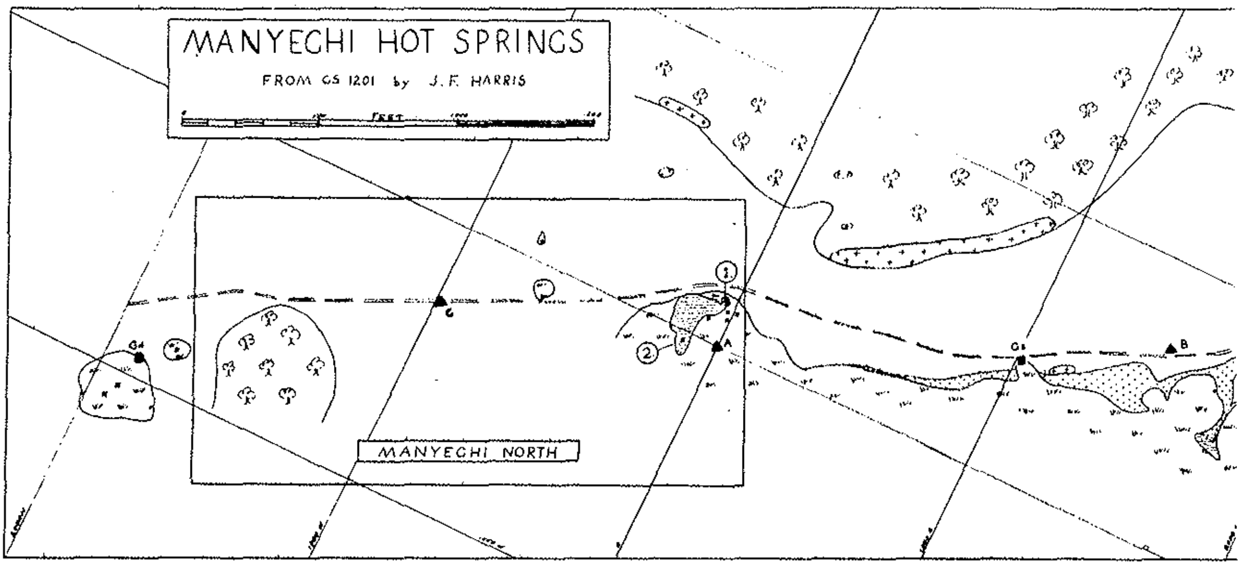

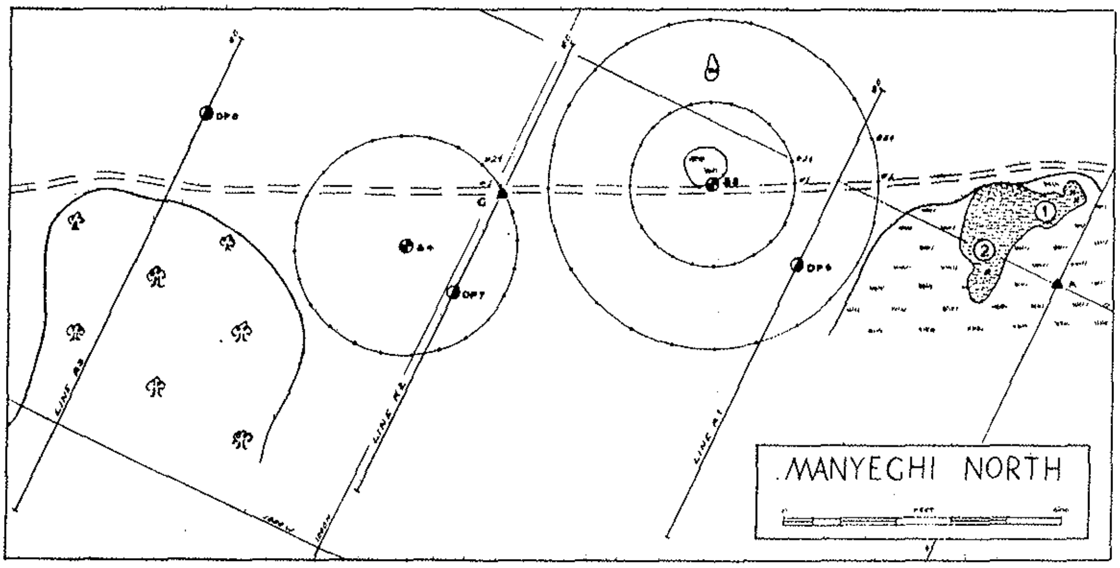

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	OUTCROP (MAINLY GRANITIC)		TRACK
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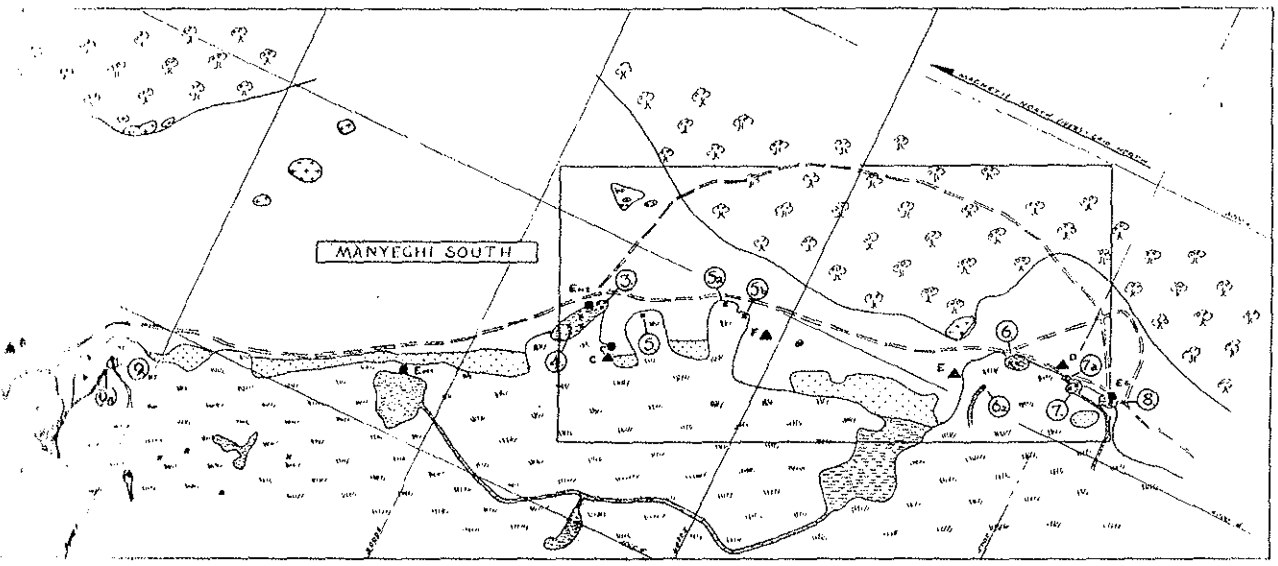

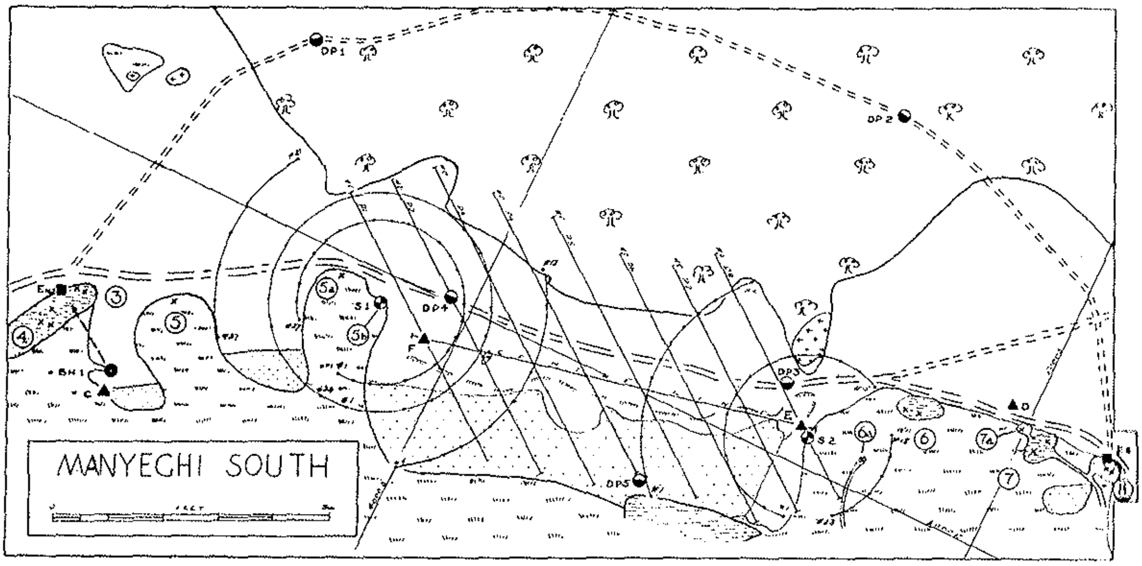

L INVESTIGATIONS
AT
GHI HOT SPRINGS

A. J. KING

GEOPHYSICAL TRAVERSES

RESISTIVITY – ALL LINES
MAGNETIC [illegible]
[illegible]

ELECTRO-MAGNETIC SURVEY
(ENSLIN [illegible] METHOD)

● S1 E-M. CENTRE ELECTRODE

■ E• DISTANT EARTH for EMAEPL

◒ DP RESISTIVITY DEPTH PROBE
DIAMETER SHOWS DIRECTION OF [illegible]

● SITE for BOREHOLE No 1
(ARROWS DIRECTION OF [illegible])

Geological Survey Department, Dodoma, 1958
Printed by Ministry of Lands & Surveys Dar es Salaam

GEOPHYSICS

16. GEOPHYSICAL INVESTIGATIONS AT MANYEGHI HOT SPRINGS

By A. J. KING, *Geologist-Geophysicist*

ABSTRACT

A short account is given of the preliminary geophysical surveys carried out at Manyeghi in Singida District. The objective was to investigate the possibility of using geophysical methods to obtain information regarding the structural control locating the helium-bearing springs. No directly useful information was forthcoming and the causes of the failure of the investigation, which lie in the abnormal nature of the superficial deposits, are discussed.

It is concluded that the problem is not susceptible of geophysical treatment by any means and that reliance must be placed on exploratory drilling.

I. INTRODUCTION

Since the first description of the helium-bearing springs at Manyeghi by T. C. James in December, 1957, more detailed examination by J. F. Harris has shown that little useful information regarding the mode of occurrence can be obtained from the surface geology. It was hoped that geophysical investigation might produce some indication of the structures controlling the location of the springs and to this end a preliminary survey was carried out by the writer in April and May, 1958.

In his initial assessment of the problem, the writer considered that it is not one that would lend itself to satisfactory treatment by geophysical methods in view of the close proximity of the suspected structural feature to the swamp and the probable saline condition of the surface material. This proved to be the case and the operations were abandoned after the preliminary programme had been completed.

II. THE PROBLEM

At Manyeghi the active brine and gas vents are distributed along the eastern margin of a swamp over a distance of about 6,000 feet. They occupy a belt about 500 feet wide, running approximately 20 degrees west of north, in which some dozen major and numerous minor foci of emission are located. A number of extinct vents and weak seepages lie beyond the northern (higher) end of the swamp but none are known at its southern end. A general plan (Plate XVIII) of the area (based on the topographic survey by J. F. Harris) and of the lay-out of geophysical operations, accompanies this report.

The extent of the swamp and the isolated extinct vents are marked by "ndagu" reeds which are typical of this type of spring. Natural areas of open water are not common (the ponds surrounding Vents Nos. 1 and 2, 3 and 4 and 7 and 8 are artificial) but, in general, the reeds grow in very thin, watery mud over most of the swamp. Although most of the major points of emission have been located it is evident that seepages and gas-vents are distributed over the whole length of the swamp at least on its eastern margin.

Local patches of sand border the swamp and where these have narrow selvedges of sand and short grass they are separated from the normal, coarse grass by a distinct erosion line. The belt of coarse grass varies from 200 feet to 1,000 feet in width and extends to the limit of thick bush which, where natural, marks a slight increase in slope.

Outcrops are few and consist of a number of varieties of granite and granitic gneiss, ranging from fine-grained to porphyroblastic, with numerous aplitic and pegmatitic veins. An outcrop of relatively undisturbed, although strongly veined, granitic gneiss occurs right on the edge of the swamp (400 feet north-west of Location Beacon B).

The quasi-linear distribution of the known vents certainly suggests that they rise along a dislocation. It is reasonable to suppose that the dislocation, if it exists, would take one of three forms:—

(a) a narrow fracture zone following the main trend of vents, the departures from a linear form being caused by transverse faults,

(b) a similar narrow feature, departure from linearity being due to selective solution along (probably basic) bands in the bedrock, or,

(c) a broad, virtually linear belt of shattering, more or less embracing all the main vents.

The main problem at Manyeghi is, therefore, firstly to prove the existence of a major dislocation and then to determine its nature and attitude and that of any transverse features displacing it. Only when this information is available would it be possible to site production boreholes with any reasonable chance of obtaining an economic gas yield.

The amount of gas delivered at the observable vents is well below that required for economic development. The widespread occurrence of gas trapped in the reeds, however, suggests that only a portion of the total supply can be measured. The best chance of obtaining an economic quantity of gas is to tap the total flow where, and if, it is localized at depth. It may be assumed that the main supply would rise along a major dislocation, if such exists, and would be preferentially located near transverse features. Accurate knowledge of these structures would, therefore, greatly reduce, but not entirely eliminate, the degree of uncertainty with which the course could be predicted. The depth from which a concentrated flow might be expected has been variously estimated at anything from 1,000 to 10,000 feet; the need for accurate information regarding the controlling structure will thus be appreciated.

There are three possible ways of obtaining this data: from the surface geology, from geophysical evidence and from exploratory drilling. There is no direct geological evidence for the existence of a major dislocation and, as will be shown in the succeeding sections of this paper, geophysical methods are inapplicable, so that reliance had finally to be placed on exploratory drilling.

III. THE GEOPHYSICAL APPROACH

The three possible forms which the controlling structure could take require investigation by different geophysical techniques:—

(a) Narrow fracture, transverse faults:—
Electromagnetic, (?) P.D.R.* and (?) Resistivity profiling;

(b) Narrow fracture, basic bands:—
Electromagnetic, (?) P.D.R. and Magnetic;

(c) Wide fracture:—
Resistivity profiling and P.D.R.

The detection and investigation of vertical or near-vertical features is a recurrent but particularly difficult geophysical problem. Where the feature is wide compared with the depth of burial (case (c) above) it can usually be considered as a pair of opposing vertical interfaces and where there is a sufficient physical contract between the feature and the country rock, it can usually be treated satisfactorily. Where, as is the case with most fractures, the feature is relatively narrow, even an extreme physical contrast is difficult to detect.

Two techniques have, however, proved of value in dealing with narrow features which possess a fairly strong resistivity contrast with respect to the country rock. Enslin (19[illegible]) describes a method embodying measurement of the horizontal component of the magnetic field set up by an alternating current applied to the ground through a point electrode situated

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*Potential-drop Ratio method in one or other of its forms.

near the feature, the return earth being at a considerable distance. When observations are made on concentric circles about the electrode, the undisturbed magnetic field would be uniform. A low-resistivity zone lying within the excited area causes a concentration of current flow in the zone and this is revealed by peaks in the field profile.

Measurements of the distortion of the potential distribution due to a point electrode along a line perpendicular to the suspected feature have been shown by Sumi (1956) to be susceptible of accurate quantitative treatment. Reliable determinations of the dip, depth to top and vertical extent have been made on very narrow features by this method, but only under ideal conditions.

The use of magnetic surveys to delineate lithological variations which might control the location of springs needs no amplification here except to note that if narrow bands are to be resolved, the magnetic susceptibility of the "normal" bedrock must be uniform.

It was decided that the Enslin technique should be used in the preliminary examination of the Manyeghi area to determine whether a narrow fracture zone is present. If positive results were obtained, Sumi's method would then be applied in order to obtain, if possible, more precise information about the nature of the structure. If the Enslin technique did not indicate a narrow zone, resistivity and P.D.R. profiles were to be observed in an attempt to locate at least one margin of the wide shattered belt, should this be the appropriate structure. Only if the presence of a major dislocation were established was the possibility of transverse features to be investigated, the method to be used being determined by the earlier results.

The chief difficulty in geophysical operations at Manyeghi is the lack of adequate working space. The distribution of the observable vents suggests that the controlling structure lies very close to the edge of the swamp over much of its length and it is thus difficult to make observations on both sides of the inferred structure. Furthermore, since all the main geophysical methods appropriate to the problem involve the measurement of electrical properties, interference was expected from the saline nature of the superficial deposits.

As the initial approach at Manyeghi, it was decided to attempt to trace a conducting zone between two of the main vents. For this purpose, a section between Vents Nos. 5b and 6a, where a small embayment in the swamp affords some space on the western side of the line joining the vents, was chosen. This was termed the Manyeghi South area. Should the investigation here fail for any of the reasons stated above, a second area, Manyeghi North, was chosen lying beyond the northern extremity of the swamp between Vents Nos. 1 and 2 and the extinct vents further north-west. Here more working space is available and the effect of saline ground conditions might be less. Investigation here, of course, only concerned possible extensions of the controlling structure but there is no reason to suppose that it is truncated at the northern end of the swamp.

IV. GEOPHYSICAL RESULTS, MANYEGHI SOUTH

It will be seen in the accompanying plan that it was possible to complete only one full circle of electromagnetic observations ($r = 200$ feet on S. 1). On the partial circles, which were observed first, it was found that the H_T-curve* descends from each end of the arc observed to form a broad minimum about a point roughly opposite the line joining the centre to the distant earth. On the complete circle and on those at Manyeghi North, this was confirmed when it was seen that two broad minima occurred, separated by peaks at the overlapped portions of the curve. That this was not a statistical effect was proved by recomputation on several bases and the form of the curve was shown to be unrelated to the actual position of the return cable. *A posteriori*, therefore, this effect must, in some way, be due to the change in current distribution when the position of the distant earth is moved. In other words, the current flow outward from the centre electrode, instead of being radial, is almost entirely concentrated in a path directly back to the distant earth. This might

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*This is Enslin's term for the profile round the circle of relative values of the horizontal component of the tangential magnetic field.

happen if the two electrodes were connected by an extremely good conductor which does not extend beyond the centre. In this case, however, one peak would be present when the second distant earth were used. If the conductor extends beyond the centre two peaks would be present because, even though much of the current would return along the direct path, some would be concentrated in the portion of the conductor remote from the distant earth. In this case the broad minima would be present but would have peaks imposed on them in the appropriate positions.

The observed field distribution would, however, be produced if the immediate surface material were of extremely low resistivity compared with the deeper rock. Current flow from the centre electrode would then be radial only for a distance roughly equal to the thickness of the surface layer and would then be sharply distorted back towards the distant earth in both the horizontal and vertical dimensions. This tendency would, of course, be accentuated by the "skin effect" which would be appreciable at 1000 c.p.s. in conditions of low surface resistivity. The electromagnetic field distribution under such conditions would be independent of any less extreme, deeper resistivity changes and a narrow conducting zone would probably remain undetected.

The remaining work at Manyeghi South was performed with a view to obtaining corroborative evidence for the above conclusion and to determine whether any of the other available methods were applicable.

A series of resistivity profiles at constant electrode separation of 25 feet were observed at an angle of about 50 degrees to the suspected line of fracturing. All these showed a marked decrease in resistivity from north-east to south-west, values at the north-east end being between 2,000 and 5,000 ohm-cm. dropping to less than 500 ohm-cm. near the swamp. The greatest range was found on Line P-6 where the resistivity dropped from more than 5,000 to less than 200 ohm-cm.

The contact between high and low resistivity zones is not clearly defined, the decrease taking place in a series of steps. Particular events in each profile could, however, be correlated and their traces in plan are irregular and roughly follow the contour lines. One line was re-observed at a separation of 50 feet, producing a profile not substantially different from the shallower observations. Values were somewhat higher than those for 25 feet at the north-eastern end but only slightly higher nearer the swamp. This indicates that the normal working rule of penetration equals separation is probably not followed and that the resistivity decrease marks the increase in salinity of the superficial deposits. It should be noted that values of 200 ohms-cm. are extremely low and almost certainly result from saturation of the deposits by highly saline solutions.

It is probable that the resistivity decrease also indicates a bevel in the bedrock surface which may or may not have a structural significance. It is obvious, however, from its form in plan and in the variations of resistivity in profile, that it has been modified by weathering.

Potential-drop Ratio profiles over the same series of traverses using point electrodes at Em and Es were observed. Anomalies of the type associated with vertical interfaces were located on all the profiles, but these were found to coincide closely with the positions of the main resistivity contrast. It was thus demonstrated that the potential distribution is entirely controlled by the disposition of surface resistivities.

Resistivity depth-probes were observed to 100 feet at the positions shown on the plan. Conditions are such, however, that interpretation in terms of depths is only approximate. Nos. 1 and 2, which are probably on "normal" ground, show that weathered bedrock is within about 10 feet of the surface. Nos. 3 and 4 are situated at intermediate positions on the resistivity profiles and both show an interface, at between 25 and 30 feet, which probably marks the base of a zone of mixed weathered rock and saline deposits. All four depth-probes show a fairly sharp interface between 75 and 80 feet which is interpreted as being the top of partially unweathered bedrock.

An attempt was made to observe a depth-probe on the sand-flats near the swamp, but low contact resistances and high natural potentials precluded accurate measurements. The results obtained suggest that at a separation of 100 feet the resistivity is still less than 400 ohm-cm. Under such conditions, however, penetration must have been very much less than 100 feet even though direct current was used to avoid "skin effect".

Magnetic observations were made over four of the resistivity traverse lines and the central line. The variation of intensity is small (maximum range about 100 gamma) and so distributed as to indicate that it arises from the slight differences of depth to bedrock. The anomalies, however, are too small to be of diagnostic value in locating accurately the position of the bedrock bevel. No magnetic indication of the presence of basic rocks in the bedrock was seen.

V. Geophysical Results Manyeghi North

In view of the disappointing results obtained at the southern area, attention was turned to the section north of the swamp where there is more working space and where, it was hoped, ground conditions might be less saline. Here it was possible to lay out complete circles for the electromagnetic survey, but the profiles obtained were identical to those at Manyeghi South. The complete HT-curves available made it possible to study the statistical aspects of the results exhaustively and the conclusions reached at Manyeghi South were confirmed.

The HT-curves indicate that, notwithstanding the apparently drier ground conditions, the surface layers possess as low a resistivity as those to the south. Three resistivity profiles were measured to confirm this, an electrode separation of 50 feet being used since a greater thickness of superficial deposits might be expected. Except at the eastern end of Line R-1, all the values measured lay below 400 ohm-cm. and, at one point on Line R-3, even dropped below 200 ohm-cm. The profiles are uniform and show nothing that could be construed as being due to a fractured zone.

The three depth-probes measured at Manyeghi North are interesting in that they are all substantially different despite their close proximity to each other. D.P. No. 6 is more or less normal, the apparent resistivity at $a = 10$ feet being 225 ohm-cm., dropping slightly as the water table is reached at about 17 feet and then rising steadily to a value of 485 ohm-cm. at $a = 100$ feet. Interfaces were detected at 34 feet (base of surface deposits) and 72 and 90 feet (transitions to unweathered bedrock). The surface values at D.P. No. 7 were extremely high, 1,325 ohm-cm. being recorded at $a = 10$ feet, dropping rapidly to below 300 ohm-cm. at the water-table which is at about 22 feet. In the saturated ground the resistivity rises only slightly to 325 ohm-cm. at 100 feet, a weak interface at 90 feet showing transition to bedrock. Surface values are again high in D.P. No. 8, 1,530 ohm-cm. being recorded at $a =$ 10 feet. These high values decrease slowly with depth indicating a poorly defined water table, the main change occurring at 34 feet. Between 50 and 80 feet the apparent resistivity is about 300 ohm-cm., but at 82 feet there is a sharp discontinuity and a sudden rise to just over 400 ohm-cm.

The conclusion drawn from these depth-probes is that, although conditions in the northern area are variable, in general a dry crust overlies ground which is saturated with saline waters to considerable depth. Superficial deposits are probably of the order of 25 feet thick and are underlain by a considerable thickness of eluvial material and decomposed bedrock. The deep interfaces detected in the depth-probes probably only represent stages in the transition to unweathered bedrock which probably lies at a greater depth than 100 feet.

The variations in magnetic field, which were observed along the three traverses, are even smaller than at Manyeghi South, the maximum range being only 70 gamma. There is no indication in the magnetic profiles of any deepening of bedrock in the suspected position of the fracture zone, nor any sign of important lithological variations.

The investigation at Manyeghi North served only to confirm the conclusions reached at the southern area and to suggest that the springs may have migrated southward leaving behind a few extinct or dying vents.

VI. CONCLUSIONS

The preliminary geophysical work at Manyeghi has shown conclusively that the problem is not one that can be resolved by such methods. The reason for this is to be found in the abnormally low surface resistivities which prevent any effective penetration of either direct or alternating current. Unfortunately the nature of the problem is such that all the appropriate geophysical methods involve electrical parameter.

The geophysical work has led to a few conclusions which may be of value. It has been shown, in the southern part of the area at any rate, that the surface of bedrock forms a bevel close to the swamp where the superficial cover increases in thickness from a few feet to about 25 or 30 feet. The results in the northern part suggest that the depth to weathered bedrock, even under the main portion of the swamp, may not exceed this figure significantly. This is in conformity with experience at similar swamps at Maji Moto in Musoma District and others in North Mara District*.

It seems probable that the swamp has migrated southwards to some extent; a conclusion which is in agreement with the observed distribution of old vents.

The fact that the geophysical surveys have failed to reveal any indication of a major structure controlling the location of the springs cannot be inferred to mean that no such structure exists. The quasi-linear distribution of foci of emission strongly suggests that the gas and brine reach the surface along a planar feature, probably a major fracture zone which it has not been possible to detect geophysically. The magnetic results, however, have not revealed any major transcurrent basic bands or dykes such as would locate vents preferentially along the trace of the major structure. In fact, the writer is of the opinion that there is no need to suppose that there is any such lateral control. It is believed that the gas and brine may rise at random anywhere along the whole length of that part of the structure at present covered by swamp and that the detailed distribution of vents at the surface is determined by local conditions in the superficial deposits.

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*Descriptions of these occurrences are contained in unpublished reports by T. C. James, the present writer and members of the staff of the Dodoma office of the United Kingdom Atomic Energy Authority.

Degree Square	Lc
52	Msan
54 SE. & 64 NE.	Ruvu
55	Wam Ba
71	Kihu Iga

APPENDIX A

LIMESTONE ANALYSES DONE IN 1958

Degree Square	Locality	Sample No.	Composition						Type and Age	G.S.D. File No.
			Acid insoluble	R_2O_3	CaO	MgO	Loss on ignition	Total		
			%	%	%	%	%	%		
52	Msanga	—	18·6	1·0	39·3	4·1	35·4	98·5	Superficial: Neogene	X/6076
64 SE. & 64 NE.	Ruvu Syncline	AW.170	17·1	0·4	26·3	17·3	38·4	99·5	Crystalline: Usagaran	X/6182
		AW.171	57·7	0·5	14·2	7·1	18·2	97·7		X/6176
		AW.172	36·1	0·4	21·1	12·6	29·4	99·6		X/6182
		AW.173	2·8	0·4	31·1	18·3	45·1	97·7		X/6176
		AW.174	18·9	0·7	26·5	16·6	37·1	99·8		X/6182
		AW.175	40·6	0·2	19·6	12·1	27·1	99·6		X/6182
		AW.176	4·9	0·2	28·8	19·4	44·8	98·1		X/6176
		AW.177	16·5	0·6	25·6	17·0	39·0	98·7		X/6176
		AW.178	12·1	0·3	28·5	17·8	40·5	99·2		X/6182
		AW.179	19·7	0·6	25·1	16·1	37·0	98 6		X/6176
		AW.180	4·9	0·2	30·6	19·9	44·3	99·9		X/6182
		AW.181	4·6	0·3	29·4	19·2	44·8	98·3		X/6176
		AW.182	0·3	0·2	30·6	20·0	46·9	98·0		X/6176
		AW.183	0·4	0·3	30·4	20·0	47·2	98·3		X/6176
		AW.184	1·6	0·3	31·4	19·7	46·0	99·0		X/6182
		AW.185	14·9	0·4	26·9	17·1	39·8	99·1		X/6182
		AW.186	7·2	0·4	29·2	18·7	45·0	100·5		X/6182
		AW.187	6·8	0·3	27·6	20·1	44·0	98·8		X/6182
		AW.188	2·0	0·3	29·4	20·9	46·8	99·4		X/6182
		AW.189	14·7	0·7	25·3	17·6	39·1	97·4		X/6176
		AW.190	0·6	0·3	30·7	20·4	45·9	97·9		X/6182
		AW.191	3·3	0·6	30·7	18·6	44·3	97·6		X/6176
		AW.192	16·0	0·4	26·6	18·7	36·8	98·5		X/6182
		AW.193	5·9	0·3	30·4	18·7	44·0	99·3		X/6176
65	Wami River, Bagamoyo.	J.25	4·6	0·7	31·2	20·2	42·2	98·9	Crystalline: Ubendian	X/6241
		J.53	2·8	0·6	30·7	19·5	46·0	99·6		
		J.54(1)	34·5	1·2	19·3	20·2	23·6	98·8		
		J.54(2)	36·3	0·9	15·7	21·3	25·4	99·6		
		J.54(3)	16·9	0·7	31·4	15·2	34·8	99·0		
		J.55	33·7	0·8	16·6	24·1	24·2	99·4		
		J.58	21·6	2·7	24·5	21·1	29·7	99·6		
		J.59	2·9	0·8	44·6	7·8	43·6	99·7		
		J.60	0·6	0·2	19·8	29·1	48·4	98·1		
		J.61	14·8	0·7	30·5	18·7	34·8	99·5		
		J.76	7·3	1·0	27·8	18·5	43·5	98·1		
		J.77	19·8	1·3	26·4	14·2	37·5	99·2		
		J.78	15·5	1·7	33·3	10·5	37·5	98·5		
71	Kihumbi, Igawa.	Y.538	0·6	0·3	31·3	21·1	46·0	99·3	Crystalline: Ubendian	X/6045
		Y.542	5·1	0·5	31·5	18·6	43·4	99·1		
		Y.548	0·6	0·4	54·9	1·5	42·4	99·8		
		Y.552	1·5	0·3	33·6	18·7	45·0	99·1		
		Y.558	0·8	0·4	46·4	7·0	43·4	98·0		
		Y.560	6·2	0·2	31·7	17·9	43·7	99·7		
		Y.562	2·3	0·2	33·6	18·5	45·0	99·6		
		Y.568	3·9	0·5	32·6	18·4	44·5	99·9		
		Y.572	11·3	0·5	34·6	15·8	37·1	99·3		
		Y.578	12·4	0·1	39·3	12·3	35·5	99·6		
		Y.582	7·9	0·5	35·5	15·2	40·8	99·9		
		Y.588	3·3	0·3	33·4	17·9	44·5	99·4		

APPENDIX B

COMPLETE ANALYSES OF ROCKS CARRIED OUT IN 1958

During the year 38 silicate analyses of rocks were carried out, all by W. H. Herdsman, Esq., Chemical and Metallurgical Laboratories, 141, Bath Street, Glasgow. In the following tables the analyses are arranged in nine groups:—

I. *Granulites and Charnockites*—10 analyses of granulites and charnockites from Uluguru and Songea.

II. *Metamorphic Rocks—Various*—5 analyses of metamorphic rocks, 2 analyses of acid gneisses, one of an amphibolite, one of a phyllonite and one of a metasomatic albitite.

III. *Metamorphosed Igneous Rocks*—3 analyses of meta-anorthositic and metagabbroic rocks.

IV. *Basic Igneous Rocks—Kapalagulu*—4 analyses of the various members of the Kapalagulu Basic Complex.

V. *Bukoban Eruptive Province—Dolerites*—6 analyses of dolerites from the Bukoban Eruptive Province, all from the Ukinga and Ubena chiefdoms.

VI. *Bukoban Eruptive Province—Gabbroic Rocks*—5 analyses of rocks from the Nkenza Gabbroic Eruptive (3 anorthosites from Phase I and 2 gabbros from Phase II).

VII. *Sediments—Bukoban*—An analysis of a greywacke from the Buanji Series.

VIII. *Kimberlitic and Carbonatitic Rocks*—2 analyses of rocks associated with kimberlite and carbonatite intrusions.

IX. *Neogene Volcanics—Rungwe*—2 analyses of olivine basalts from the Rungwe Volcanic Province of south-western Tanganyika.

A. E. WRIGHT

I.—GRANULITES AND CHARNOCKITES

	DNS. 1066	DNS. 1089	DNS. 1568	DNS. 1050	DNS. 1488	DNS. 1572	DNS. 1497	J. 419	J. 712	[illegible]
SiO_2...	59·72	55·03	59·01	60·97	74·99	58·85	59·72	59·62	51·91	[illegible]
TiO_2	1·04	0·58	1·16	0·77	0·28	1·06	0·78	1·08	0·88	[illegible]
Al_2O_3	16·42	18·56	16·10	17·69	13·59	14·65	17·43	22·23	25·94	[illegible]
Fe_2O_3	1·91	1·62	2·14	1·58	0·16	4·33	1·69	1·43	5·26	[illegible]
FeO...	5·06	5·34	5·31	4·06	2·31	3·17	4·76	8·19	6·18	[illegible]
MnO	0·06	0·14	0·11	0·05	0·05	0·08	0·08	0·16	0·16	[illegible]
MgO	3·04	5·03	2·84	2·55	0·54	4·27	3·17	3·13	3·16	[illegible]
CaO...	7·08	8·41	6·02	6·39	2·13	3·56	6·91	0·73	0·92	[illegible]
Na_2O	3·88	3·83	3·58	4·11	4·08	2·26	3·81	0·59	1·09	[illegible]
K_2O...	1·12	0·87	3·06	1·23	1·35	2·48	1·19	2·39	4·07	[illegible]
H_2O+	0·59	0·39	0·29	0·38	0·41	3·02	0·39	0·27	0·19	[illegible]
$H_2O—$	Nil	0·10	Nil	0·11	Nil	0·55	Nil	0·19	0·23	[illegible]
CO_2	Nil	Nil	Traces	Traces	Traces	Traces	Nil	0·08	0·05	[illegible]
P_2O_5	0·17	Traces	0·41	0·18	0·05	0·08	Traces	0·01	0·02	[illegible]
C	–	–	–	–	–	1·75	–	–		
S	0·08	0·08	0·13	0·08	–	–	0·06	–		
	100·17	99·98	100·16	100·15			99·99			
Less O for S ...	0·02	0·02	0·03	0·02			0·02			
Totals ...	100·15	99·96	100·13	100·13	99·94	100·11	99·97	100·10	100·06	[illegible]
S.G. ...	2·81	2·91	2·85	2·80	2·74	2·72	2·80	2·82	2·69	[illegible]

DNS. 1066. Biotite-hornblende granulite. 3 miles S. of Mkololo, Mbakana Valley, Uluguru, Morogoro District, Quarter Degree Square 64 NE. Collected by D. N. Sampson, 28/7/55. Analysed by W. H. Herdsman, 26/6/58.

DNS. 1089. Pyroxene granulite. 2 miles NW. of Bwakira Juu, Uluguru, Morogoro District, Q.D.S. 64 NE. Collected by D. N. Sampson, 4/8/55. Analysed by W. H. Herdsman, 26/6/58.

DNS. 1568. Melanocratic pyroxene granulite. Kihunza, Uluguru, Morogoro District, Q.D.S. 64 NE. Collected by D. N. Sampson, 17/8/57. Analysed by W. H. Herdsman, 26/6/58.

DNS. 1050. Banded garnet-pyroxene granulite. 5 miles N. of Kisaki, Uluguru, Morogoro District, Q.D.S. 64 NE. Collected by D. N. Sampson, 25/7/55. Analysed by W. H. Herdsman, 26/6/58.

DNS. 1488. Band
District, Q.D.S. 6

DNS. 1572. Garne
Q.D.S. 64 NE. C

DNS. 1497. Garn
Collected by D. N

J. 419. Garnet gra
15/9/49. Analys

J. 712. Migmatise
92 NE. Collecte

J. 426. Intermedia
Collected by T. C

DNS. 1488. Banded pyroxene granulite. Hela on the Matombo-Tawa Road, E. Uluguru, Morogoro District, Q.D.S. 64 NE. Collected by D. N. Sampson, 29/7/57. Analysed by W. H. Herdsman, 11/7/58.

DNS. 1572. Garnet-graphite granulite. Kihunza on upper Mvuha River, E. Uluguru, Morogoro District, Q.D.S. 64 NE. Collected by D. N. Sampson, 18/8/57. Analysed by W. H. Herdsman, 11/7/58.

DNS. 1497. Garnet charnockite. Bwakira Juu, Southern Uluguru, Morogoro District, Q.D.S. 64 NE. Collected by D. N. Sampson, 31/7/57. Analysed by W. H. Herdsman, 26/6/58.

J. 419. Garnet granulite. Ndongosi River, Songea District, Q.D.S. 93 NW. Collected by T. C. James, 15/9/49. Analysed by W. H. Herdsman, 26/6/58.

J. 712. Migmatised sillimanite granulite. 2 miles E. of Chulela Hill, Matengo, Songea District, Q.D.S. 92 NE. Collected by T. C. James, 22/10/49. Analysed by W. H. Herdsman, 26/6/58.

J. 426. Intermediate (granodioritic) charnockite. 2 miles S. of Mtua, Songea District, Q.D.S. 93 SW. Collected by T. C. James, 15/9/49. Analysed by W. H. Herdsman, 26/6/58.

IX.—NEOGENE VOLCANICS—RUNGWE

	DH. 1149	DH. 1196
SiO_2	45·21	44·32
TiO_2	1·58	0·91
Al_2O_3	15·95	17·03
Fe_2O_3	2·74	3·01
FeO	9·29	8·26
MnO	0·31	0·32
MgO	8·37	7·02
CaO	12·39	13·13
Na_2O	2·12	2·51
K_2O	0·45	0·68
H_2O+	0·99	1·89
H_2O-	0·19	0·29
CO_2	Nil	Traces
P_2O_5	0·52	0·72
Totals	100·11	100·09
S.G.	2·78	2·98

DH. 1149. Olivine basalt. Tukuyu-Njugiro road, 6 miles S. of Njugiro, Tukuyu District, Q.D.S. 78 NE. Collected by D. A. Harkin, 26/9/51. Analysed by W. H. Herdsman, 4/4/58.

DH. 1196. Olivine basalt. Kiwiru Valley, just N. of Makete Leper Settlement, Tukuyu District, Q.D.S. 78 NE. Collected by D. A. Harkin, 10/10/51. Analysed by W. H. Herdsman, 4/4/58.

APPENDIX C

Analyses of Natural Gases and Accompanying Spring Waters

During the year nine analyses of natural gases from springs were made by the Government Chemist, London. All of the accompanying waters, with the exception of one, were analysed by W. K. L. Thomas, Chemist; the other water was analysed by A. P. Muley, Assistant Chemist. One gas and accompanying water, I, is from Itebu Spring below the western fault scarp of the Iramba Plateau, Iramba District. All of the other gases and accompanying waters, II to IX, belong to the Mponde River group of springs, Singida District. These springs were the subject of an intensive investigation, including diamond-drilling, to assess their potential as sources of helium. All of the gases are of the nitrogen type containing between 5·1 and 10·2 per cent helium; the argon content, ranging between 1·2 and 1·6 per cent, is also appreciable. The spring waters are all of the mixed sodium sulphate-sodium carbonate type and are remarkable in showing the rapid variation of these components in waters that come from localities very close together.

Examination of these analyses and of analyses reported in previous years (Records, Vol. VI, 1956 and Vol. VII, 1957) suggests that the helium content of the nitrogen gases may be related to the temperature of the juvenile spring waters. It is noticeable that spring waters with a high temperature at the surface invariably contain a high proportion of helium. The converse is not true, but this may be explained by the juvenile spring waters being diluted and cooled very near the surface by a large volume of cold groundwater. In this latter case the helium content of the gases would not be immediately affected.

T. C. James

I. *Itebu Spring, Main vent.*—Nitrogen gas and sodium carbonate water. Sekenke, Singida District, Quarter Degree Square 29 NW. Gas collected by Commander Bicchieri, Kirondatal, 18/1/58. Water collected by E. G. Haldemann, 31/8/59. Gas analysed by Government Chemist, London, 14/5/58 (X/6156). Water analysed by W. K. L. Thomas, 23/9/59 (X/6745).

II. *Manyeghi Springs, Vent No. 1.*—Nitrogen gas and mixed sodium carbonate and sodium sulphate water. Mponde River valley, Singida District, Q.D.S. 41 NW. Gas and water collected by T. C. James, 16/10/57. Gas analysed by Government Chemist, London, 12/12/57 (X/5891). Water analysed by W. K. L. Thomas, 11/57 (X/5891).

III. *Manyeghi Springs, Vent No. 4.*—Nitrogen gas and mixed sodium carbonate and sodium sulphate water. Mponde River valley, Singida District, Q.D.S. 41 NW. Gas and water collected by T. C. James, 16/10/57. Gas analysed by Government Chemist, London, 12/12/57 (X/5891). Water analysed by W. K. L. Thomas, 11/57 (X/5891).

IV. *Manyeghi Springs, Vent No. 3.*—Nitrogen gas and mixed sodium carbonate and sodium sulphate water. Mponde River valley, Singida District, Q.D.S. 41 NW. Gas collected by J. F. Harris, 29/7/58. Water collected by J. F. Harris, 4/9/58. Gas analysed by Government Chemist, London, 4/9/58 (X/6269). Water analysed by W. K. L. Thomas, 11/58 (X/6318).

V. *Manyeghi Springs, Vent No. G.S. 11.*—Nitrogen gas and mixed sodium carbonate and sodium sulphate water. Mponde River valley, Singida District, Q.D.S. 41 NW. Gas collected by J. F. Harris, 29/7/58. Water collected by J. F. Harris, 4/9/58. Gas analysed by Government Chemist, London, 4/9/58 (X/6269). Water analysed by W. K. L. Thomas, 11/58 (X/6318).

VI. *Manyeghi Springs, Vent No. 2.*—Nitrogen gas and mixed sodium carbonate and sodium sulphate water. Mponde River valley, Singida District, Q.D.S. 41 NW. Gas and water collected by T. C. James, 16/10/57. Gas analysed by Government Chemist, London, 12/12/57 (X/5891). Water analysed by W. K. L. Thomas, 11/57 (X/5891).

VII. *Manyeghi Springs, Vent No. G.S. 10.*—Nitrogen gas and mixed sodium carbonate and sodium sulphate water. Mponde River valley, Singida District, Q.D.S. 41 NW. Gas collected by J. F. Harris, 29/7/58. Water collected by J. F. Harris, 28/6/58. Gas analysed by Government Chemist, London, 4/9/58 (X/6269). Water analysed by A. P. Muley, 28/7/58 (X/6226).

VIII. *Takwa Springs.*—Nitrogen gas and mixed sodium carbonate and sodium sulphate water. Mponde River valley, 8 miles SE. of Manyeghi, Singida District, Q.D.S. 41 NW. Gas and water collected by T. C. James, 16/10/57. Gas analysed by Government Chemist, London, 12/12/57 (X/5891). Water analysed by W. K. L. Thomas, 11/57 (X/5891).

IX. *Mponde Springs.*—Nitrogen gas and mixed sodium carbonate and sodium sulphate water. Mponde River valley, 15 miles S. of Manyeghi, Singida District, Q.D.S. 41 SW. Gas and water collected by T. C. James, 16/10/57. Gas analysed by Government Chemist, London, 12/12/57 (X/5891). Water analysed by W. K. L. Thomas, 11/57 (X/5891).

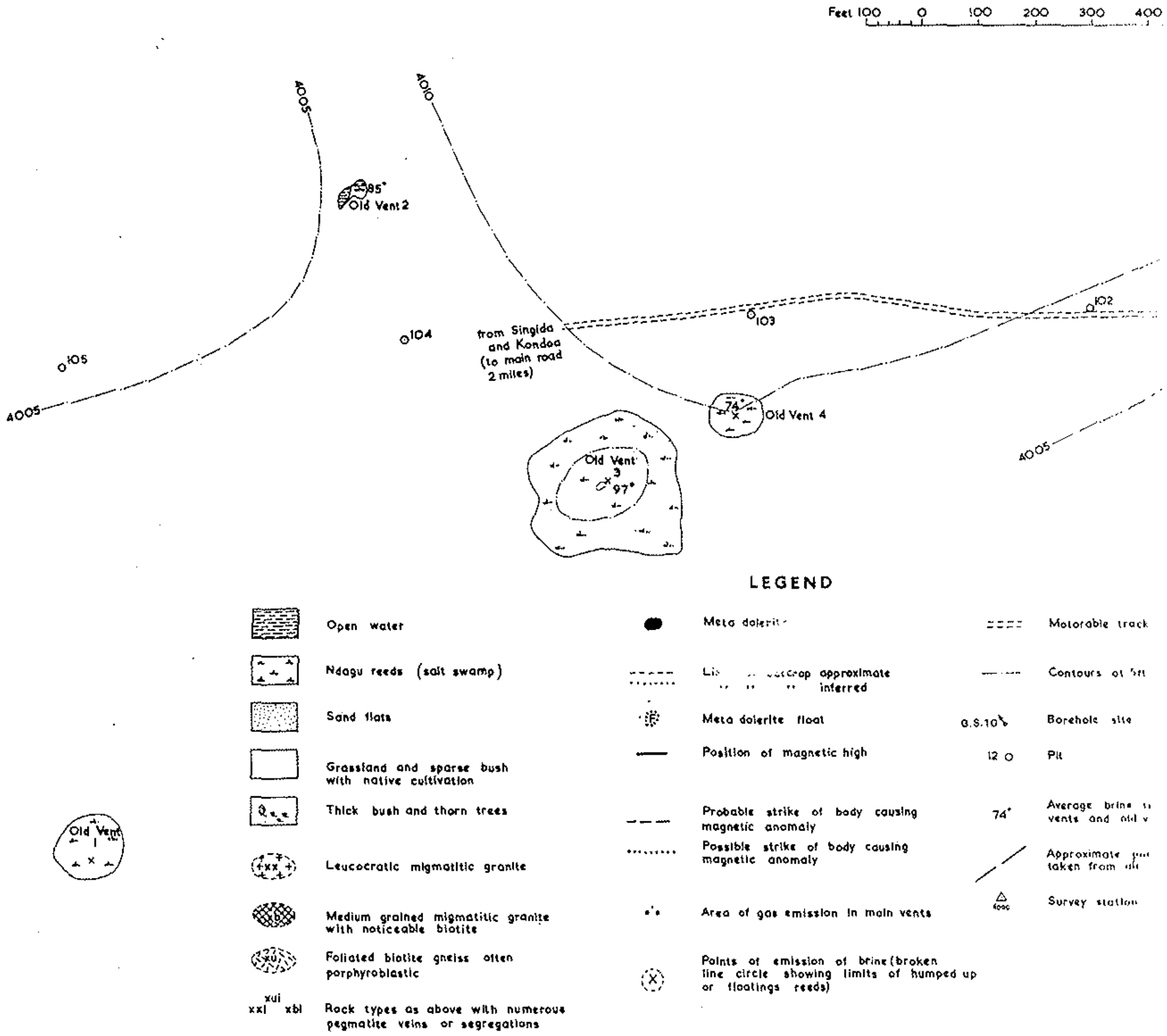
ANALYSES OF GASES AS VOLUME PER CENT AND OF WATERS IN PARTS PER MILLION

	I	II	III	IV	V	VI	VII	VIII	IX
GASES:									
CO_2	4·2	1·3	1·3	1·4	1·2	1·8	1·4	1·6	0·2
H_2S	0·4	0·5	0·2	0·2	0·02	0·6	0·1	0·9	Tr.
CO	0·1					Neg.		Neg.	
O_2	0·4	Neg.	0·4	0·1	0·01	0·3	0·01	0·1	0·2
H_2		Neg.		0·8	0·01	0·3	0·7	0·5	
CH_4, etc.	1·6	0·2	0·2			0·4		1·1	0·4
He	0·74	5·2	5·1	5·5	6·7	5·4	6·7	7·0	10·2
A	1·02	1·2	1·4	1·5	1·6	1·2	1·6	1·3	1·5
N_2	91·6	91·6	91·4	90·3	90·2	90·0	89·3	87·5	87·5
WATERS:									
NaCl	26	1,437	1,556	1,569	1,534	1,442	1,551	1,010	1,189
Na_2CO_3		27	32	130	110	27	42	27	48
$NaHCO_3$	396	810	854	730	750	819	840	277	264
Na_2SO_4	30	592	450	630	930	592	620	649	530
NaF	2	23	27	20	23	30	28	9	24
KCl		19	19	17	19	19	19	15	11
$Ca(HCO_3)_2$	89	53	40	40	40	32	32	88	20
$Mg(HCO_3)_2$	151		18	18	18	18	18	24	
pH	7·5	8·5	8·5			8·5	9·0	8·5	9·5
Temperature	22°C.	*c.*25°C.	33°C.	36°C.	–	*c.*25°C.	–	38°C.	42°C.
Estimated flow of water in gallons per hour	720+	medium	*c.*10,000		*c.*3,000	–	*c.*3,300	–	–
Estimated flow of gas in litres per hour	medium	small	640		200	*c.* 100	240	*c.* 100	*c.* 200

Tr.=Trace.
Neg.=Negligible.

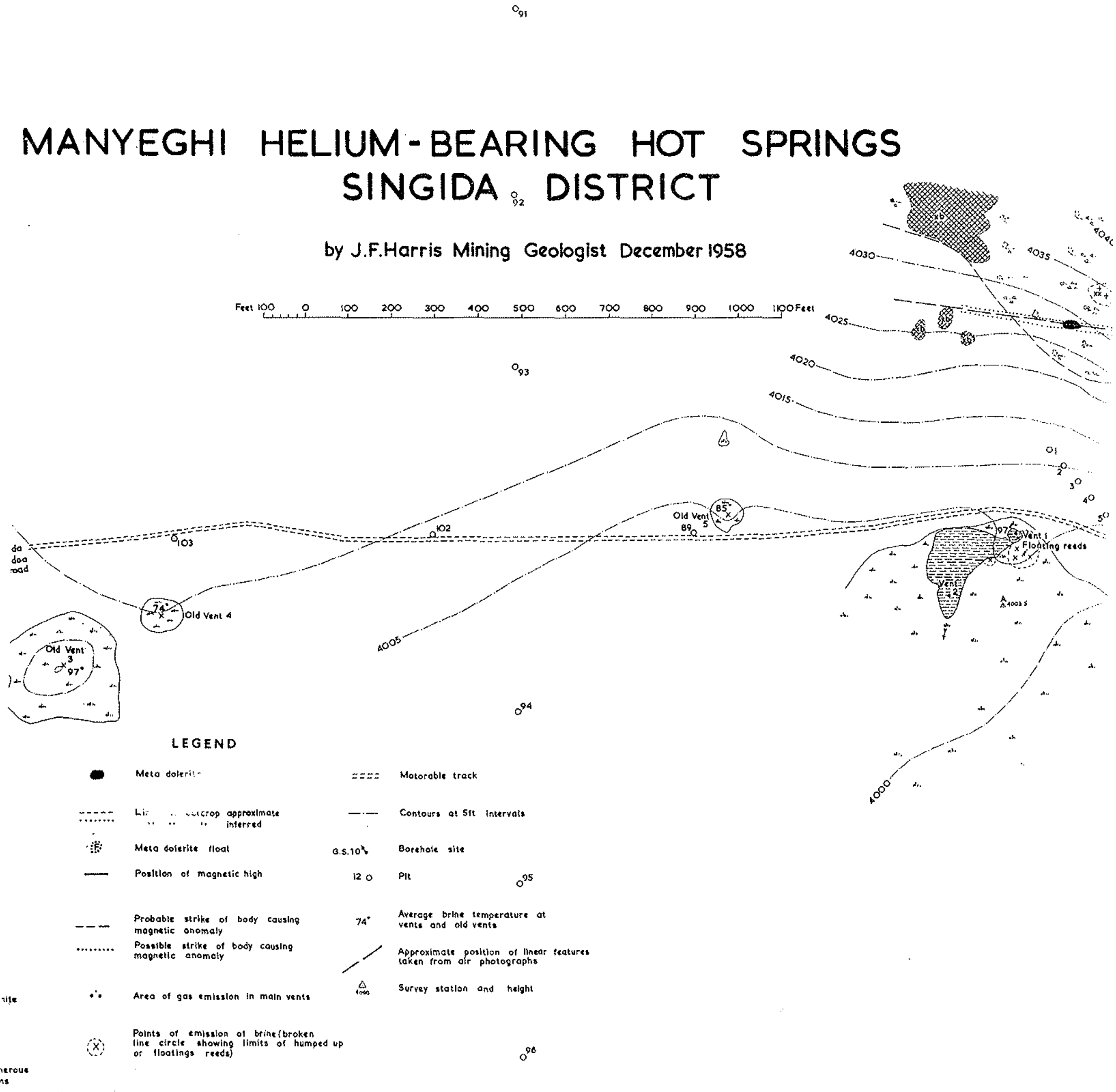
MANYEGHI HELIUM-BEA
SINGIDA

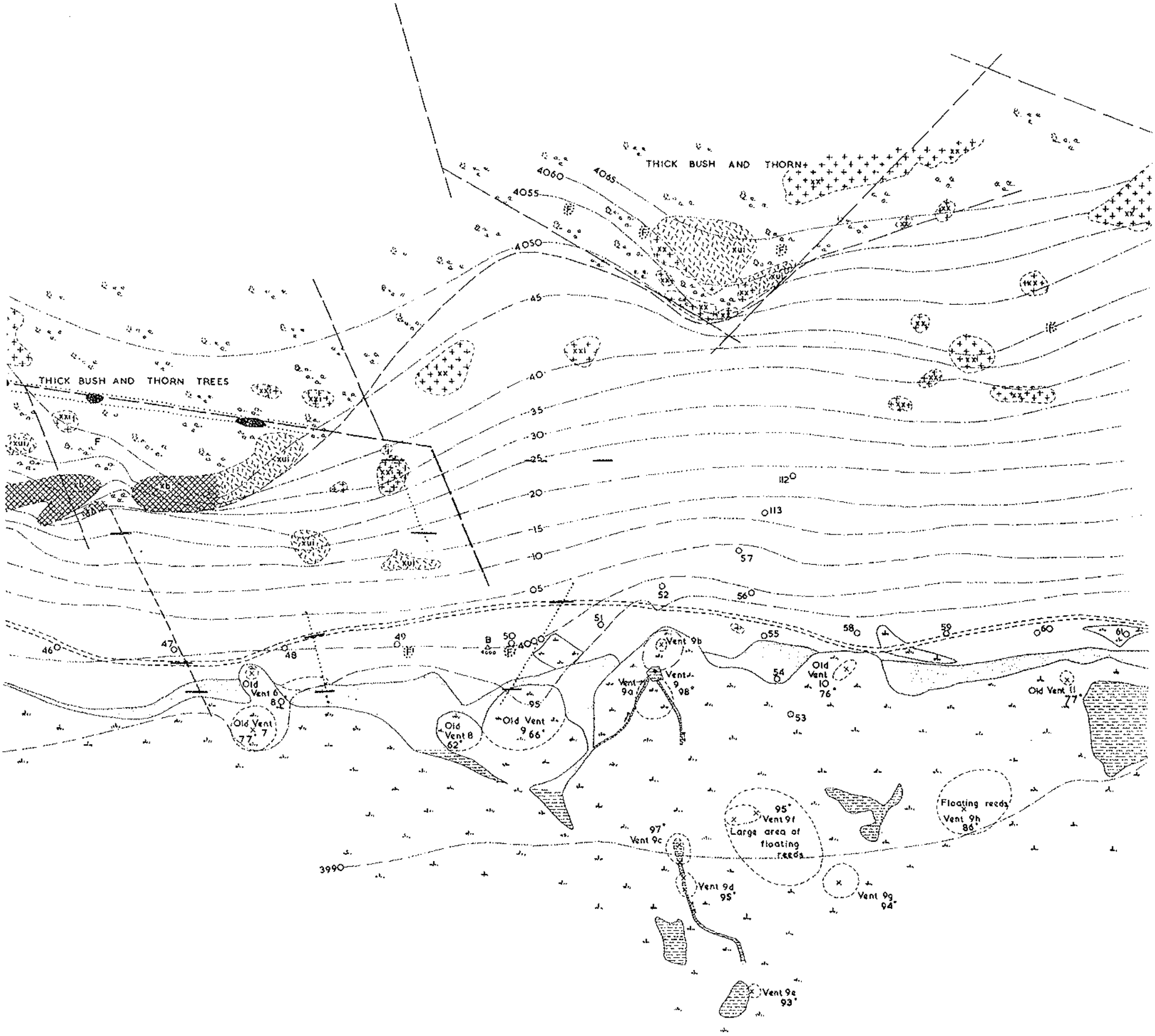
by J.F.Harris Minin

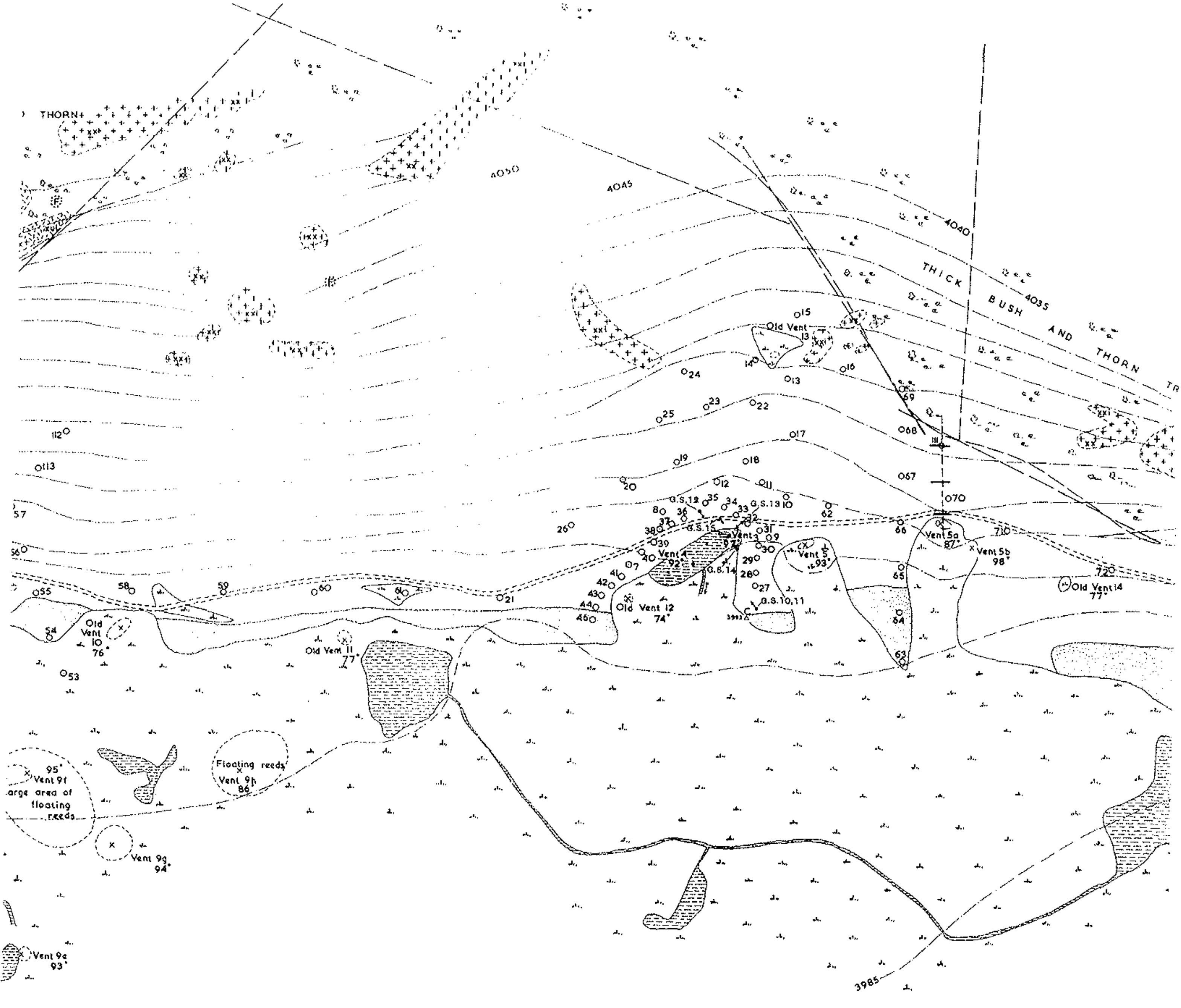


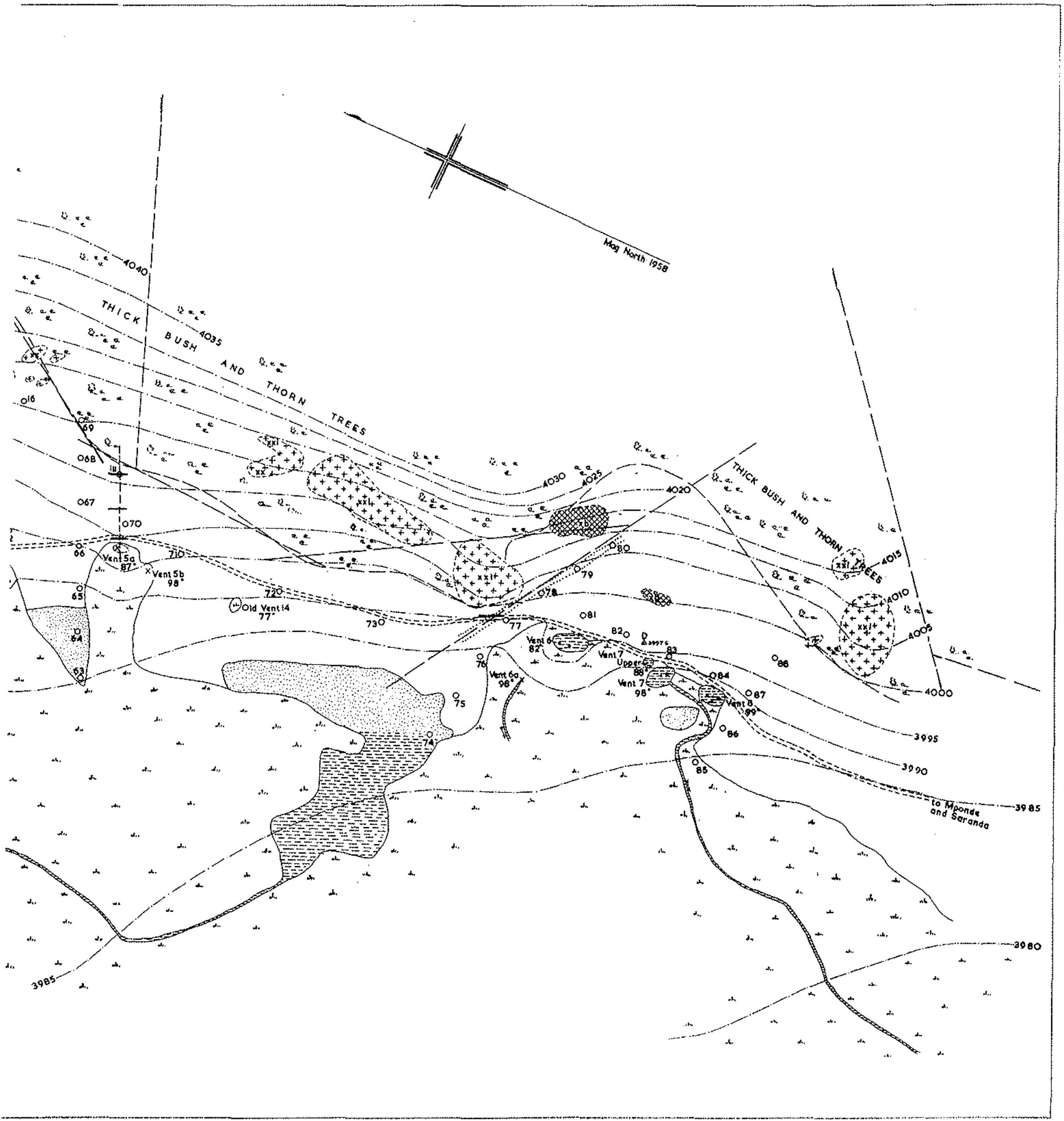
MANYEGHI HELIUM-BEARING HOT SPRINGS
SINGIDA DISTRICT

by J.F.Harris Mining Geologist December 1958




THICK BUSH AND THORN
THICK BUSH AND THORN TREES
4065
4060
4055
4050
45
40
35
30
25
20
15
10
05
4000
3990
xui
xxi
xb
F
B
112
113
57
52
56
51
46
47
48
49
50
55
58
59
60
61
54
53
Old Vent 6
Old Vent 7
77°
Old Vent 8
62°
Old Vent 9
66°
95
Vent 9a
Vent 9
98°
Vent 9b
Old Vent 10
76°
Old Vent 11
77°
95°
Vent 9f
Large area of floating reeds
97°
Vent 9c
Vent 9d
95°
Vent 9g
94°
Floating reeds
Vent 9h
86°
Vent 9e
93°


THORN
4050
4045
4040
4035
THICK BUSH AND THORN TR
Old Vent
15
13
14
16
24
13
69
25
23
22
17
68
19
18
67
20
12
11
10
62
70
112
113
57
56
G.S.12
35
34
33
G.S.13
8
36
37
32
G.S.15
38
26
39
Vent 3
97°
31
9
30
40
Vent 4
92°
7
G.S.14
29
28
27
41
42
43
44
46
Old Vent 12
74°
G.S.10,11
3993
Vent 5
93°
66
Vent 5a
87°
Vent 5b
98°
71
72
Old Vent 14
77°
65
64
63
55
58
59
60
61
21
54
Old Vent 10
76°
Old Vent 11
77°
53
95°
Vent 9f
Large area of floating reeds
Floating reeds
Vent 9h
86°
Vent 9g
94°
Vent 9e
93°
3985



Geological Survey Department, Dedema, 1958.
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