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A RECONNAISSANCE SURVEY OF THE HOT AND MINERALISED SPRINGS OF ZAMBIA

by

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Abstract

This report presents the results of a preliminary study of fifty hot or mineralised springs or groups of springs investigated between 1971 and 1974. Measurements of water temperature, discharge and radioactivity were made, the geological setting briefly studied, and samples of water and chemical deposits collected for analysis. More detailed investigations were made at a few springs of outstanding interest.

The hot springs of Zambia occur mainly on major, probably deep, faults, often at the contacts of Karroo sediments with older rocks. The water compositions and temperatures are compatible in most cases with deep circulation by gravity, convection in fault zones, and leaching by the hot water of the more soluble constituents from wall rocks. A few of the springs are the source of salt, but the concentration and yield of the brines are probably too low to permit commercial salt production, other than on a village scale. None of the springs appears to be of volcanic origin, and detailed studies of two of the hottest spring systems indicates that the potential for geothermal power generation is low. Many of the springs are situated in National Parks and are potential tourist attractions.

Acknowledgments

Acknowledgment is given to Mr. D. Hough, Public Analyst in Lusaka since 1947, who carried out the water analyses; the staff of the Department of Wildlife, Fisheries and National Parks, especially Mr. W.L. Astle, formerly Chief Research Officer (Wildlife), who encouraged the study of hot springs in the National Parks, Mr. C.L. Uys, Chief Pilot, Mr. P.S.M. Berry, formerly Chief Ranger, who indicated the location of many previously unknown springs, and Mr. T. Osborne, biologist at Lochinvar, who provided hospitality and was helpful in many other ways. The hospitality of the Fathers at Rosario Mission, Puta; of Mr. and Mrs W.A. Bruce-Miller, Choma; and of Mr. and Mrs. Kropacek, of the Hippo Mine, is acknowledged with thanks. Dr. K.D. Topfer, Dr. B. Edwards, Dr. I. Cowan and Mr. D. Chapman of the Physics Department of the University of Zambia, co-operated in the study of the Lubungu spring, and have helped with equipment and advice on many other occasions. Messrs. C.J. Hickman, C.D. Kerr, H.R. Ayres, M.C. Barr, P. Reichwalder and B.A. Klinck of the Geological Survey Department collected samples and described hot springs located in the course of regional mapping. Dr. P. Hadwen and Dr. P. Lee, formerly of the Department of Water Affairs, gave valuable information on hot springs and the northern lakes of Zambia. The advice of and analytical facilities provided by Dr. G. Robson of the United Nations Development Programme, New York, are acknowledged. The report was edited by Dr. H.C.T. Brown.

INTRODUCTION

Although there is no evidence of Recent volcanic activity in Zambia, there are numerous hot and mineralised springs, most of them related to relatively young faults affecting Karroo rocks, and some of them related to the rift system of East Africa. The existence of many of the springs has been long known, and some are sources of salt for traditional salt industries.

The purpose of the present study - the first to be made of the springs - was to determine the potential for production on a commercial scale of dissolved salts, particularly sodium chloride; to determine the potential for thermal energy, either for power generation or for other purposes; and to investigate the temperatures, water compositions, mode of occurrence and the variations and similarities between individual and groups of springs.

Previous work

The first published reference to hot springs in Zambia is by Wallace (1899), a hunter and explorer who visited and described the springs along the southern edges of Lakes Mweru Wa Ntipa and Chishi, and also observed the production of salt by villagers. Nkala (Longola) springs are referred to in a letter dated 1903 from the British South Africa Company (BSAC) to the Bechuanaland Exploration Company (*in* Geological Survey Mining Records Office), wherein the BSAC urges preservation of the springs as features of natural interest and potential spas. The first analyses of Zambian spring waters are given by Ferguson (1902) who mentions two springs in the Zambezi Valley, near the old Walker's Drift, and gives a detailed description of the 'Goa Geysers', which can be identified as the hot springs on the farm Muckleneuk, to the north of Choma. He also speculated on the relationships between hot springs and mineral deposits, and considered that the springs might prove to be a valuable future tourist attraction. References to springs are made in various unpublished correspondence and geologists' reports (in the Geological Survey Mining Records Office) and in 1941 Guernsey compiled from this data an unpublished summary description of the springs of the Loangwa Concession areas. He lists thirty-one springs or groups of springs, and briefly describes many of them. Since 1950 some springs have been examined by geologists of the the Geological Survey in the course of regional mapping, and others have been visited by representatives of the Department of Water Affairs or the major mining companies. Some spring waters and associated deposits were analysed, and summaries of these studies are given by Reeve (1963, 1969).

Methods of investigation

The preliminary phase of the work involved the collection of samples of water and of encrustations or efflorescence, which were analysed by the Public Analyst, Lusaka, or at the laboratories of the Geological Survey for as many major and trace elements as possible. The maximum water temperature was measured using a Telemax thermistor unit, which permitted remote measurements to be made in deep pools. The unit was found to be rugged and reliable. The radiation level over the springs and surrounding areas was measured, initially with a simple scintillometer with ratemeter output, and later with a Scintrex GIS-3 gamma-ray spectrometer. Water pH was measured using narrow-range indicator papers, and the spring discharge was estimated by measuring the rate of flow in a channel of measured cross-section, or in some cases over a small V-notch. The geology of the area around each spring was studied briefly, and air-photo interpretation was carried out to determine the geological setting. Following this preliminary study, certain springs were selected for more detailed examination.

Location and access

The locations of the hot and mineralised springs of Zambia are shown in fig. 1. Most of the springs lie in relatively isolated and undeveloped areas, the greatest concentrations being along major faults, particularly at Karroo-basement contacts. Areas affected by such major faulting often form topographic depressions, which experience hot weather and are infested with tsetse fly, and not favoured for human settlement. Many of the springs lie within Zambia's National Parks. Some are accessible by road in the dry season, but others are inaccessible throughout the year. Many of the latter were visited on foot; for access to others in and near the Luangwa Valley national parks a helicopter was provided by the Department of Wildlife, Fisheries and National Parks. Some springs in the Zambezi Valley, which forms the boundary between Zambia and Rhodesia and Mozambique, were not visited. Other springs, reported by Concession geologists forty years ago, could not be re-located, either by detailed traversing on the ground or by examination of air photographs and it is concluded that they may have dried up since they were first reported.

Descriptions of the springs

The springs are described under seven geographical groups:

- The Northern Group
- The Mansa-Copperbelt Group
- The Western Group
- The Eastern Group
- The South-eastern Group
- The Choma Group
- The Lochinvar Group

The locations of the groups are shown in plate I.

Included in the descriptions are tables of water composition and a modified Piper Diagram (*after* Hem 1970) which illustrates graphically the range in water composition within the group.

FIG. 1 Water composition of the springs of the northern group

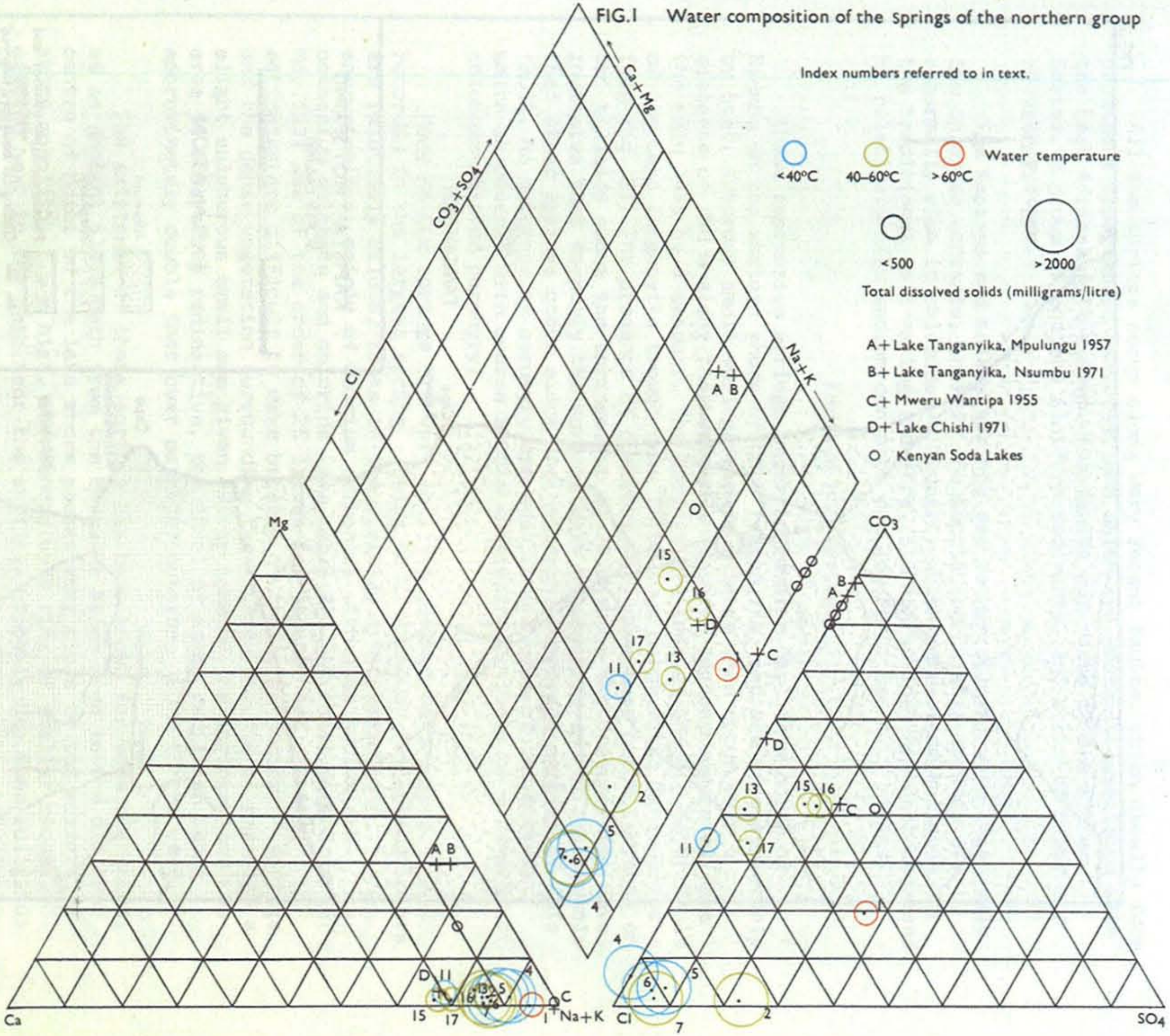
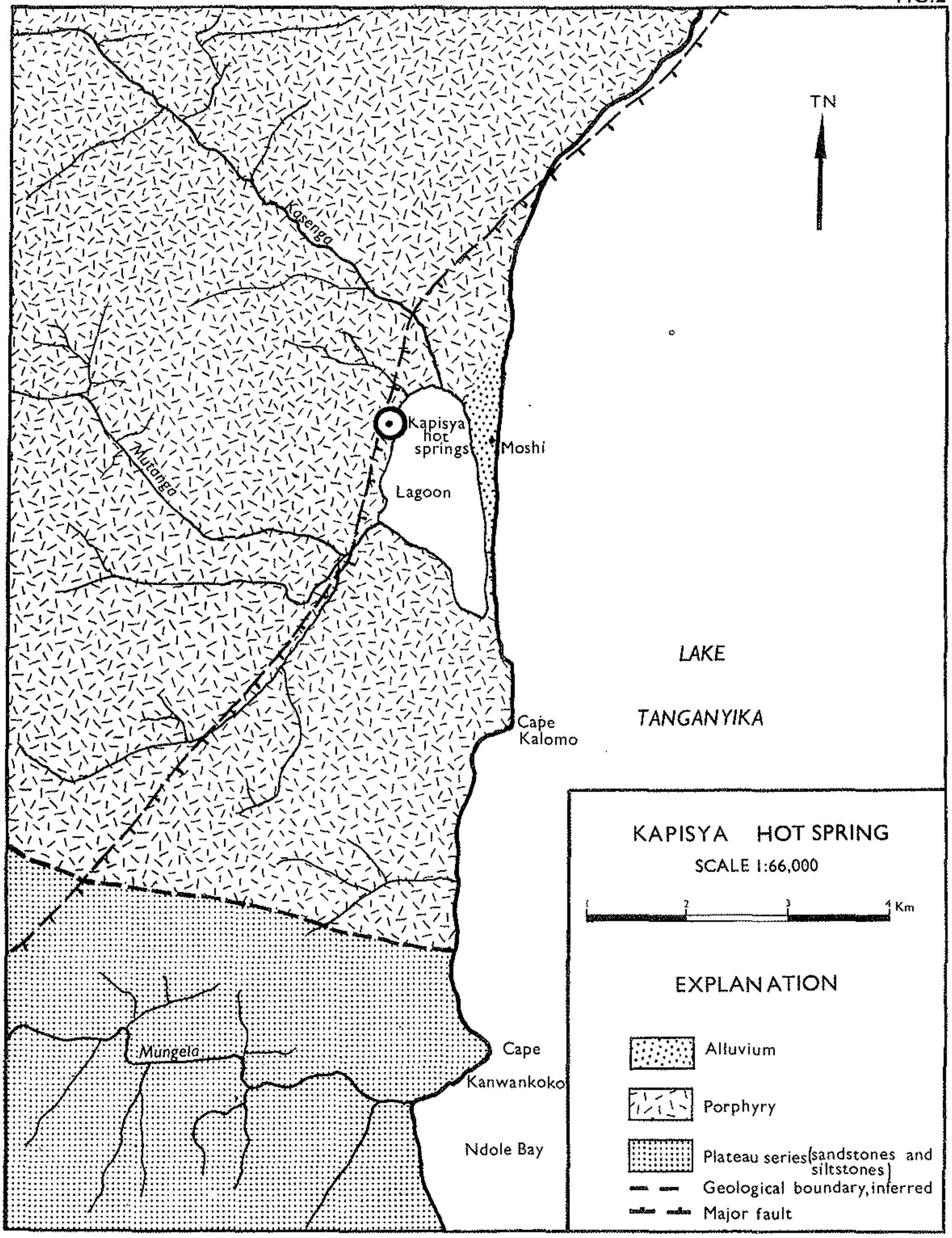


FIG.2


TN
Kasenga
Mutanga
Kapisya hot springs
Moshi
Lagoon
LAKE
TANGANYIKA
Cape Kalomo
Mungela
Cape
Kanwankoko
Ndole Bay
KAPISYA HOT SPRING
SCALE 1:66,000
1
2
3
4 Km
EXPLANATION
Alluvium
Porphyry
Plateau series (sandstones and siltstones)
Geological boundary, inferred
Major fault

THE NORTHERN GROUP

The water compositions, temperatures and discharges of the springs of this group are given in table 1, and a Piper Diagram is shown in fig. 1.

All the springs occur along very recent faults, which usually form prominent topographic features, and which are probably associated with the East African rift system. The faults cut rocks of the Plateau Series, a group of ancient platform sediments, and rocks of older and younger systems.

The Kapisya and Kalaye springs are rather dilute, with relatively low chloride contents, whereas the Kaputa and Chiengi springs are abnormally rich in chloride, a property which makes them suitable for the traditional salt-making industry. All the springs are characterised by relatively high sodium contents and low Na/Li and K/Li ratios.

Kapisya hot springs

These impressive springs occur in Cameron Bay, 8 km north of Nsumbu on the western shore of Lake Tanganyika, and are accessible only by boat. Numerous small springs and four large ones occur over a distance of 350 m along the western shore of a lagoon, separated from the main lake by a sandbar. The springs are located where a major fault of the Lake Tanganyika trough cuts impervious porphyritic igneous rocks (*see* fig. 2). The presence of numerous well-developed beach terraces on the hillside above the springs, up to 20 m above the present lake level, indicates that formerly the springs were subaqueous, and it is probable that other springs occur along the northern, submerged portion of this fault. No outcrops of porphyry are seen in the area of the springs, which is covered with coarse rubble consisting entirely of fragments of columnar-jointed porphyry.

Many of the springs are very hot, the maximum temperature - recorded in the largest spring - being 85°C. Although the spring waters are relatively dilute, rocks in the vicinity are covered with encrustations, mainly of calcium carbonate with less sodium and potassium sulphate and chloride (*see* table 2). The total discharge in May 1971 was of the order of 25 litres per second, but accurate estimates are difficult to make because of the large number of springs and the dense vegetation surrounding them. Large amounts of gas with a slight sulphurous smell are given off by some of the springs, and the area is moderately radioactive, the level of gamma radiation being approximately double that over porphyry outcrops 100 m to the west.

The existence of these springs has been known for some centuries, as an ancient slave path from the Mweru Wa Ntipa area to the old Arab centre of Moshi on the lake shore passes very close to the springs. A stone monolith, 1.5 m high, surrounded by a ring of smaller stones, erected next to the path near the springs, probably has some religious significance.

Although the high temperature and relatively high discharge indicates that steam may be found by drilling, the local energy requirements are small, and could easily be met by utilisation of the numerous waterfalls. The springs, which are of considerable scenic and

Table 1

Water compositions of springs of the Northern Group

No.	Name	Ca	Mg	Na	K	CO_3	Cl	SO_4	SiO_2	Li	Temp. (^oC)	Discharge (lit/sec)
		(milligrames per litre)										
1	Kapisya	5	1	100	5	36	80	65	30	0.6	85	25
2	Kaputa	120	18	800	6	30	1200	355	24	1.0	51	2
4	Kabutuka	130	24	1300	30	150	2150	nil	24	3.0	24	nil
2	Kaputa Pans	116	2	1300	26	120	2000	100	30	3.0	-	-
2	Kabwi Dambo	7	2	55	2	18	84	nil	20	nil	-	-
5	Paulo	140	36	1450	30	84	2400	200	16	4.0	37	4
6	Kapisya Wa Ntipa	200	24	1600	3	96	2700	150	12	4.0	35	1.5
7	Katete	260	24	1860	115	60	3250	240	16	9.0	46	2
11	Kalaye No.2	12	1	44	2	30	56	nil	16	nil	27	1
13	Kalaye No.6	13	2	86	2	66	86	6	32	nil	43	2
15	Kalaye No.4	22	1	75	2	66	66	20	24	nil	45	5
16	Kalaye No.3	14	2	82	2	66	62	25	40	nil	46	4
17	Kalaye No.1	22	2	85	4	60	100	12	20	0.6	51	7

Table 2

Encrustations, efflorescences, soils and finished salt from springs of the Northern Group

Name	Na	K	Ca	Mg	CO_3	SO_4	Cl	Ti	Mn	Ni	Cu	Zn	As	Sr	Fe	Sb
	(per cent by weight)							(relative concentration of trace elements determined by X-ray fluorescence)								
Kapisya Encrust.	1.20	0.52	5.72	0.37	3.98	0.24	0.16	x	xx	xx		x	x	xxx	xxx	
Kapisya Encrust.	1.71	0.42	3.16	0.46	2.84	0.25	0.29		xx	xx		x	x	xxx	xx	
Kaputa pan	6.40	0.20	4.52	0.37	4.10	3.20	8.11		xx	xxx				xx	xxx	
Kaputa	41.00	0.04	0.45	0.09	0.10	0.60	59.15		xx	xx	xx	x	x	x	xxx	xx
Kalaye No. 1 (encrustation)	0.69	0.08	14.60	0.18	19.91	0.49	0.28		xx	xxx	x	x	x	xxx	xxx	x
Lalaye No. 4 (encrustation)	1.30	0.06	18.06	0.27	nd	nd	0.39	nd	nd	nd	nd	nd	nd	nd	nd	nd
Lake Chishi (efflorescence)	20.75	0.02	1.43	0.05	2.01	39.71	3.91		xx	xxx	x	x	x	xxx		xx
Katete Soil	3.29	1.00	1.05	0.18	2.60	5.99	4.40	nd	nd	nd	nd	nd	nd	nd	nd	nd
Kasua Soil	0.54	3.40	0.45	0.46	0.56	3.17	0.28	xxx	xx	xx		xx	x	x	xxx	

natural interest and are situated near the Nsumbu National Park, are a potential tourist attraction.

Analyses of Lake Tanganyika water collected in 1957 at Mpulungu (A) and in 1971 offshore from Nsumbu (B), are included in fig. 1 for comparison with the spring waters. It appears that springs of the Kapisya type exert little or no influence on the composition of the lake water.

Kalaye group of springs

These springs are situated at and near the base of the Kalaye Escarpment, marking a major fault in arkoses and shales of the Plateau Series at the southern ends of Lakes Mweru Wa Ntipa and Chishi (*see* pl. II). There are at least eight springs in this area, three along the foot of the scarp and five along a complementary fault one km to the north of the main fault. Some of the springs were inaccessible at the time of the visit in 1971 because of exceptionally high lake levels.

All the springs lie within the Mweru Mars National Park. Access is by motor track from Nsama to Kakoma game guard camp, and then by foot, with a climb down the near-vertical, 200 m fault scarp.

The only accessible spring at the foot of the scarp (Kalaye No. 2) was just below lake level at the time of the author's visit, and the water sample was probably much diluted. The maximum temperature recorded was only marginally higher than that of the surrounding lake water, but the spring is reputedly too hot for bathing when the lake level is low. The five springs to the north of the main scarp issue along a low ridge of indurated, current-bedded quartzite. Examination of air photographs suggests that this ridge may be the surface expression of a complementary fault, downthrowing to the south, and the location of these springs is thus very similar to many springs in the Gregory Rift valley of Tanzania described by James (1967). All the springs have well-defined eyes in outcrops of fractured quartzite, and the spring waters flow into Lake Chishi or Lake Mweru Wa Ntipa. There are no encrustations on the rocks around the springs, due probably to the low total dissolved solids content.

Lakes Chishi and Mweru Wa Ntipa are inland drainage areas, fed by a number of rivers draining Plateau Series rocks, and by hot springs along the Kalaye escarpment and in the Kaputa area. Figure 1 indicates that the composition of the lake waters is very close to that of the springs, and it appears likely that the latter have contributed much of the dissolved material. Rivers feeding the lakes generally have a very low content of dissolved solids. Kalungwishi River, which overflows through the Mofwe Dambo into Lake Mweru Wa Ntipa in times of flood, has only 54 milligrammes per litre of dissolved solids, 39 of which are calcium and magnesium carbonates. The compositions of waters of some Kenyan soda lakes (*from* Baker 1958) plotted on fig. 1 indicate that while the Mweru Wa Ntipa and Chishi waters show some similarities with Rift Valley soda lake waters, they have lower carbonate and higher calcium contents, and a much lower total content of dissolved solids.

Kaputa springs

These springs occur in an area of dense vegetation ('mushitu') on the north side of the Kabwi dambo, 4.5 km north-west of Kaputa Boma.

Access from Kaputa to Mitawa Village is by motorable track, and for the remaining 2 Km by foot.

Air-photo interpretation suggests that the springs lie on a north-east trending fault between older granites to the north-west and Plateau Series quartzites to the south-east, but there are no outcrops to confirm this. A number of small springs which rise in the bed of a stream, have a total combined flow of about three litres per second. Part of the discharge appears to flow into the main Kabwi dambo, and part into a group of shallow pans along the northern flank of the dambo. These pans form the basis of a salt industry of considerable antiquity, which is of economic importance to the surrounding villages. Salt from here and from the salt workings in the Chiengi area was taken to the large Arab settlement of Abdulla Bin Sulemani near Nsama, and thence along the 'salt road' via Bulaya to Lake Tanganyika, probably to Moshi near Kapisya. The pans along the Kabwi dambo dry up after the end of the rainy season, and salty efflorescences develop on the surface of the fairly pure quartz sand around them. This is scraped off and carried in baskets to nearby villages where it is placed in funnel-shaped constructions of wickerwork and leached with water. The brine issuing from the funnels is collected in basins and evaporated to dryness over a fire. The resulting salt has a grey or brownish colour, and has a more bitter taste than pure table salt, due probably to its content of calcium sulphate (*see* table 2). With similar salt from Chiengi and from Kaimbwe in the Kasempa District, it is prized for its superior flavour, and is sold as far away as the Copperbelt for up to twice the price of imported salt.

It appears unlikely that the present salt production could be significantly increased. The salt content of the spring waters is low by comparison with commercially exploited brines elsewhere in the world, and the pan waters have concentrations of sodium and chloride only one-seventh those of sea water. Drilling might prove more concentrated brines, but would have to be preceded by detailed geological and geophysical surveys.

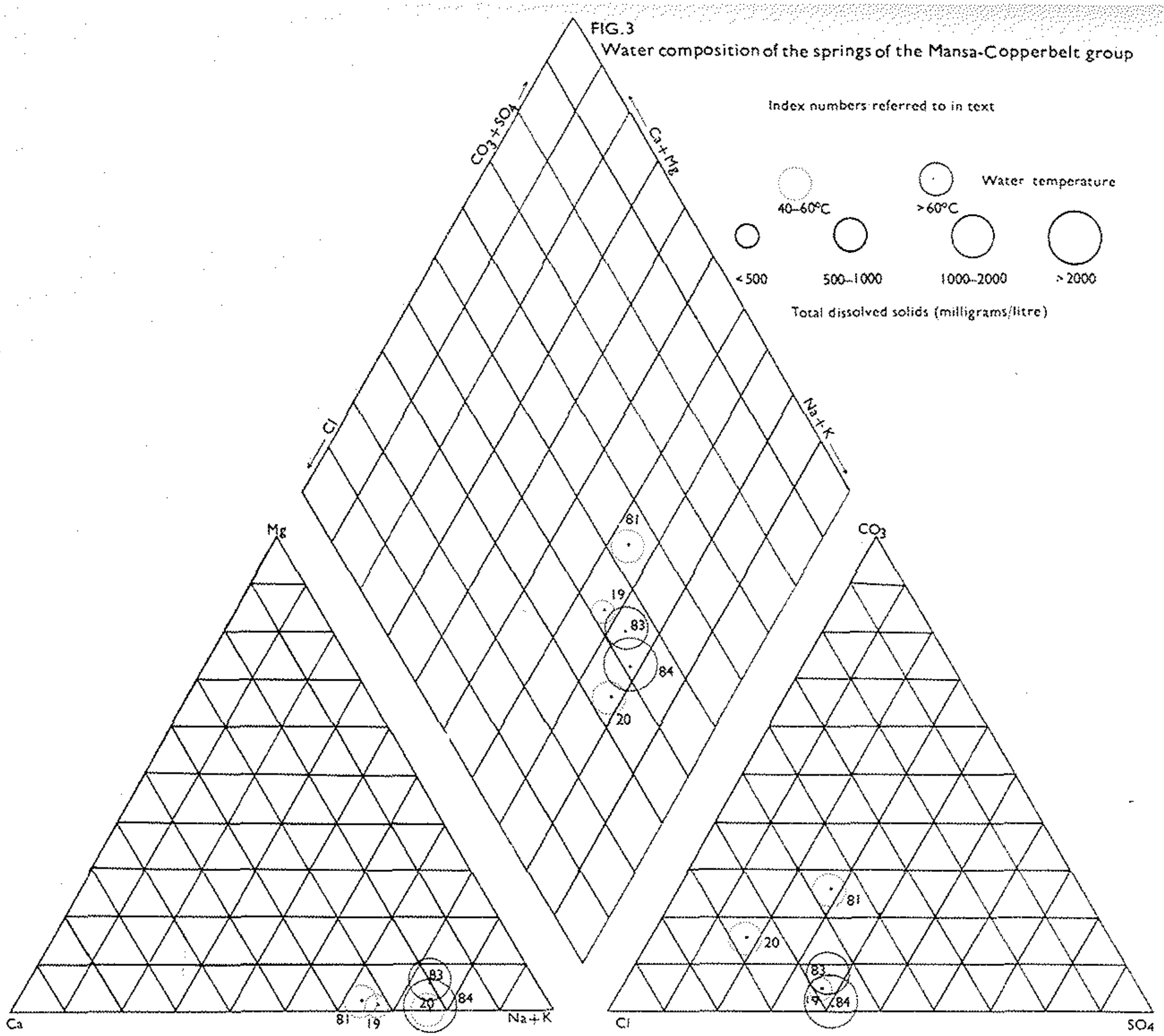
Chiengi springs

This group of springs occurs at the north end of Lake Mweru, along a major fault separating Kundelungu rocks to the west from older granites to the east (*see* p1. III). The area is known for its salt production. all of which is derived ultimately from the springs. As in the Kaputa area, most of the salt is obtained by scraping off the efflorescences during the dry season, although some burning of salt-rich marsh grasses, with subsequent leaching of the ash, is practised. Water from most of the springs flows into the Loshiba marsh separated from Lake Mweru by a sand bar, and most of the salt is obtained from the fringes of the marsh.

All the waters are of medium to low temperature, and the rates of discharge moderate. The Kasua and Kabutuka seepages to the north are seasonal cold springs. The Paulo spring has the largest discharge, and is the only one to show appreciable radioactivity, with a radiation level of up to four times the local background. All the springs emit small amounts of gas which is odourless, except where thick layers of rotting vegetation produce hydrogen sulphide. The Paulo and Kapishya Wa Ntipa springs are surrounded by characteristic groves of raffia palms, but the other springs occur in marshy dambo-like areas without dense vegetation.

The salt content of the primary brines is higher than at Kaputa, and drilling into the major fault zone might locate more concentrated material. Detailed geological and geophysical investigations would be required before drilling.

FIG. 3
Water composition of the springs of the Mansa-Copperbelt group



THE MANSA-COPPERBELT GROUP

This group comprises two sets of springs in the Mansa district, a few springs, artesian boreholes and hot underground seepages in the Copperbelt area, and one hot spring to the west of the Copperbelt. The locations of the springs are indicated on plate I; water compositions, temperatures and discharges are given in table 3; and the water compositions of some of the springs are shown in fig. 3.

Hot underground seepages are not considered in this report, as those at Luanshya (Legg 1972) and elsewhere that have been studied in detail, have temperatures little more than the natural rock temperatures at the depths of the seepages, and few of them are significantly mineralised.

All the hot spring waters have a relatively high chloride to sulphate ratio, higher than normal contents of calcium, and low Na/Li and K/Li ratios. Their chemical uniformity is surprising, considering the wide diversity of geological environments in which the springs occur.

Mansa hot springs

These springs occur in an area of numerous exfoliated outcrops of granite, 0.5 km north of the Samfya road and 3 km east of the centre of Mansa (p1. IV). There are seven areas in which hot water discharges into large, irregular pools amongst the rocks, before flowing northwards into the nearby Mansa River. Another spring occurs at the locality where the water flows into the river (JETS 1973).

The springs appear to occur along a shear zone in the Medium Grained Granite described by Thieme (1970). Hot water issues from a number of parallel fractures in a gneissose biotite-chlorite granite. The fractures trend north-south, parallel to the foliation of the granite, and sub-parallel to the shear-zone marked on Thieme's (1970) structural map. Discharge appears to be greatest at the intersections of the north-south fractures with a second set of west-north-west trend. Where exposed the surfaces of the fractures are not altered or coated. An investigation by the JETS club of Kawambwa Secondary School (JETS 1973), involving auger drilling into some of the springs, indicated a near-surface thermal gradient of up to 2^{o}C per metre, although this is probably exaggerated by surface cooling in the large pools.

The springs are very popular for bathing, as the water temperature of the pools is about 35^{o}C for most of the year.

Kabunda hot springs

These springs occur as small, clear pools in a broad dambo about one km to the south of Kabunda Mission. They have a linear arrangement, and extend for about 500 m in a north-easterly direction. There are no rock outcrops in the area of the springs, but from Thieme's (1970) map they appear to lie along or near the contact of granodiorite with medium-grained granite, or they may occur along an unexposed shear zone similar to that with which the Mansa springs are associated.

Within some of the larger pools, individual discharge points have a linear orientation. There is no surface discharge from the springs, but

Table 3

Water compositions of springs of the Mansa-Copperbelt Group

No.	Name	Ca	Mg	Na	K	CO_3	Cl	SO_4	SiO_2	Li	Temp (^oC)	Discharge (lit/sec)
		(milligrammes per litre)										
19	Mansa	37	1	72	5	12	116	75	25	0.8	49	4
20	Kabunda	64	1	200	18	72	300	75	40	2.0	42	3
79	Kafue River Spring 1955	88	11	nd	nd	nd	nd	142	nd	nd	41	0.6
80	Nchanga 3100 level	50	2	90	5	500	11	83	40	0.1	40	nd
81	Luano Borehole 1955	41	2	142	nd	100	219	70	68	nd	48	nd
81	Luano Borehole 1971	50	5	90	7	87	150	90	30	1.0	50	10
83	Chendwe	360	35	80	20	80	525	360	25	2.0	62	8
84	Luano Hot Springs	310	10	980	65	18	1420	960	30	0.5	80	5

water appears to seep away through the dambo into the adjacent Mansa River. A moderate amount of gas is emitted but there is no noticeable smell, and the radiation level is not greater than the local background level.

Luano borehole

An exploration borehole for copper drilled in the Luano syncline, struck hot artesian water at a depth of 63.5 m on the 30th June 1927. The borehole has continued to flow since then, with a relatively constant discharge of between 8 and 10 litres per second, a water temperature of between 48 and 52^{0}C and a relatively constant water composition (*see* table 3). The water was intersected in Lower Roan arkose overlying Nchanga Red Granite. It is reported that hot springs issued close to the borehole, but these ceased to flow when the borehole was sunk. There is no prominent faulting in this area, and it appears that the artesian water must owe its high temperature to deep circulation either within a syncline of permeable Katangan rocks, or of groundwater in fractures in the underlying basement granite. Underground waters in Copperbelt mines rarely have temperatures exceeding the ambient rock temperatures at the depths at which they occur (Legg 1972). The exceptions are waters issuing from fractures in Basement Complex rocks, in which deep circulation appears to have taken place.

Kafue River hot springs

A former group of springs along the Kafue River between Chingola and Chililabombwe have dried up within the past ten years, probably as a result of the lowering of the local water table by mine dewatering.

Chondwe hot spring

This spring rises in a dense thicket in the broad flat dambo which forms the source of the Kafulafuta River. No rocks are exposed in the vicinity of the spring, but from the geological map prepared by Moore (1967) the spring appears to be situated at or near the contact between an outlier of Lower Roan arkose, and quartzite and phyllite of Kalonga age. The main eye of the spring is obscured beneath a dense mat of rotting vegetation, but on emerging from it the water flows through a well-defined channel into the open dambo, where it is used for watering cattle during the dry season. Partially eroded calcareous tufa occurs along the channel from the spring, indicating that the spring water actively deposited calcium carbonate in the past.

Luano hot springs

These hot springs, which should not be confused with the Luano Borehole, are situated 110 km west of Kitwe in the centre of the Luswishi Dome, an area of Basement Complex rocks surrounded by rocks of the Katanga System. Water is discharged from multiple vents over an area 70 m by 50 m and flows through a number of channels into the Casho Stream, near its confluence with the Mikelo River. The main rock type in the area is a nodular orthoclase gneiss, veined with feldspar, and interbanded with fine-grained, grey-black, micaceous quartzite. As a result of the high total dissolved solids content of the spring water, rocks in the spring pools are thickly coated with salty encrustations. (The description of this spring is after H. Ayres, Geologist, of the Geological Survey Department, who collected the water sample for analysis.)

SPRINGS OF THE WESTERN GROUP

This group comprises diverse hot and mineralised springs with a wide range of water composition and geological setting, considered together mainly because of their geographical distribution. The locations of the springs are shown on plate I, and those in the Lubungu area on a larger scale on plate V. The compositions of the spring waters, their temperatures and discharges, are given in table 4, and the compositions are shown graphically in fig. 4. The springs lie in a zone of unusually high seismicity coincident to some extent with a large linear negative gravity anomaly.

Kaimbwe hot spring

The Kaimbwe spring and its associated salt pan have been known for a long time as a source of common salt, and was the site of the only attempt at medium-scale commercial salt production in Zambia. The Kaimbwe salt pan is of great traditional importance to the Kaonde people. They conquered the tribe which originally controlled the pan, before occupying the whole of the Kasempa and Solwezi districts. The salt pans are considered to be the centre or home of the tribe, and are (or were) the site of yearly religious ceremonies to ensure good crop yields in the following season (affidavit by Chief Kasempa, 1947, in the Mining Records Office File).

The geology of the area is imperfectly known, but the spring appears to be located at the intersection of two, or perhaps three, sets of fractures in argillites of presumed Upper Katanga age (*see* fig. 5). There is only one obvious spring, although any others that occur in the swamps surrounding the salt pan would be difficult to locate.

The spring has been considerably modified by the construction in 1961 of a small salt factory by H. Going, then District Commissioner at Kasempa. A brick tank was constructed over the spring, and the water level raised sufficiently to feed hot saline water by gravity along a brick channel into solar evaporation tanks. The concentrated brine from these tanks was evaporated to dryness in shallow pans over a wood-fired oven.

Since the plant has been closed, the spring water runs into the sub-circular Kaimbwe salt pan. As indicated in table 4, the concentration of common salt in this pan, even late in the dry season, is not significantly higher than that in the spring water. Dilution by rain and surface waters apparently counteract the effects of natural evaporation. An analysis of water from the Mushingashi River, which drains the pan, indicates an even higher level of dilution.

Traditional salt production is based on the collection of salty efflorescences from the swampy ground around the pan, an activity normally restricted to the dry season, and the leaching of this material in small boat-like troughs made of bark. The concentrated brine so produced is evaporated in enamel bowls over fires, and the salt packed in bundles of about 1.5 kilogrammes wrapped in leaves. The average annual production is unknown, but is unlikely to be more than two or three tonnes.

For similar reasons to those outlined in the case of the Kaputa and Chiengi springs, no great expansion of salt production by traditional

Table 4

Water compositions of springs of the Western Group

No.	Name	Ca	Mg	Na	K	CO_3	Cl	SO_4	SiO_2	Li	Temp	Discharge
				(milligrammes per litre)							(^oC)	(lit/sec)
85	Kaimbwe	220	20	3700	90	108	3750	440	30	5	53	2.5
85	Kaimbwe Pan	440	30	3800	160	150	6300	500	25	7	-	-
85	Mushingashi River	60	12	740	15	120	1200	0	-	-	-	-
89	Meshi	120	10	160	20	205	100	230	30	2	28	10
90	Lupiamanzi	11	2	150	6	162	72	0	40	4	79	15
91	Lubungu A	360	15	550	26	30	920	250	40	1	76	15
91	Lubungu B	354	14	554	42	-	-	-	-	4	-	-
91	Lubungu C	510	72	680	25	50	390	2360	40	0.3	76	15
91	Lubungu D	436	49	674	33	-	-	-	-	4	-	-
91	Lubungu E	360	12	500	22	30	760	1000	40	0.3	76	15
91	Lubungu F	370	1	600	30	24	800	1060	40	1	76	15
91	Lubungu G	382	2	560	22	24	772	920	105	0.7	-	-
91	Kafue River	52	24	14	7	76	23	118	11	-	-	-
92	Chibemba 57^o	160	5	400	30	66	315	750	50	5	57	1
92	Chibemba 49^o	120	10	160	20	205	100	230	30	2	49	-
92	Chibemba dold	225	15	940	110	54	930	1350	50	8	-	-
93	Kapiamema	103	10	75	6	140	120	60	40	1	36	2
95	Kassip 1968	64	35	95	15	180	72	124	-	-	-	-

Table 4 (Continued)

No.	Name	Ca	Mg	Na	K	CO_3	Cl	SO_4	SiO_2	Li	Temp	Discharge
95	Kassip 1971	64	10	300	15	120	240	320	25	2	46	2
97	Longola	50	5	400	18	36	206	650	40	0.2	70	10
113	Bilili 1966	45	5	275	16	36	20	640	-	-	-	-
113	Bi-i-i West 1974	54	3	160	15	36	22	380	40	0.6	62	5
113	Bilili East 1974	74	1	270	15	66	28	620	40	0.9	30	3

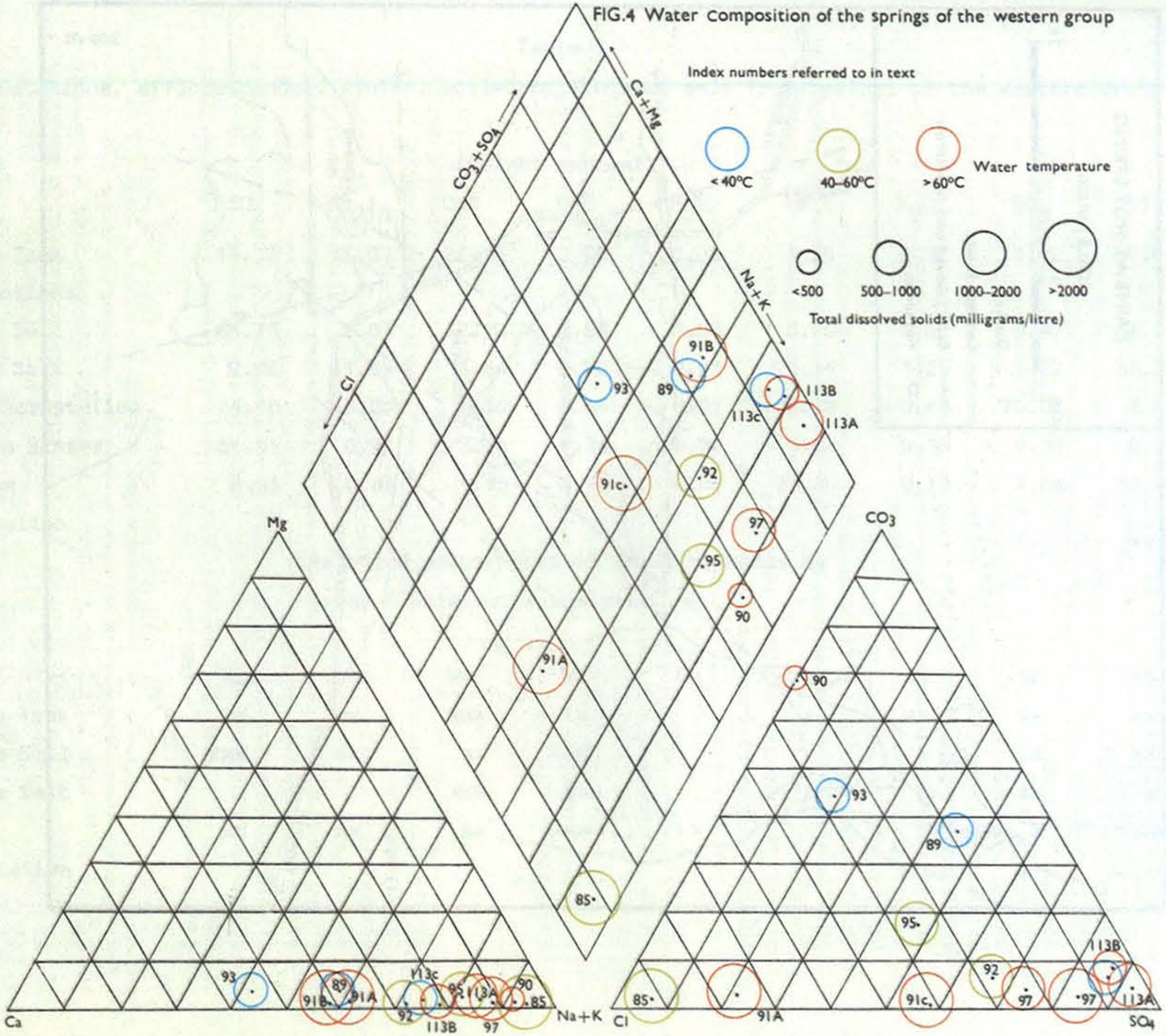
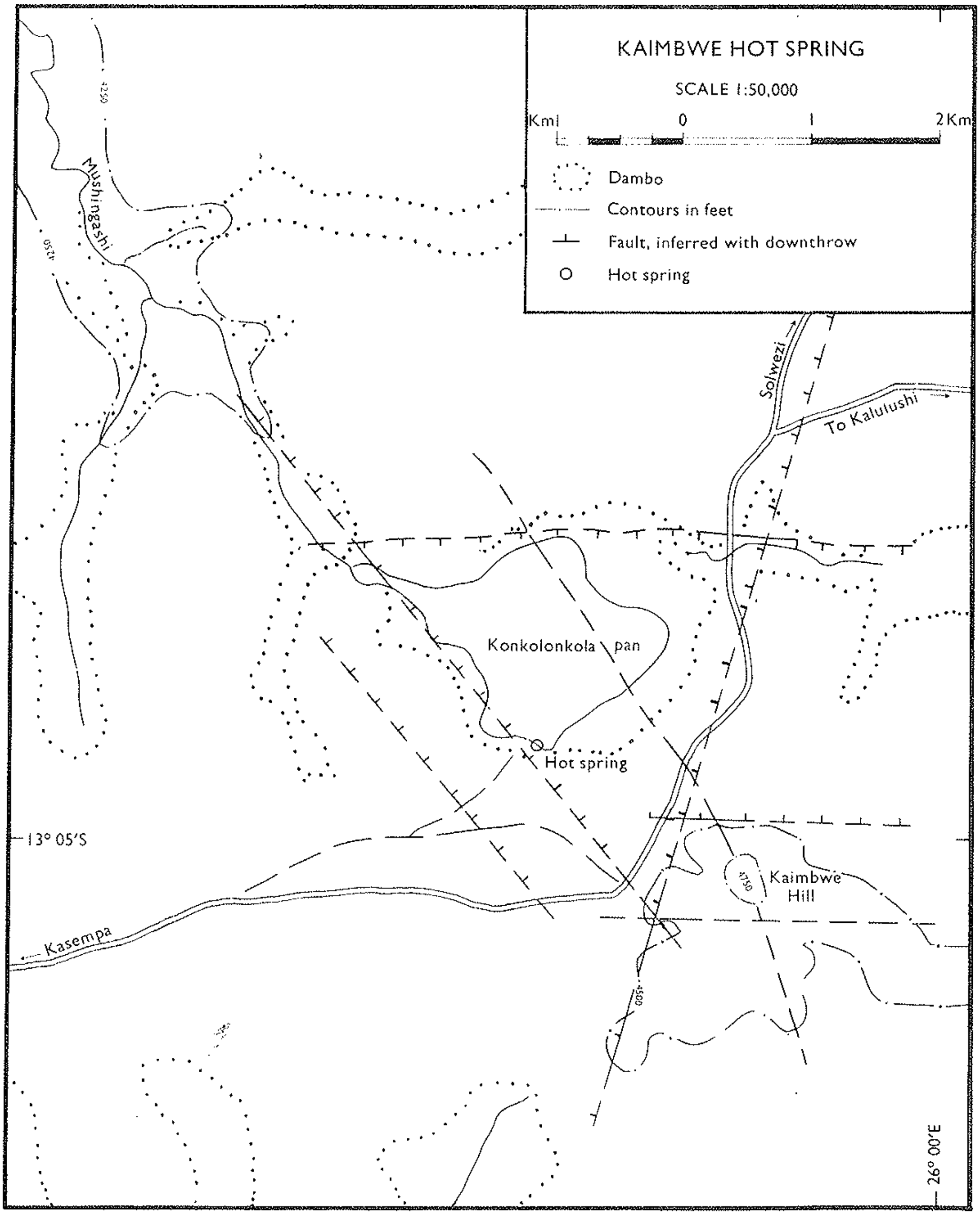


FIG.4 Water composition of the springs of the western group

FIG. 5



KAIMBWE HOT SPRING
SCALE 1:50,000
Km 1
0
1
2 Km
Dambo
Contours in feet
Fault, inferred with downthrow
Hot spring
Mushingashi
Solwezi
To Kalulushi
Konkolonkola pan
Hot spring
13° 05'S
Kaimbwe Hill
Kasempa
26° 00'E

Table 5

Encrustations, efflorescences, sinter, soils and finished salt from springs of the Western Group

(Weight percent)

		SiO_2	$Al_2)_3$	CaO	MgO	P_2O_5	Na_2O	K_2O	SO_3	Cl	CO_2
85	Kaimbwe Tank Encrustations	14.12	15.02	29.75	0.56	0.06	1.75	0.12	1.42	1.67	20.26
85	Kaimbwe Soil	65.76	2.87	2.10	0.66	0.03	6.20	1.02	0.47	9.51	1.54
85	Kaimbwe Salt	0.09	1.65	1.84	0.10	0.01	28.14	1.20	1.22	58.71	0.24
89	Meshi Encrustation	24.10	16.20	1.58	0.95	0.02	22.26	0.48	20.01	8.46	0.69
92	Chibemba Sinter	81.91	0.77	3.29	0.28	0.04	1.62	0.36	0.39	0.41	4.26
92	Chibemba Encrustation	0.55	0.88	1.58	0.19	0.01	25.30	0.79	1.06	58.49	6.92

(Relative proportions of trace elements by X-ray fluorescence analysis)

		Ti	Cr	Mn	Ni	Cu	Zn	As	Sr	Fe	Sb	Pb
85	Kaimbwe Tank	x	xx	xxx	xx		x	xx	xx	xxx	xx	
85	Kaimbwe Soil	xxx	xx	xx	xxx			x	x	xxx		x
85	Kaimbwe Salt			xxx	xx		x	x	xx	xx	x	
89	Moshi Encrustation	xx	xx	xx	xxx	x			x	xxx		x

methods can be expected. The area covered by efflorescences is limited, and is fully exploited at present; also production is necessarily of a seasonal nature. The attempt to expoit salt on a commercial scale failed because of the cost of evaporating the relatively dilute brine (0.94 per cent NaCl) and in particular the very large quantities of coal needed in the final evaporation stages.

The measured discharge of the spring at the time of the author's visit in October 1971 was 2.5 litres per second. With a mean NaCl content of 0.94 per cent, this could provide a total salt yield of 740 tonnes per year, which is insignificant compared with the annual Zambian consumption of 45 000 tonnes in 1969. A possible method of producing salt economically at Kaimbwe would involve raising the height of the water to about 5 m above ground level, and allowing the water to trickle down over material of large surface area, such as brushwood, where considerable preliminary evaporation could occur. The more concentrated brine could then be led into large, shallow, solar evaporation tanks, as recommended by Anders (1962). The tanks should be arranged in cascade so that salt precipitation could take place by solar heating; thereby fuel would be required only for final drying. Salt produced in this way would probably be less pure than that prepared by traditinal methods (*see* table 5), in which efflorescence and some selective leaching probably serve to concentrate sodium chloride at the expense of other salts.

The most promising method of developing the springs would appear to be to increase the brine discharge by means of boreholes. The siting of the boreholes to intersect the controlling faults at depth would have to be based on detailed geological and geophysical studies, although geophysical work would probably be complicated by the high salinity of the soils and the extent of the swamps.

Moshi salt spring

A group of three strongly flowing springs rise in a marshy area at the foot of a low bluff of fine-grained arkosic quartzite of probable Karroo age. The quartzites are strongly fractured, the predominant fracture direction being east-west, parallel to the bluff. Some of the fractures are infilled with quartz and hematite. The spring water is only slightly above ambient temperature, and abundant salty efflorescences, consisting mainly of sodium sulphate and chloride, develop on the muds around the springs. The springs are a considerable attraction to game, and this, combined with the perennial flow of water and the proximity to the Moshi game camp, makes them a popular game-viewing spot on the Moshi Loop.

Chibemba hot spring

This spring is unique in Zambia in that it issues from the summit of a large mound, roughly elliptical in plan, measuring 400 m by 350 m and 10 m high, composed of white to light grey, siliceous sinter. The discharge is relatively small, and the water is not abnormally rich in silica; it is concluded that the springs were once much more active and silica-rich than at present.

Water is discharged at numerous points over the surface of the mound, but most of the springs are very small and the water is cool.

Two hot springs near the summit are characterised by the development of thick mats of red algae, encrusted with salts consisting mainly of sodium chloride. As indicated by the analyses in table 4, there is a considerable variation in water composition between the different springs, and this, together with the variations in temperature, are considered to be a result of the low rate of discharge. Water passes slowly through a network of small channels in and below the mound, which allows time for complex exchange reactions between the water and sinter to occur, so modifying the water composition. Further reactions probably occur on the surface of the mound, with deposition of some components and probably re-solution of others from the abundant efflorescences.

The mound is composed of fine-grained, chalk-like material containing numerous irregular nodules of chert. Banding or other regular textures are rare. The margins of the mound are under active erosion, probably by run-off during the rainy season, with the formation of a series of low bluffs.

There are no rock outcrops in the area of the spring, but according to Page (in press), the spring occurs in Karroo rocks within the Lubungu-Lufupa graben.

The spring occurs in an area having a rich variety of game, and would be an attraction to tourists visiting the northern part of the Kafue National Park. It is 29 km from the Moshi Camp.

Lupiamanzi hot springs

These springs, remarkable for their high water temperature and low content of total dissolved solids, occur on the eastern margin of a small fault-bounded outlier of lower Karroo rocks containing thin seams of coal - the 'Hot Springs Coalfied' (Cikin 1971). Although there are no rock outcrops in the vicinity of the springs, fragments of siltstone, sandstone, quartzite and vein-quartz occur in the eyes of the springs. Water is discharged from large numbers of small eyes in broad areas of muddy seepage extending for 140 m in a north-westerly direction. The most southerly springs are located along the banks and the bed of the Lupiamanzi River, and the others drain into the river through tributary streams. The springs provide most of the flow of the Lupiamnzi River during the dry season, and attract large numbers of game in this otherwise dry area. Hippopotami appear to enjoy wallowing in the hot muds around the springs, and are apparently unaffected by temperatures in excess of 65°C. The springs are a popular camping site for hunters in this Game Management Area.

Kassip hot spring

This spring rises in the bed of the Chibila River, near Kassip Village, 2 km north-east of the centre of Mumbwa. Hot water issues from fissures dipping at 40° to the east in grey, well-banded marbles of presumed Upper Katanga age (Vajner in press), the two main discharge points being 1.5 m apart. As indicated by the water analyses in table 4, the spring waters are relatively dilute. The differences between the 1968 and 1971 analyses may be explained by dilution with river water in the case of the former. There are no encrustations or efflorescances in or around the springs, which are a popular bathing place with the local villagers.

Table 6

Travertine and other deposits of the Lubungu hot spring

(Weight per cent)

	SiO_2	Al_2O_3	CaO	MgO	P_2O_5	Na_2O	K_2O	SO_3	Cl	CO_2	Fe_2O_3	TiO_2	MnO
Black Travertine BRGM analysis	28.30	1.45	3.50	0.25	0.09	0.40	0.16				47.40	0.04	3.45
Black Travertine GSD analysis	1.29	1.40	23.69	0.85	0.03	10.24	0.36	1.25	0.95	38.22			
Older White Travertine	0.35	1.33	53.44	0.28	0.05	0.27	0.19	0.65	0.18	38.22			
Salty Encrustation	3.77	0.44	30.54	2.46	0.02	0.81	0.24	35.84	0.11	1.06			

Relative proportions of trace elements by X-ray fluorescence analysis

	Mn	Fe	Sr	Ba	Pb	Rb	Hg	Zn	Ni	As	W	Mo
Older White Travertine	xxx	xxx	xxx	xx	xx	xx	x	x	x	x		
Older Black Travertine	xxx	xxx	xx	xx						xx	x	x
Older Red Travertine	xxx	xxx	xx	xx		x	x	x	x	xx		
Older Speckled Travertine	xxx	xxx	xxx	xx			x	x	x	xx		
Young Black Travertine	xxx	xxx	xx	xx						xx	x	x
Orange Ochre	xxx	xxx	xxx						x	xx	x	
Green Ochre	xxx	xx	xxx						x	xx	x	x

Table 7

Atomic absorption analysis of Lubungu travertine

(ppm)

Sample	Ag	Be	Hg
Older White Travertine	0.13	1.64	12.2
Older Black Traverine	0.36	40.0	157
Older Red Traverine	0.36	7.0	19.0
Older Speckled Traverine	0.25	4.2	15.4
Young Black Travertine	0.47	14.1	188

Table 8

Trace elements in Lubungu hot spring water

Element	Spring Eye 1969 UNDP	Spring Eye 1972 BRGM	Kafue River 1972 BRGM	Units
F	-	3.6	1.7	mg/lit
Br	0.6	-	-	"
I	0.004	-	-	"
B	0.76	0.8	* 0.1	"
Cs	-	1.4	* 1	"
Sr	-	6.95	0.32	"
Ba	-	* 1	* 1	"
Li	-	670	9	mg/m^3
Rb	-	260	*10	"
Cr	-	* 1	* 1	"
Mo	-	* 1	* 1	"
Cu	30	3	7	"
Fe	340	800	380	"
Zn	60	2800	6	"
Co	-	* 1	* 1	"
Cd	-	* 1	* 1	"
Ni	-	* 1	* 1	"
Mn	-	110	50	"
Pb	* 5	* 1	* 1	"
Hg	-	*10	*10	"
Ag	-	* 1	6	"
Au	-	* 1	* 1	"

* more than

Table 9

Analysis of gas from Lubungu hot srping

(analysis by Prof. E. Tongiorgi, International Institute for Geothermal Research, University of Pisa, Italy)

	Vol. %
CO_2	4.96
CH_4	1.20
N_2	91.56
O_2	2.28
H_2	Trace

Table 10

Oxygen isotopes, Lubungu hot spring

(isotopic analyses by Prof. E. Tongiorgi, International Institute for Geothermal Research, University of Pisa, Italy)

	Delta O^{18} parts per thousand
Lubungu Hot Spring Water	-8.0
Kafue River Water	-3.6

Kapiamema hot spring

This spring, located 5 km to the south of the Hippo Mine, rises in a pool at the base of a bluff of coarse, pink, porphyritic granite. The spring probably occurs on a southern extension of the Lubungu fault zone, as described by Page (in press). Granite exposed in outcrops is somewhat fractured, with films of tourmaline and hematite along some of the fracture surfaces. At the time of the author's visit late in the dry season, the water in the large pool was probably derived mainly from the spring, but for much of the year considerable dilution probably takes place. Much gas, having a slight odour of hydrogen slphide, is emitted from the spring.

Longola hot spring

This spring is situated about 6 km south-west of the Mezhi-tezhi Gap, near Shamande Village. The spring apparently occurs on an extension of the north-south striking fault between Upper Karroo rocks and granite and metasediments of the Hook Granite complex which has been exposed in the excavations for the Mezhi-tezhi Dam. The spring is innaccessible for much of the year due to seasonal flooding on the Kafue Flats. A water sample was collected by Sweco, the consulting engineers for the dam, who also estimated flow and water temperature.

Bilili hot springs

These are among the most visited of hot springs in Zambia,as they were for many years on the main access road to the southern part of the Kafue National Park, and were a very popular site. Now that the road has been re-aligned, and the old road has been allowed to fall into disrepair, access to the spring is more difficult, and a four-wheel drive vehicle must be used. The springs occur along a major fault separating Lower Karroo rocks to the north from rocks of probable Katanga age to the south. There are two main springs, about 700 metres apart. The eastern springs rise in large pools which, at the time of the author's visit in January 1974, were flooded with surface water, with a consequent lowering of the water temperature below the probable normal for that time of the year. The western spring is a well-defined, single eye situated above the level of local flooding. An anomalous feature is that the water from the cooler, and evidently diluted, eastern spring is more concentrated than in the western spring (*see* table 4). The most likely explanation is that solar evaporation takes places from the large pools around the eastern spring. Water from the springs flows into a large area of densely vegetated swamp, within which there may be other springs. The springs are not noticeably radioactive, but a small amount of almost odourless gas is emitted.

Lubungu hot spring

This is without doubt the most spectacular hot spring in Zambia from a scenic point of view, with its large discharge, multicoloured travertine mound and dense tropical vegetation. Furthermore, its waters are exceptionally hot, of complex composition and have a high radioactivity. This spring has been studied in detail by the Geological Survey, and by the staff and students of the University of Zambia Physics Department.

The location and geological setting of the spring are shown in plate V. The spring is located 1 km north of the Kafue River, and within the Kafue National Park, 92 km by road to the north-west of Mumbwa. The spring occurs in an area of medium-grained and strongly tourmalinised pink granite, probably a roof phase of the Kafue Hook granitic intrusive complex (Page in press). The Lubungu Fault occurs a short distance to the west of the spring, and appears to form the eastern boundary of a northward-trending graben containing downfaulted metasediments of probable Upper Katanga age. The fault zone is marked by intense tourmalinisation and hematisation, giving rise to a prominent and very persistent ridge. A minor, east-north-east trending fault branches from the Lubungu fault near the Kafue-Lunga confluence, and is marked by the patchy development of metasomatic magnetite, hematite and tourmaline, and by alteration and brecciation of the granite. The Lubungu hot spring appears to occur on the northern edge of this fault or shear zone.

Detailed geoelectric, magnetic and gravimetric surveys have been conducted over the area of the spring by the Physics Department of the University of Zambia (Chapman, Cowan, Legg and Topfer 1972 and Legg, Topfer and Cowan in prep.), in order to define more accurately the position and attitude of the fractures controlling the position of the spring. The results are summarised in plate VI, and tend to confirm the east-north-east to easterly orientation of the fracture system supplying water to the spring, and indicate that the granite bedrock has been downthrown by about 5-7 metres to the south. The water channel is apparently a zone of fracturing and brecciation rather than a well-defined planar fracture, and as far as can be ascertained the dip is steep to vertical.

Hot water issues from the top of a mound of travertine, which is up to 4 m high and 40 m in diameter, as shown in the insets to plate V. Much of the mound is covered with dense vegetation of a typical 'rain forest' type, but the south-eastern slope is open, with grass growing between the active streams. Water is emitted from a large number of individual vents over the flat top of the mound, and groups of vents are commonly surrounded by level terraces of travertine. The difference in elevation between the highest and lowest springs is of the order of 30 cm. Much gas is emitted, giving the springs an impression of boiling, although the water temperature is well below boiling point.

Close to the vents, the newly-deposited material is reddish-brown to deep red ochre. Further down the slope from the vents, the colour changes through bright yellow, light green to olive-green and finally to nearly black. All the material appears to weather to a finely-banded, black or dark grey travertine. The chemical composition of some of the travertines and ochres is given in tables 6 and 7, from which it is apparent that iron and manganese are major components of the recent ochres and the black banded travertine. Analytical limitations have not permitted detailed trace element analysis to be made, but strontium, barium, mercury, zinc, nickel, arsenic, tungsten and molybdenum are present in appreciable amounts. The fine banding of the late travertine may be seasonal or may be related to periodic changes in water composition; in either case the character of material deposited by tha spring appears to have changed with time. On the south-western side of the mound there are exposures of older travertine, much lighter in colour than the younger material, and showing a very vuggy texture. Some of it is coarsely crystalline calcite, with red and brown staining, and irregular patches of finely-banded black material. At the south-eastern edge of the mound, in the grassy area, there are outcrops of a light grey to white travertine showing crude banding and abundant cavities. Microscopic examination of the travertines shows them to be made up of alternating bands of calcite - microcrystalline in the younger material and more coarsely crystalline in the older varieties - with opaque, dendritic material, apparently composed of iron and manganese oxides. X-ray diffraction confirms the presence of calcite, and indicates that in most samples the remainder of the material is amorphous. In one sample, the diffraction results indicated the presence of bementite, a hydrated manganese silicate.

An attempt to drill into the travertine mound using a power auger failed due to the presence of numerous large cavities and continual jamming of the drill tools, so that a continuous section through the mound could not be obtained. Shallow auger drilling on the soil-covered northern parts of the mound showed that light coloured travertine occurs here also, indicating that spring activity has gradually migrated southwards.

The composition of waters from the Lubungu spring are given in table 4. The results indicate that the composition is fairly constant, except for samples A and B, collected in October and December 1971 respectively. The first sample is abnormally rich in sulphate. This change in composition is discussed in a later section. Trace element analyses of Lubungu water given in table 8 indicate the presence of abnormally high amounts of boron, caesium, strontium, iron, zinc and manganese. These elements correspond to some extent with those which are anomalous in the travertine.

The Lubungu spring is very highly radioactive, the radiation level over the spring being more than 400 times the background value at a distance of 200 m from the spring. Gamma-ray spectra of travertine indicate that the radiation is due to the presence of isotopes of both the uranium and thorium decay series, the relative proportions varying from sample to sample. Gases emitted from the spring are also radioactive, due apparently to the presence of radon.

An analysis of gas emitted from the spring (table 9) shows that the main constituent appears to be nitrogen, although it is not clear whether other inert gases, especially helium, which might be expected to occur in the products of such a radioactive spring, were grouped with nitrogen. An approximate measurement of the volume of gas emitted from the spring made in December 1971 indicated a flow of 0.15 litre per second. This can be compared with the water discharge at the same time of 14.7 litres per second, giving a gas emission of about 1 per cent water volume. If, as seems likely from the composition, most of the gas emitted is simply dissolved air, the expected rate of gas emission from water which was saturated with air at 20^{o}C and then heated to 76^{o}C, can be shown to be about 0.8 per cent by volume, which, considering the relative crudeness of the measurement, is in agreement with the observed values.

An analysis of oxygen isotopes in water from the spring and from the Kafue River (table 10) indicates no significant difference in delta O^{18} values between them. This suggests that the spring water is deep circulating groundwater, derived at least partly from the river, and that there is unlikely to be any juvenile volcanic component.

A detailed study of the groundwater conditions around the spring (Cisler 1972) shows that the influence of the spring on the local hydraulic regime is slight. There is no evidence for sub-surface emission of spring water, indicating that the spring channels are effectively sealed. Groundwaters in the valley south of the spring are, however, very saline (Legg, Topfer and Cowan in prep.), and it appears that lateral surface flow probably occurs from the Lubungu stream during the latter part of the dry season, when the normal inflow into the dambo is at a minimum. Downstream from the spring, crystals of gypsum are found in clays over a wide area of the dambo and are most abundant at a depth of between 1 and 2 m. This depth may represent the surface of the water table during the dry season, and it is possible that evaporation, coupled with exchange reactions between sulphate-rich waters and clay minerals, resulted in the crystallisation of gypsum. There is a close association of gypsum occurrences with hot springs in Zambia - the Lochinvar deposits being the best known example - but those at Lubungu are the only occurrences which do not overlie Karroo rock, the evaporite minerals in which could not have contributed to the formation of gypsum in this case.

The spring is located within the Kafue National Park, but as it is isolated from the developed part of the park by the Lunga River, it has few visitors. It is suggested that any development of the Lubungu area should include protection of the spring, perhaps by declaring it a national monument, and appointing a caretaker. There are opportunities for much interesting research at Lubungu, such as detailed studies of spring activity, including the monitering of water flow, temperature and composition, studies of gas discharge and radioactivity which would provide much useful information regarding this spring and hot springs in general. Other suggested studies concern the deposition and geochemistry of travertine, particularly in relation to metallogenesis and the processes of gypsum formation. The dense vegetation around the spring would prove interesting to botanists and biochemists, especially with regard to the possible effects of radiation, and the mechanism of survival at high root temperatures in saline waters.

Table 11

Water compositions of springs of the Eastern Group

No.	Name	Date	Ca	Mg	Na	K	CO_3	Cl	SO_4	SiO_2	Li	Temp. (°C)	Discharge (lit/sec)
			(milligrammes per litre)										
21	Sitwe		48	5	90	5	198	6	nil	24	0.1	38	7
25	Shiwa Ngandu	4/73	4	4	3	1	16	4	nil	8	nil	41	5
25	Shiwa Ngandu	9/73	2	2	1	nil	8	2	nil	20	nil	41	5
28	Kanunshya		4	2	90	4	84	8	66	40	nil	28	1
29	Kalamulilo		28	2	295	15	30	100	520	32	0.4	40	3
30	Chongo		42	1	500	40	140	30	970	40	1.84	12	-
31	Nabwalya South		40	1	500	30	24	170	910	40	1.0	67	10
32	Kasakaza		90	4	445	15	30	60	1050	40	0.2	55	2.5
33	Nsefu B/H	9/67	144	8	500	25	36	56	1300	-	-	-	-
33	Nsefu B/H	9/72	68	20	450	30	24	100	1040	40	0.4	56	5
33	Nsefu B/H	6/73	90	4	410	25	30	75	810	32	0.6	56	5
33	Nsefu Spring	9/72	260	8	1050	65	84	220	2500	40	1.1	30	2
34	Manze		3	2	142	2	10	200	nil	24	0.1	29	5
36	Chikoa		13	1	205	8	24	40	390	24	0.3	64	6
37	Kasenengwa River		38	7	110	5	120	20	134	-	-	-	-
39	Msoro		105	1	315	20	24	104	800	20	0.7	58	5
40	Musaope	9/72	50	1	500	40	110	36	1000	40	0.5	74	8

Table 11 (Continued)

No.	Name	Date	Ca	Mg	Na	K	CO_3	Cl	SO_4	SiO_2	Li	Temp. (°C)	Discharge (lit/sec)
40	Musaope	6/73	51	1	380	34	36	108	760	30	0.6	75	7
41	Malanga		42	9	420	10	63	90	800	40	0.4	58	2
42	Mwape		120	12	315	10	72	80	780	20	0.5	46	4
56	Kanzi		350	1	270	9	24	130	130	20	0.3	35	2
126	Chilube		20	8	325	30	486	16	16	24	nil	30	nil

SPRINGS OF THE EASTERN GROUP

The locations of springs of the Eastern Group are shown in plate I, the water compositions, temperatures and discharges are given in table 11, and shown graphically in fig. 6. The majority of the springs of this group are in areas underlain by Karroo rocks, or at the contacts between Karroo and basement. With very few exceptions, the springs are relatively rich in sulphate, and poor in magnesium. Many of the springs are in remote parts of the Luangwa valley where access is difficult and some of them have not been visited.

Sitwe hot springs

These springs are situated about 0.5 km north of Sitwe primary school, on the eastern side of the north Luangwa Valley. Eight springs of a group rise along the base of a southward-facing, east-west bluff. The streams flowing from the springs coalesce into a single westward-flowing stream, which joins the Luwumbu River, a tributary of the Luangwa River. A small amount of odourless gas is emitted from the springs, and the radiation level is not above the local background. There are no encrustations on pebbles around and within the springs, a consequence of the relatively low dissolved solids content of the spring water. Large trees around the springs provide shade, and the lack of undergrowth makes a favourite camp site for many visitors to the area. The local villagers appear to make little use of the spring, probably because of easy access to the Luwumbu River.

Shiwa Ngandu hot springs

These attractive springs lie about 20 km to the west of the main Shiwa Ngandu Estate, in the grounds of the Kapisya cottage, named after the springs and built as a weekend spa. The springs appear to be associated with major fractures in quartzites of probable pre-Katanga age, and lie on the western side of a north-west trending ridge of pure white quartzite. The water level around the springs has been artificially raised by the construction of a low brick dam, and a wooden platform with steps provides easy access for bathing in the warm spring water. The water in the pool is very clear, with a slight greenish tinge due to the presence of algae. Much gas is emitted, but there is no smell and the radiation level is not above the local background. There are no encrustations of other deposits around the spring, as the water is extremely dilute (*see* table 11).

Kanunshya mineral spring

The Kanunshya spring has been named after the game guard camp which is situated on the south bank of the Lundazi River, 1 km north of the spring. The spring occurs at the foot of a low northward-facing, east-west trending bluff of Karroo grits and sandstones - probably a minor fault scarp running parallel to the lower course of the Lundazi River. At the time of the author's visit in February 1973, the area around the spring was water-logged, and no temperatures above ambient were recorded, although the game guards report that even late in the dry season the water is not noticeably hot. Surface discharge from the spring is very small, and the salt marsh, or chichele, is of limited extent. The spring has no potential as a tourist attraction, and does not appear to be much frequented by game.

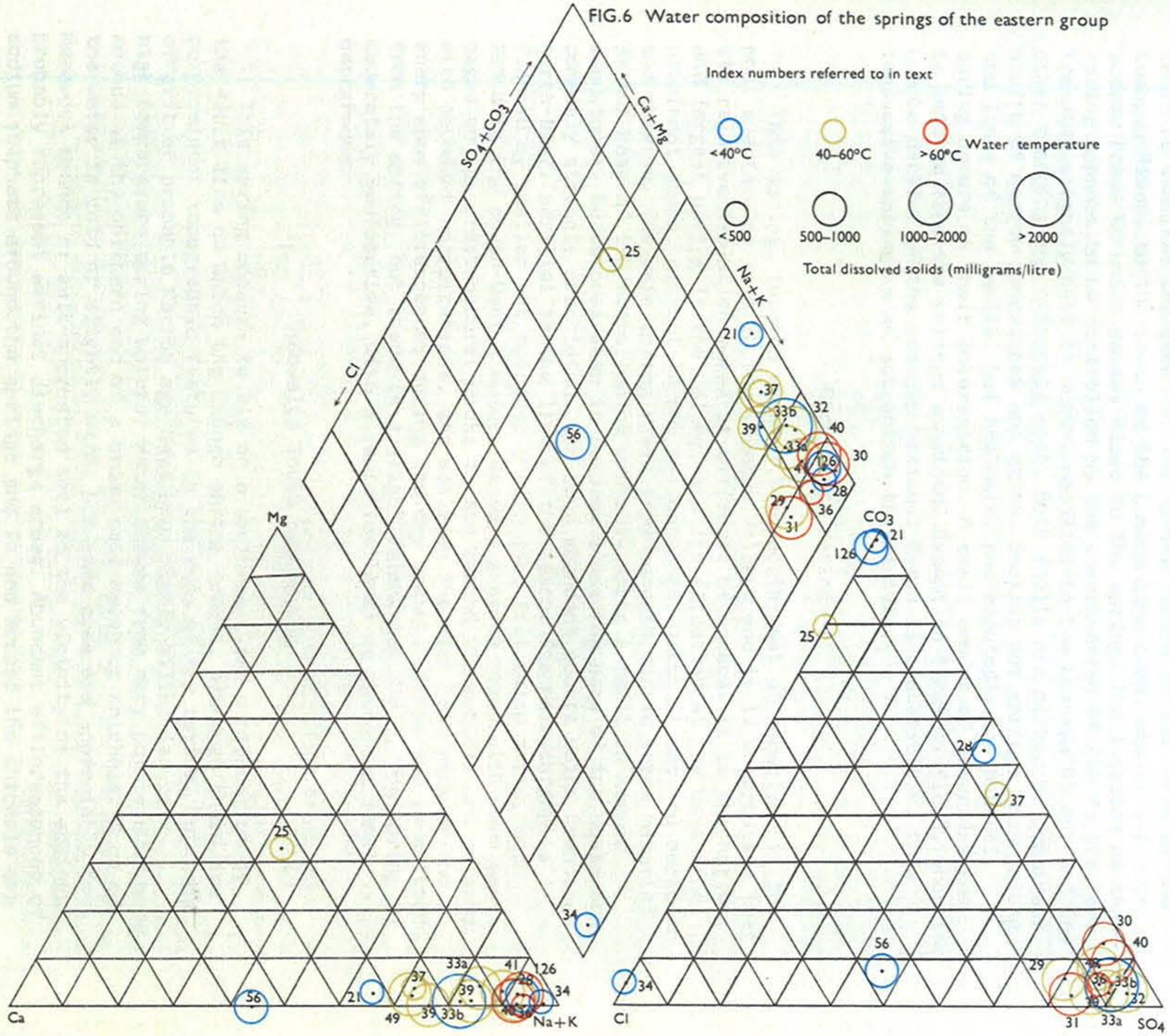


FIG.6 Water composition of the springs of the eastern group

Kalamulilo hot spring

This spring, which is reported to be of considerable size, was largely flooded at the time of the author's visit in February 1973. As a result, only smaller springs on ground higher than the main spring could be examined and sampled. The spring occurs on the banks of the Luangwa River, to the south of the Lusaka game camp, one of the main access roads to which passes close to the spring. The location of the spring appears to be controlled by the intersection of two faults, one trending slightly east of north, parallel to the Luangwa River, and the other trending approximately east. Both faults are marked by prominent bluffs of Karroo sandstones and grits. Smaller hot springs occur along the lines of the faults, but the main, and reputedly the hottest, spring occurs at their intersection. A small amount of odourless gas is emitted from the springs examined. Except in times of flood, when the Luambe portion of the Luangwa National Parks is inaccessible, this impressive spring is an attraction to tourists.

Chongo hot spring

This spring, located about 1.5 km north-west of Nabwalya, is the most spectacular seen in the Luangwa Valley, and it is unfortunate that its relative isolation makes it difficult of access. It is the hottest and largest spring in the valley, and its situation at the base of a prominent scarp, without marshy surroundings, makes it easy to approach and observe. The main spring rises from beneath coarse scree material at the base of the scarp, which probably marks a fault in Karroo sandstones. Sandstones seen in outcrop along the base of the scarp are commonly strongly brecciated, and have abundant quartz veins trending north-east, parallel to the line of the scarp. The main spring is flanked by smaller hot seepages rising also from below scree, and 200 m to the south-west a muddy, densely grassed mound with warm seepages on its crest,occurs. Rocks in and around the springs are covered with abundant encrustations, and soils on the flat land west of the scarp show efflorescences during the dry season. Little gas is emitted from the spring, but there is a slight sulphurous smell. The spring is moderately radioactive, with a radiation level of twice the local background.

Nabwalya South hot spring

This spring appears to lie on a south-westward continuation of the fault line on which the Chongo spring occurs, although there are no prominent topographic features in the area of the spring. Outcrops of grit of probable Karroo age have been highly silicified by high-temperature spring waters. Water issues from many points over mudd mounds at the northern end of a broad salt marsh or chichele. Much of the water is cold or slightly warm, but some eyes are appreciably hot. Numerous mounds of salt-encrusted soil in the vicinity of the springs probably represent extinct discharge areas. Abundant efflorescences of sodium sulphate around the springs and in and around the chichele are an attraction to game.

Kazakaza hot spring

This spring is situated on the south bank of the Chilimanyama River 4 km upstream from its confluence with the Lukusuzi River. A zone of hot seepages trends north-north-west across a broad sub-circular gravelly area 150 m in diameter, parallel with the strike of the surrounding psammites and graphitic schists. The zone is apparently coincident with the outcrop of a distinctive band of graphitic schists. Other rocks exposed in the area include ilmenite-rich gneisses and conformable quartz-feldspar pegmatites. Water from the springs overflows the lip of the sub-circular depression into the Chilimanyama River. Encrustations and efflorescences were few at the time of the author's visit in March 1973, but may be more abundant during the dry season. A small amount of gas with a slight sulphurous smell is emitted. The spring is markedly radioactive, with a radiation level of four times the local background.

Nsefu salt spring

This spring, because of its situation on the main access road to the popular Nsefu Game Camp, 10 km to the west, and because of the abundance of game, is undoubtedly the spring in the Luangwa Valley best known and most visited by tourists. Game is attracted to the spring because it is the only source of water during the dry season, and because of the abundant salty efflorescences.

Cool, mineralised water (*see* table 11) rises in a roughly circular muddy area some 200 m in diameter, the surface of which is raised slightly above the surrounding ground. There are no well-defined eyes, and the water seeps from numerous broad patches on the muddy surface. No gas in emitted, there is no smell, and the radioactivity is not above the local background level.

The standpipe of the Nsefu artesian borehole, drilled some years ago in an attempt to provide water for a proposed tourist hotel intended to overlook the chichele, is situated 250 m north of the spring. The borehole intersected hot water at an unknown depth, but probably less than 60 m, and has discharged water of relatively constant composition and temperature ever since. The fact that water samples collected late in the dry season are slightly more concentrated than a sample collected soon after the end of the rains (*see* table 11) may indicate a seasonal variation in water composition as a result of dilution by surface water, but the data are insufficient to confirm this.

No rocks crop out near the spring, but is seems probable that the area is underlain by rocks of Karroo age. The spring and borehole are probably located on a north-south striking fault system; the lower rate of flow and lower temperature of the spring water compared to the borehole may be a result of the gradual sealing and constriction of the uppermost part of the fracture system by material deposited from the rising water. The borehole appears to have intersected the fault itself or a good aquifer, such as sandstone. Differences in relative proportions of ions in borehole and surface water are small, but the spring water is more than twice the concentration of the borehole water, due probably to rapid evaporation in the shallow pools from which the spring water was collected.

Manze salt spring

This is the most northerly of a group of four springs occurring along a Karroo basement contact fault along the eastern margin of the Luangwa trough. Water issues from two broad, marshy, *see*page areas on either side of a low ridge, and flows north-eastwards into the Manze River, and thence to the Luangwa River. There are no well-defined eyes, and no water temperatures in excess of the ambient air temperature were recorded. No gas is emitted, there is no smell, and the spring is not radioactive. The abundant salty encrustations on the soils around the spring are a great attraction to game, and access to the springs is by a game-viewing route.

Chilube salt spring

This seepage, 20 km south of Chinzombo on the Chilongozi road, has no surface discharge of water, and the temperature is not above ambient. Three small seepage points on the north side of the track to the Wilderness Trails camp, and another seepage 10m to the south, are surrounded by areas of deep plastic mud. Soundings with a long pole indicated a depth of mud in excess of 5 m. Apparently attracted by the saline encrustations on the thin crust over the mud, animals as large as giraffe rapidly become trapped. No rocks are exposed in the area of the spring, although it appears to occur along the same major fault as the Manse spring. Water issuing from beneath a thick cover of alluvium apparently keeps the fine silty material permanently moist and plastic. The water composition is unusual in its high carbonate content and lack of sulphate.

Musaope hot spring

This spring is situated about 2 km to the east of the Chinzombo-Chilongozi road, 1.5 km south of Musaope Village. Although the spring is outside the National Park, there would be little difficulty in making it accessible to tourists visiting the Luangwa Valley.

Hot water is emitted at numerous points over an area of 30 m by 5 m at the base of the eastern escarpment of the Luangwa Valley. Rock fragments in and around the spring include quartzite, amphibolite and gneiss, all apparently derived from rocks of the Basement Complex. The spring almost certainly lies on a Karroo-basement contact fault, although no Karroo rocks are exposed. In the area of the spring there are a few fragments of vuggy, finely-crystalline quartz, identical in appearance to material found in the Lochinvar fault zone in the Southern Province of Zambia. A few metres to the south of the spring a mound of banded, grey material, rich in calcium carbonate, with abundant cavities, identical in appearance to the travertine which makes up the spring mound at Lubungu, occurs. The spring water at Musaope is richer in sulphate than either the Lochinvar or Lubungu waters, and is poorer in carbonate than Lubungu. The only material at present being deposited at the surface by the spring water is a white substance, composed mainly of sodium sulphate, which encrusts all the rocks in the area of the spring pools. It appears likely, therefore, that silica was deposited originally and was superseded by the material rich in calcium carbonate. This possible evolutionary trend is discussed more fully in a later section of this report.

Orange, yellow, red and green algae are abundant in the spring pools. Small amounts of gas having a slightly sulphurous odour, are emitted from the spring. The radiation level is slightly above the local background level. Water from the spring flows down a well-defined channel to the west through sparse bush, and discharges into a broad elongate salt marsh.

Malanga hot spring

These springs occur about 1 km from the base of the eastern scarp of Luangwa Valley, 500 m east of the Malanga River. Three springs in a distance of 500 m occur along the base of a low, north-north-east trending ridge, apparently composed of basement quartzite, although exposure is very poor. Only the southern spring, the largest of the group, has been sampled. The central spring is a muddy seepage, while the the northern spring discharges into a small chichele. The main spring rises in a small area of swamp, and then flows westwards through a pebbly channel into a swampy chichele. Pebbles around the spring are covered in salty encrustations, and pebbles in the soil are cemented by calcareous tufa or calcrete. A small amount of gas with a slightly sulphurous odour is emitted. The radiation level over the spring is four times the local background.

Chikoa hot spring

This spring, also known as Kabilubilu, is situated along the Kasenengwa River, 3 km north-west of Chikoa Mission in the Jumbe District. Water issues from numerous points in the bed of the Kasenengwa River, and from the northern rockly bank up to one metre above the water level. The rocks exposed are well-foliated biotite and chlorite schists, with irregilar, roughly equant inclusions of amphibolite up to 2 m across; all the rocks are fractured. The spring appears to be situated a short distance to the east of the major fault bounding the trough of the Luangwa Valley. At the time of the author's visit on the 9th June 1973, the springs provided most of the flow of the river at this point, and numerous small fish and abundant green algae were seen in the pools of warm saline water. The pools are used by the local villagers as a bathing place. Abundant encrustations cover the rocks in the vicinity of the springs. A small amount of gas, with a slight sulphurous smell, is emitted from some of the larger eyes.

Msoro hot spring

The location of this spring is 2.5 km to the north-west of Msoro Mission. Water issues from a number of eyes aligned roughly north-west, in a pool 1.5 m deep, and 1.5 m by 4 m in area. The pool water is very clear, but the surface of the pool is covered by green algal mats with abundant encrustations. Water from the spring flows through two channels into an extensive chichele, and pools of water around the fringes of the marsh are used as a bathing place by people from the mission and the surrounding villages. A small amount of odourless gas is emitted, and the radiation level is slightly higher than the local background. The soils over a broad area around the spring and chichele are covered during the dry season with abundant sulphate efflorescences. Although there are no rock outcrops in the area of the spring, its location appears to be controlled either by a Karroo-basement contact fault, or by a subsiduary fault within the Karroo.

Mwape hot spring

This spring, also known as Ntibi, occurs along the Mvuvye River 4 km south-east of Chieftainess Mwape's headquarters. Small, warm springs rising from the bed and the banks of the river were contributing about 80 per cent of the flow at the time of the author's visit in June 1973. The springs have a roughly east-west alignment, and are apparently located on a Karroo-basement contact fault. A quartz-mica-tourmaline pegmatite crops out to the south of the spring, and although there are no outcrops immediately to the north, Karroo conglomerates are well exposed further upstream. Some gas having no odour, is evolved from the springs. The radiation level is about 1.5 times the local background.

Kanzi hot spring

This spring is situated along the Nyimba River. 15 km east-south-east of Nyimba township, near Chikuwe school. Warm water flows from a series of north-south trending fractures in well-foliated. leucocratic biotite gneisses. The foliation is flat-lying, and there are some irregular boudin-like inclusions of amphibolitic material and some simple pegmatites. There are numerous small eyes in pools in the bed of the Nyimba River, as well as some small seepages along the south bank. At the time of the author's visit in June 1973, almost the entire flow of the river at this point was derived from the springs, and many small fish inhabited the warm saline water. The high contents of calcium and chloride in the spring water are abnormal for the area. A small amount of odourless gas is emitted. The springs have up to three times the local background radiation level, and encrustations, mainly of sodium and calcium chlorides, are abundant on rocks around the margins of pools.

SPRINGS OF THE SOUTH-EASTERN GROUP

This is a heterogeneous group of isolated springs which have received little attention. The group extends from the north part of the Lukusashi Valley, through the Luano Valley, to the Zambezi River at Lake Kariba. Only two of the springs have been visited by the author, but others have been visited by geologists engaged in regional mapping. Most of the springs have been located from a helicopter, but many remain to the sampled.

The water chemistry, temperature and discharge of the sampled springs are given in table 12, and the composition is shown graphically in fig. 7. The spring waters tend to be rich in carbonate and sulphate at the expense of chloride. A few springs are unusually rich in calcium and magnesium.

Mililo hot spring

The spring is situated along the Mililo stream in the Chisomo area, and is probably on a Karroo basement-contact fault. Water is emitted from the banks and the bed of the stream in a zone about 5 m long having an approximately north-south trend. There may be other springs upstream, as the water is warm, and excavations for a grave in the bush to the east of the springs encountered hot water. A little gas having a sulphurous odour is emitted, and the sand along the stream bank is covered with encrustations during the dry season.

Masaka hot spring

The spring occurs 500 m up a north bank tributary of the Masaka River. The tributary joins the Masaka River 1 km upstream from its junction with the Tumbwe River. The spring occurs on a north-east trending fault which is parallel to the boundary faults of the Lukusashi Valley, but within basement rocks. On the escarpment to the north-west of the fault metasediments and pegmatites occur, while gneisses are found on the lower ground to the south-east. Hot water issues from an elongate seepage area, from which it flows through a shallow channel into the nearby stream. A small amount of gas with a slight sulphurous smell, is emitted. Pebbles in and around the spring are covered with encrustations during the dry season.

Bwingi River hot spring

This spring is located on the Bwingi River at the foot of the main escarpment of the Lukusashi Valley. The Bwingi River, which rises in an area underlain by garnet schists and quartzites, cuts down through these rocks in the escarpment zone to the valley, where Karroo sediments are downfaulted against basement. The spring rises at a locality about 12 m east of the main, boulder-filled channel of the Bwingi River, where it emerges from the escarpment. The water from the spring flows parallel to the river, and joins it about 60 m downstream. No gas is emitted, there is no smell, and there are no encrustations or efflorescences, due probably to the very low content of solids in the spring water.

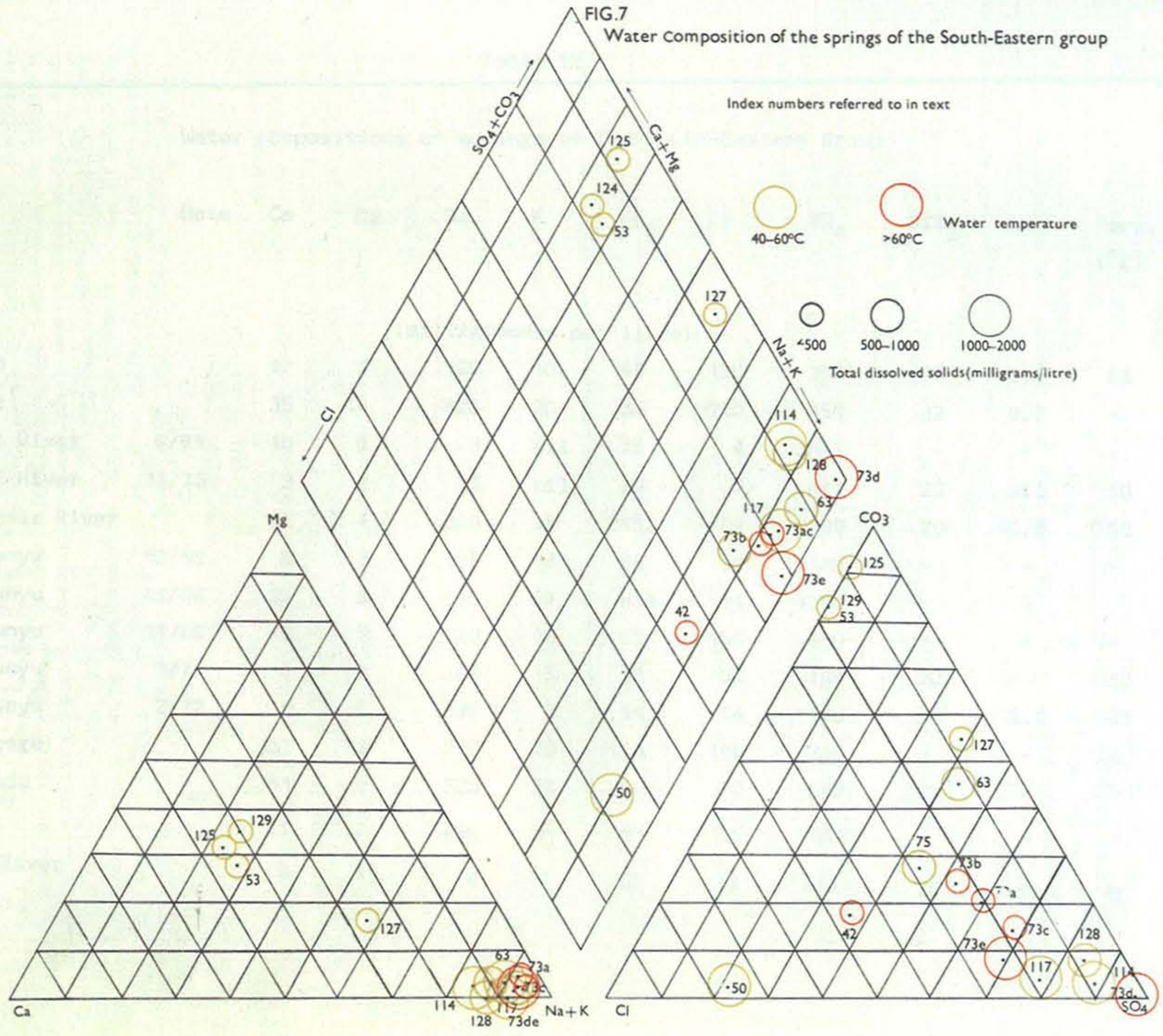


FIG.7 Water Composition of the springs of the South-Eastern group

Table 12

Water compositions of springs of the South-Eastern Group

No.	Name	Date	Ca	Mg	Na	K	CO_3	Cl	SO_4	SiO_2	Li	Temp. (°C)	Discharge (lit/sec)
			(milligrammes per litre)										
42	Mililo		17	1	120	10	48	120	100	40	0.6	65	
50	Masaka		35	14	420	20	30	920	250	32	0.3	-	
53	Bwingi River	9/65	10	9	3	nil	35	4	nil	-	-	-	
53	Bwingi River	11/73	3	2	2	nil	10	2	nil	20	nil	50	3
63	Kalingala River		22	4	300	15	246	64	230	20	0.8	50	6
73	Chinyunyu	10/59	6	3	128	4	36	50	180	-	-	-	
73	Chinyunyu	11/69	29	5	510	57	nil	11	1050	-	-	-	
73	Chinyunyu	11/69	16	5	320	18	60	150	480	-	-	-	
73	Chinyunyu	3/71	7	2	84	5	36	36	104	32		63	6
73	Chinyunyu	2/72	8	5	120	5	54	54	130	40	0.1	61	
75	Chakwenga		32	6	270	10	150	150	230	-	-	-	
114	Chirundu		51	3	320	20	18	70	680	-	-	-	
117	Barare		51	2	488	38	48	192	862	-	-	-	
125	Mikwa River		6	4	2	1	20	2	nil	20	nil	60	2

Table 12 (Continued)

No.	Name	Date	Ca	Mg	Na	K	CO_3	Cl	SO_4	SiO_2	Li	Temp (^oC)	Discharge (lit/sec)
127	Unnamed		32	20	55	15	120	14	85	24	0.1	40	1
128	Mafwasa		36	1	270	14	50	48	520	40	0.6	60	2
129	Chitopolo		8	7	4	1	30	6	nil	30	nil	60	1.5
130	Kampoko No. 1		23	2	176	9	90	36	250	30	0.5	35	0.5
131	Kampoko No. 2		37	6	92	9	96	20	135	30	0.2	40	0.5

Kalingala River hot spring

This spring was sampled by P. Reichwalder, Geologist, during regional mapping, and was visited later by the author. The spring is situated at the foot of the major escarpment along the southern side of the Luano Valley, and appears to be located at the intersection of the main Karroo-basement boundary fault with a north-south cross fault. Water is discharged from a number of springs having an approximate north-south alignment, and flows northwards through an area of salt marsh into the Kalingala River. There are abundant efflorescences on the soils during the dry season, and the springs are a source of water for game.

Chinyunyu hot spring

This spring is situated on the Great East Road within easy reach of Lusaka, and is the best-known spring in Zambia.

The main spring is situated on the eastern slope of the Chinyunyu Valley, about 100 m north of the Great East Road. Water from the spring has been artificially channelled into a large excavated pool which is used as a bathing place. Since the undiluted spring water at the numerous small sources is much too hot for comfortable bathing, it is mixed with surface water to reduce the temperature. A second spring occurs 300 m south of the main road, and has been modified by the construction of a small concrete dam and pool which is used as a laundry. The springs occur in an area underlain by basement rocks, on an extension of the young faults which define the margins of the Mwapula re-entrant on the southern side of the Luano Valley.

A small amount of odourless gas is emitted from the springs. The springs are slightly radioactive, with a radiation level about 1.5 times the local background.

As indicated in table 12, the results of analyses of water samples taken at different times differ widely. This may be due in part to variation of the composition at different points. Samples taken from the main pool, for example, are probably diluted and contaminated with soap and detergents. The samples collected in March 1971 and February 1972 were collected from the same spring eye, and are similar in composition, although there is a higher concentration of most constituents in the later sample.

Mikwa River hot spring

A number of small springs rise in an area of brecciated quartzite, rubble and soil to the north-east of the Mikwa River. Water issues from fissures in the basement quartzite, which occurs adjacent to a boundary fault between basement and Karroo rocks, which cuts into the escarpment zone in this area. A small amount of odourless gas is emitted from the springs; encrustations are not common, probably because of the very low dissolved solids content of the water.

Unnamed hot spring

This small hot spring lies 8 km to the east of the Lukusashi River, on a basement-Karroo boundary fault, and is visible on air photographs as a distinctive patch of evergreen trees. No gas is emitted and because of the low content of dissolved solids, there are no encrustations.

Mafwasa hot spring

A group of six small springs occur in a distance of 100 m along a north-north-easterly zone on the western side of the Mlembo River where it crosses a Karroo-basement boundary fault. No gas is emitted, but there is a faint smell of hydrogen sulphide, and there are minor encrustations on rocks around the springs.

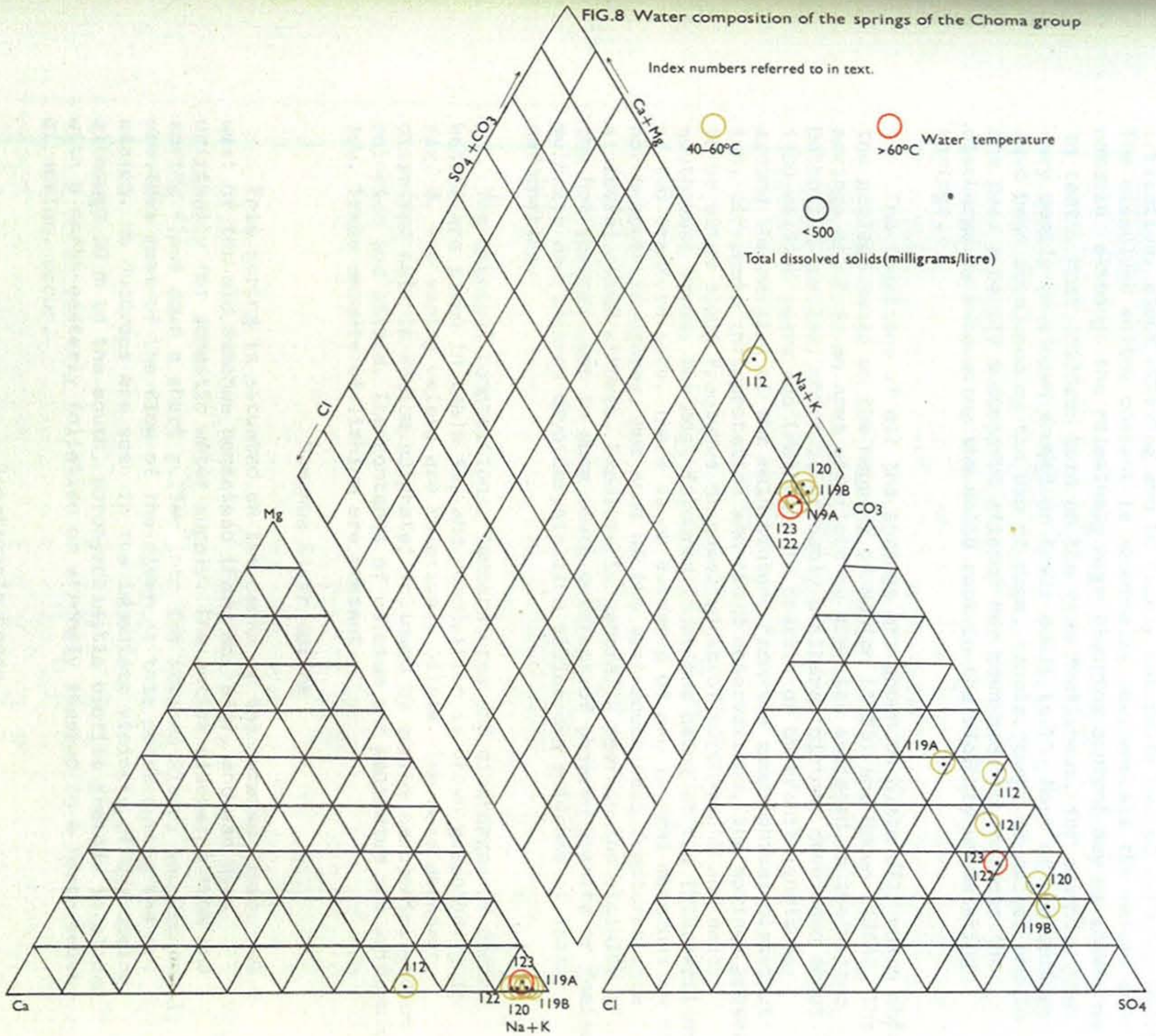
Chitopolo hot spring

Water issues from two main areas of fault breccia 25 m apart, immediately uphill from the Karroo boundary fault at the edge of the escarpment zone. The spring can be seen on air photographs as a dark patch of luxuriant vegetation. No gas is emitted, there is a slight unpleasant smell, and encrustations are few.

Kampoko River springs

The No. 1 Kampoko River spring is located at the point where the river enters the Lukusashi Valley, on the east bank, 150 m downstream from the entrance to the Kampoko gorge. The spring is located on a boundary fault, with basement quartzites and schists to the north and Karroo grits and conglomerates to the south. No gas is emitted, there is no smell, and there are no encrustations. No. 2 spring is located about 150 m to the north of No. 1 and, apart from being slightly warmer, the water has similar properties. The five springs at Kampoko River were sampled by A.C. Hickman, Senior Geologist, during regional mapping.

FIG.8 Water composition of the springs of the Choma group



THE CHOMA GROUP OF SPRINGS

The hot springs to the north of Choma form a compact and isolated group apparently situated along fractures in basement granite. They occur on commercial farms, and are used for domestic water supply, irrigation, stock watering and to supply naturally heated swimming pools. The dissolved solids content is abnormally low, and all the waters are potable, although the relatively high fluorine content may be injurious to teeth. Most children born on the farm Muckleneuk, for example, have very poorly-developed enamel on their adult teeth. Most of the springs have been developed by the use of dams, canals, tanks or wells, and in one case a partly successful attempt has been made to increase the discharge by excavating the solid rock in the vicinity of existing springs.

The locations of all the springs are shown on plate VII, which shows the geology based on the mapping of Newton (1963) and Brown (1964). The springs occur in an area underlain by granites assigned to the Kalomo Batholith complex, which is probably a Kibaran pluton, developed about 1100 million years ago (Matheson in press), or by granite-gneisses around the margins of the main pluton. From the geographical distribution, air-photo interpretation and field observations, the springs appear to be sited along fractures or shear zones of north-south and east-south-east trend, the most favoured locations being at the intersections of two fracture sets. There is no evidence of any lateral movement on the north-south fractures, but some of the east-south-east fractures show sinistral shear effects. Exposure is generally poor in the vicinity of the hot springs, but in some cases outcrops of sheared granite or gneiss, mylonite and sheared cryptocrystalline silica are evidence of local deformation.

The chemical compositions, temperatures and discharges of spring waters are given in table 13, and composition is shown graphically in fig. 8. The spring waters are relatively dilute. The most abundant dissolved salt is sodium sulphate, followed by sodium carbonate, sodium chloride and silica. The contents of calcium and magnesium are uniformly low. Trace amounts of lithium are present.

Semahwa River spring

This spring is situated on the banks of the Semahwa River, 400 m west of the old Semahwa homestead (Farm No. 81a), and was used originally for domestic water supply. The entire discharge from the spring flows down a short gulley into the Semahwa River, and apparently provides most of the flow of the river at this point during the dry season. No outcrops are seen in the immediate vicinity of the spring, although 30 m to the south, porphyroblastic biotite gneiss, in places with a north-easterly foliation or strongly sheared in a north-south direction, occur.

Sportsman's Lodge

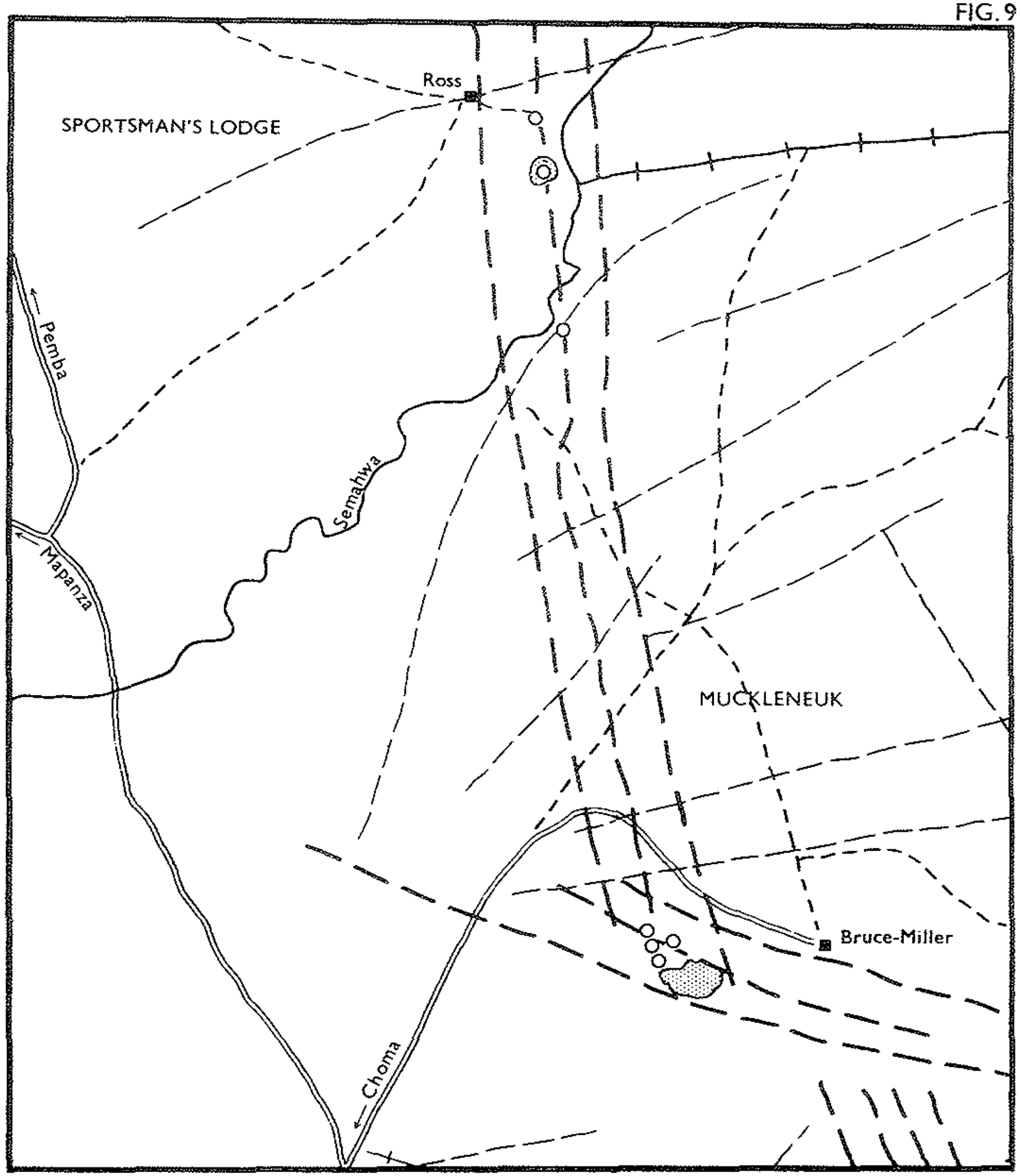
The springs on the farm Sportsman's Lodge (No. 213a) are used for domestic water supply, irrigation and stock watering, and formerly for the swimming pool. There are at least four springs in this group, two in swimming pools and others in a large circular earth dam. The

Table 13

Water compositions of hot springs of the Choma Group

No.	Name	Ca	Mg	Na	K	CO_3	Cl	SO_4	SiO_2	Li	Temp. (^oC)	Discharge (lit/sec)
		(milligrammes per litre)										
112	Semahwa River	36	3	95	6	108	12	115	40	0.1	46	1.3
119	Chibimbi North	3	1	100	4	84	20	65	40	nil	58	0.6
119	Chibimbi South	4	1	100	4	36	18	130	32	nil	48	1.9
120	Mosali	7	1	140	10	60	24	190	40	0.8	52	0.4
121	Sportsmans Den	4	1	110	7	72	22	108	40	0.1	48	3.3
122	Muckleneuk North	5	1	110	6	60	24	124	40	0.1	44	0.3
123	Muckleneuk Main	5	1	110	6	60	24	124	40	0.1	74	6.3

FIG. 9



HOT SPRINGS ON FARMS
MUCKLENEUK AND
SPORTSMAN'S LODGE
CHOMA DISTRICT

Scale 1:30,000

m 300 0 300 600 900 m

Road
Farm track
Boundary fence
Dam
Homestead
Hot spring
Major trend on air photos
Minor trend on air photos

discharge has been measured at intervals for a period of years by the farmer, and is reported to remain constant at all seasons. No rocks are exposed in the area of the springs, but examination of air photographs indicates that the springs occur at the northern end of the fracture system on which the Muckleneuk springs are located (*see* fig. 9). The composition of the water from the springs on both farms is almost identical.

Muckleneuk North springs

These springs are situated on the farm Muckleneuk (No. 60a), about 150 m east of the Semahwa River and 300 m south of the Sportsman's Lodge springs. Muddy seepages occur over a fairly wide area of approximately north-south trend. The total discharge is very small, and few of the springs are noticeably hot. An attempt was made in the past to use the spring water to fill a shallow dam for cattle watering, but this appears to have failed due to the low discharge. There are no rock outcrops around the springs, but spoil from the excavations for the old dam contains fragments of granite, vein-quartz and finely-banded chalcedonic silica.

Muckleneuk Main springs

These springs are located 0.5 km to the south-west of the Muckleneuk homestead, and are the largest and hottest in the area (fig. 10). They are used for domestic water supply, for bathing, and to fill a large dam from which water is pumped for irrigation and stock watering purposes. The springs were visited in 1901 by D. Ferguson, a mining engineer who described them in a paper presented to the Rhodesian Scientific Association in 1902. He refers to the springs as the Goa Geysers, and presents measurements of water temperature, discharge and chemical analyses. A sample from Muckleneuk Main spring gave the high value of 7 milligrammes per litre fluorine. None of the springs is markedly radioactive. The water compositions are compatible with derivation of the dissolved solids by leaching of hard, relatively impermeable granite by normal groundwaters, heated by percolation to depths of at least 3 km and carried upwards by convection.

Chibimbi springs

These springs are situated on Chimbimbwe Farm (No. 62a), the most northerly farm in the Choma Intensive Conservation Area. There are two separate groups of springs, one to the north-west and the other to the south-west of the farmhouse.

The northern group is undeveloped and is not used, except for bathing. Two main groups of eyes, orientated east-west, were seen at the time of the author's visit, although there are probably other smaller seepages in the surrounding swampy valley. Exposed rocks are mainly gneisses amd migmatites, with some bands of fine-grained sericitic quartzite to the south and west. All rock types show a well-developed, near vertical foliation striking east-south-east.

Formerly, the springs of the southern group were used for domestic water supply, for irrigation, and to serve a swimming pool. The two main groups of eyes are in sub-circular pools, probably artificially enlarged, and are connected by a channel. Two trenches 15 m long and up to 2 m deep, orientated parallel to the strike of the fine-grained, well-foliated sericitic quartzites were dug in an attempt to increase the supply of water, with the result that warm water issues along the foliation planes exposed in parts of the trenches.

Mosali spring

This spring is located on the farm Mosali (No. 37a), near Chimbimbwe. The spring has been used for stock watering, a small dam having been constructed downstream from the swampy spring area, which is fenced off to exclude cattle. The spring discharge is very low, and no well-defined eyes are visible. The low discharge allows convection to take place in the spring pool, so that the surface water is normally hotter than water at depth - the reverse situation to that found in large, more vigorous springs. No rocks are exposed in the vicinity of the springs, but on the hills to the east there are numerous scattered outcrops of granite showing strong north-westerly shear planes or foliation.

A detailed map of the springs is shown in fig. 10, and their relation to those at Sportsman's Lodge is shown in fig. 9. At the time of the author's visit in January 1974 the water level in the dam was unusually high, so that some springs were inaccessible. The springs visited have a linear distribution along two main directions, one trending nearly north and the other east-south-east. Air photographs reveal strong lineaments parallel to these directions. The north-south lineaments appear to be displaced sinistrally by the east-south-east lineaments; the main Muckleneuk springs are located in the zone of displacement. The lineaments are interpreted as major fractures in granite, but exposure is extremely poor in the vicinity of the springs and this cannot be verified. Isolated boulders of medium-grained, non-foliated granite; gneissose, medium-grained granite; and coarse-grained, pegmatitic granite occur amongst the springs. There are also boulders of banded, vuggy, chalcedonic silica, very similar to material found along the Lochinvar fault zone.

Many of the springs occur on the crests of low mounds, the surfaces of which are usually extremely spongy and covered with vegetation. Shallow pits sunk into the mounds exposed black organic-rich soil, bonded together at the surface by abundant rootlets. Hot water was intersected at shallow depths in all the pits. The difference in elevation between the highest and the lowest springs above dam level is about 3 m, but the elevations of the springs below dam level are not known. As shown in fig. 10, there are a large number of separate eyes, and water seeps out also over the flanks of the mounds and in areas of swamp. The total discharge of the spring group is large (*see* table 13), but none of the individual eyes exposed above water level has a large discharge at the present time. Water supply for the farmhouse is obtained from a small well which was sunk about 35 years ago to a depth of 1.7 m on one of the largest and hottest springs. The vertical thermal gradient encountered during sinking of the well appears to have been nearly 10°C per metre. When completed the well was capped in the hope that the pressure would be sufficient to force water up to the level of the farm-house, some 10 m above the water level and 500 m distant, but no pressure was developed and water began to issue from the swampy ground near the well. There would appear to be potential for tapping high temperature water at a relatively shallow depth by drilling and casing the drill hole to near the base. Any borehole site should be selected on the results of detailed soil temperature and resistivity surveys.

THE LOCHINVAR GROUP OF SPRINGS

The Lochinvar springs are of special interest because they occur along a well-defined, major fault in an area in which the geology is known in some detail. The large number of boreholes sunk for the watering of cattle has allowed detailed studies of the groundwater conditions to be made and numerous water samples to be collected. Some of the spring waters are amongst the hottest in Zambia, and there may be some potential for geothermal development. There is a close spatial, and probably genetic, relationship between the hot springs and the economically important deposits of gypsum which are being worked at Lochinvar. The springs are situated in the Lochinvar National Park, and in addition to their intrinsic interest, unusual flora and fauna are to be found in their immediate vicinities.

The geology of the Lochinvar area is shown in plate VIII. The two main groups of hot springs and the Namulula spring to the south, occur along a major fault zone separating Karroo sediments overlain by alluvium to the north from older rocks of Katanga and pre-Katanga age to the south. The direction of the fault swings from easterly at Banakaila outside the eastern boundary of the park, through east-north-east at the Gwisho springs to north-east at Bwanda and Namulula. A recent gravity survey of the area, initiated by the Geological Survey and continued by the University of Zambia Physics Department, has indicated that the fault zone consists of a number of closely-spaced, sub-parallel faults, dipping steeply to the north, and with a total downthrow to the north of between one and one and a half kilometres (Topfer pers. comm. and Mazac in press).

In many places the outcrop of the fault zone is marked by a very striking breccia, made up of finely-banded, vuggy, cryptocrystalline and microcrystalline quartz with fragments of indurated mudstone and sandstone, and minor amounts of fluorite and pyrite. No fragments of undoubted pre-Karroo rocks have been observed in the breccia. It is particularly well-exposed around the Gwisho springs and in the area between the springs and Sebanzi Hill.

The main rocks exposed are quartzites and gneisses, which are well-foliated, have a constant east-south-east strike and generally dip northerly. Rock exposures near the fault zone are fractured and are traversed by narrow veins containing quartz. The only exposures of Karroo rocks are on Sebanzi Hill, which appears to be a fault-bounded block of Upper Karroo grit, which is fractured and cut by zones of siliceous breccia. On the Kafue Flats, a sequence of red mudstones and sandstones of possible Upper Karroo age (Brown 1966) are overlain by 5-10 m of alluvium (Hadwen 1971). The alluvium is normally fine-grained, with plastic montmorillonitic clays predominating. Gypsum is common as discrete crystals in the upper three metres, where it is sufficiently concentrated to permit economic exploitation (Walker and Lyall 1960).

The results of chemical analyses of Lochinvar spring waters are given in table 14, and analyses of groundwaters from boreholes in table 15. The spring waters show high ratios of sodium to potassium, a wide range of chloride to sulphate ratios and low carbonate values. The Bwanda springs are normally more chloride rich than the Gwisho springs at any given time, although over a period of years the compositional fields overlap. The main variation with time is the chloride to sulphate

Table 14

Water compositions of springs of the Lochinvar Group

Name	Date	Ca	Mg	Na	K	CO_3	Cl	SO_4	SiO_2	Li	Temp.
		(milligrammes per litre)									(°C)
Bwanda	12/59	74	5	520	26	51	270	880			
Bwanda	1/72	55	12	320	34	42	275	450	40	3.0	93
Bwanda	5/72	60	3	450	35	50	260	710	50	2.0	94
Bwanda	9/72	45	15	550	55	30	270	975	44	0.9	94
Bwanda	10/72	69	2	500	50	36	280	850	40	0.7	93
Bwanda	11/72	68	2	450	40	30	270	750	40	0.5	93
Bwanda	1/73	71	3	670	50	36	370	1090	40	1.0	94
Bwanda	11/73	9	1	700	50	36	300	1110	40	1.3	93
Bwanda	1/74	8	1	650	50	30	280	1040	40	1.3	93
Bwanda East	1/72	67	3	320	30	42	275	405	30	3.0	68
Bwanda West	1/72	48	14	300	36	42	270	410	24	3.0	76
Bwanda East	1/73	74	1	620	50	36	320	1040	40	1.0	67
Bwanda West	1/73	66	5	650	45	36	280	1150	40	1.0	76
Gwisho	7/59	102	5	560	24	30	47	1350	14		
Gwisho	1/72	80	17	350	32	72	440	350	40	3.0	69
Gwisho	5/72	86	12	252	35	50	440	720	60	3.0	71
Gwisho	9/72	64	21	700	55	54	440	1100	32	1.2	70
Gwisho	10/72	92	5	560	50	42	440	670	40	1.5	71

Table 14 (Continued)

Name	Date	Ca	Mg	Na	K	CO_3	Cl	SO_4	SiO_2	Li	Temp. (°C)
		(milligrammes per litre)									
Gwisho	11/72	95	2	650	45	48	450	970	40	1.2	72
Gwisho	1/73	94	5	620	45	36	420	980	40	1.2	72
Gwisho	12/73	11	1	750	50	54	440	980	40	1.5	70
Gwisho	1/74	11	1	760	50	36	480	980	40	1.5	71
Gwisho East A	1/72	90	10	370	36	54	480	340	45	3.0	71
Gwisho East B	1/72	83	13	370	30	60	450	360	45	3.0	75
Gwisho West	1/72	98	14	380	32	72	500	380	30	3.0	45
Namulula	1/73	72	9	540	45	60	300	900	32	0.7	52

Table 15

Composition of groundwaters of the Lochinvar area

Name	Date	Ca	Mg	Na	K	CO_3	Cl	SO_4	SiO_2	Li
		(milligrammes per litre)								
Gypsum Mine	?/62	50	10	950	30	140	350	910	-	-
Gypsum Mine	12/72	25	15	788	4	151	408	960	30	0.2
Bwenga Well	?/68	35	35	625	5	580	50	380	-	-
BH KD 27	?/68	161	133	400	6	100	380	520	-	-
BH KD 27	1/74	56	5	8	6	108	4	nil	24	nil
Lochinvar Gate	1/72	66	39	50	8	250	20	nil	20	1.0
Lochinvar Gate	12/72	81	24	39	7	224	12	13	60	0.02
Lodge A	1/72	76	44	200	12	252	160	nil	20	1.0
Lodge B	1/72	120	50	180	12	300	180	120	20	1.0
Lodge C	1/72	80	27	190	12	270	140	64	20	1.0
Mansangu	1/72	80	18	120	6	282	28	30	20	1.0
Mindeco BH	1/74	63	20	20	6	160	8	nil	32	nil

Table 16

Trace elements in Lochinvar waters

Sample	Li	Rb	Ca	Fe	Zn	Mn	Ag
	(milligı	(milligrammes per cubic metre)					
Bwanda Spring	610	380	10	95	2300	44	1
Gypsum Mine BH	190	10	1	1020	460	22	1
Lochinvar Gate BH	22	10	5	154	2620	16	2

Analyses by BRGM

Table 17

Oxygen isotopes in Lochinvar waters

Sample	Delta O^{18} parts per thousamd
Bwanda Spring	-7.7
Gypsum Mine BH	-7.6
Lochinvar Gate BH (1)	-7.9
Lochinvar Gate BH (2)	-8.2

Table 18

Analysis of gas from Bwanda hot springs
(analysis by Prof. E. Tongiorgi, International Institute for Geothermal Research, University of Pisa, Italy)

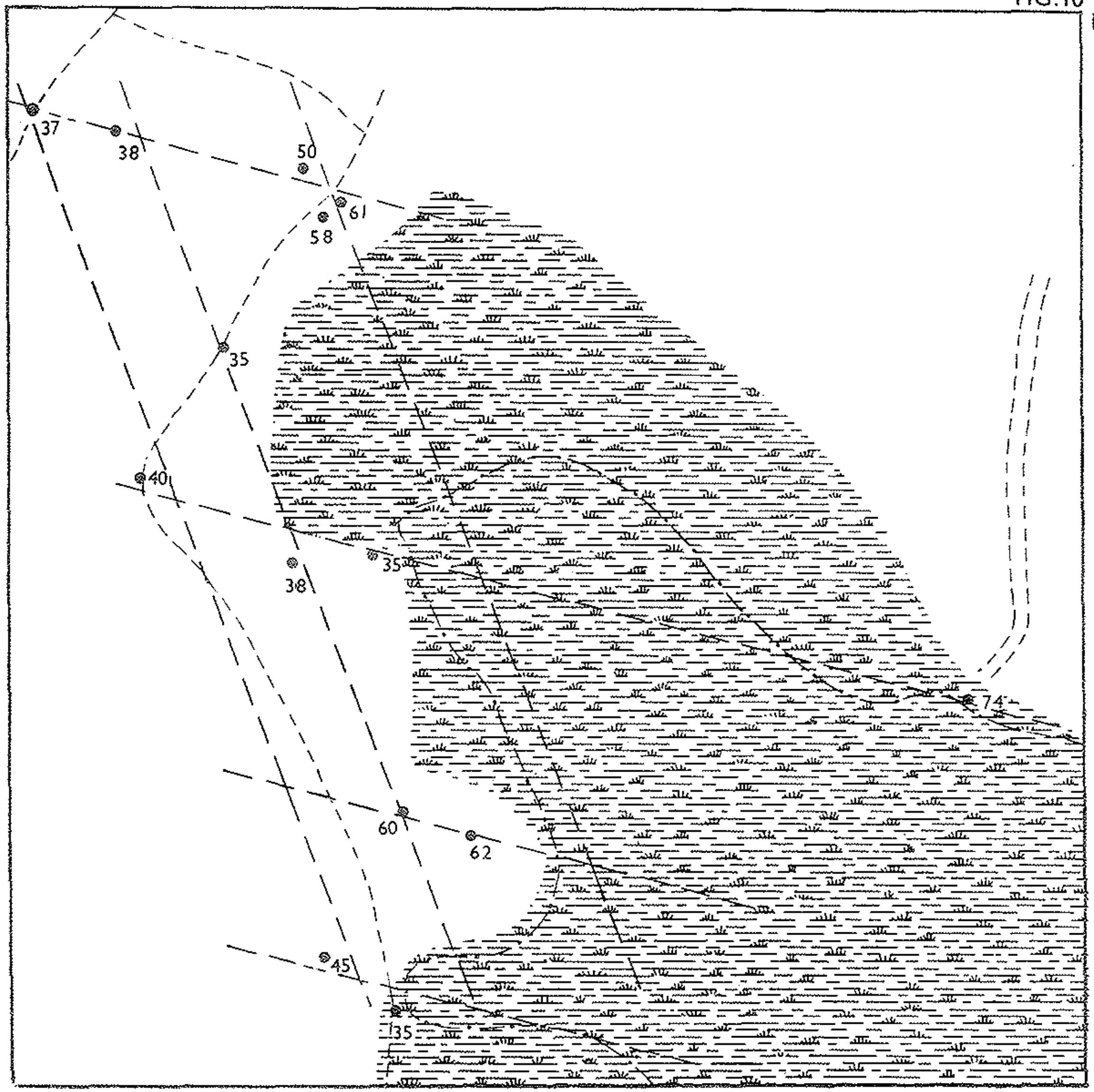
CO_2	10.31	per cent by volume
CH_4	0.86	" " "
N_2	86.42	" " "
O_2	2.41	" " "
H_2	trace	

ratio, with some slight variation in the relative calcium content. The coefficients of variation of the main constituents of Lochinvar waters are much lower than for the springs of Zambia considered together (*see* table 19). This is explained by the relatively homogeneous geological environment of this restricted group of springs. The groundwaters are generally much less concentrated than the spring waters - notable exceptions being those found in some of the boreholes on the Kafue Flats - and in most cases have much higher contents of calcium, magnesium and carbonate than the spring waters. The most anomalous groundwater is that from the borehole at the gypsum mine on the Kafue Flats, which has a composition much nearer to that of the spring waters than any other groundwater in the area. Other strongly anomalous waters, in terms of their sulphate and sodium contents, are those from Bwengwa School and borehole KD 27, both near the fault zone on the Kafue Flats. Water from the boreholes at Lochinvar Lodge, sited in basement rocks close to the fault zone, is not anomalous in composition, although the water has a temperature of up to $5^{o}C$ higher than in boreholes further from the fault.

The comparison between Lochinvar spring waters and groundwaters in the area can be made in more detail by the study of trace elements, and by isotopic studies. The results of trace element analyses of Lochinvar waters carried out by the Bureau de Reserches Geologiques et Minieres and of oxygen isotope analyses carried out at the University of Pisa are given in tables 16 and 17 respectively. Table 16 shows that the concentration of trace elements in Bwanda spring water differs from those in the groundwaters at the gypsum mine and the Lochinvar Gate boreholes, except in the case of zinc. The oxygen isotope ratios in all the Lochinvar waters are similar, and the slightly lower delta O^{18} values obtained at the springs and the gypsum mine compared with the Lochinvar Gate boreholes are probably not significant. Table 18 indicates that the water from the Bwanda springs does not contain significant amounts of rare gases. Its composition is not significantly different from that which would be expected of dissolved air emitted on heating.

Most of the characteristics of the Lochinvar spring waters indicate that they are of meteoric origin. The oxygen isotope ratios confirm the conclusion of Craig, Boato and White (1956), that significant differences in oxygen isotopes between spring waters and normal groundwaters are unusual, and that normally the former are derived from the latter by deep circulation. A possible genetic relationship between the spring waters and groundwater in the Karroo sediments of the area is indicated by the similarity of their major element composition, although some of the trace element data suggest that groundwaters from the higher basement areas to the south of Lochinvar migrated towards the Kafue River. Some of this water percolates downwards into the Lochinvar fault zone where it becomes heated and local convection cells are set up. The Karroo rocks forming the hangingwall of the fault consist of alternations of relatively permeable and impermeable beds, while the footwall rocks are relatively impermeable. With the migration of heated water into the permeable hanging wall rocks restricted convection cells are set up and terrestrial saline deposits are leached to enrich the water in dissolved solids, a process possibly aided by the incorporation of some Karroo connate water. Some of the water in the fault zone eventually reaches the surface by convection, and appears as hot springs, while some of the thermal water flows laterally into permeable Karroo rocks near the surface, mixing with northward-flowing groundwaters and enriching them

FIG. 10



MUCKLENEUK HOT SPRINGS

SCALE 1:1,000

0 10 20 30 40 Meters

EXPLANATION

Swamp

55 Hot spring with maximum temperature in °C on 3/2/74

Track

Inferred fracture

Footpath

Approximate limit of standing water

in dissolved salts. In general, therefore, basement water, such as that found in the Lochinvar Gate borehole, can be regarded as the parent water of the system, the mineralisation of the hot spring water is a result of leaching of Karroo sediments, and the water north of the fault zone, characterised by the mine borehole, is a result of mixing of spring water with northward-flowing groundwater.

The linear arrangement of the Bwanda and Gwisho springs is shown on plate IX and fig. 11. They are not used at the present time, but were used formerly for watering cattle.

The Gwisho G springs are an important Stone Age archaeological site. It appears that the springs were used mainly for protection, as the site occurs on a mound surrounded on three sides by hot springs, and on the fourth by a salt marsh. Cryptocrystalline silica from the fault zone was used extensively for tool-making by the occupiers of the site.

The Lochinvar area would appear to be one of the most promising in Zambia for the development of geothermal energy. The results of preliminary geophysical surveys indicate a basin of Karroo sediments 1-1½ km thick which, with an associated major fault, could give rise to a high geothermal gradient. The thermal conductivity of Karroo sediments is much lower than that of typical basement rocks (Bond 1953). The mean geothermal gradient in the Zambian basement appears to be of the order of 23°C per kilometre (Chapman pers. comm.), but according to Bond (1953), the geothermal gradient in Karroo rocks of the Zambezi Valley can be as high as 58°C per kilometre. Assuming a mean surface temperature at Lochinvar of 20°C, the temperature at the base of 1.5 km of Karroo sediments could be as high as 107°C, even if no deeper circulation occurred in the fault zone. The succession of the Karroo, with interlayered aquifers and aquicludes, suggests that high temperature water could be trapped at depth in favourable aquifers. The geochemistry of the Lochinvar waters is not encouraging, however, and Robson (1974) concludes that the relatively low silica content of the Lochinvar waters and the high to moderate Na/K ratios do not indicate high water temperatures at depth. However, Fournier and Rowe (1966) point out that the silica geothermometer can be used with confidence only in studies of high-silica waters, while Tonani (*in* appendix to Robson 1974), points out that the sodium content of the mine water is exceptionally high, suggesting a derivation by solution of sodium sulphate in the rocks, and it appears possible that the Na/K ratio may be a reflection of relative availabilities of these elements rather than of equilibration temperatures. It is recommended that studies be continued at Lochinvar, firstly to elucidate the geological structure by means of detailed gravity and telluric surveys, and secondly to attempt to gain more information on the possible presence of geothermal reservoirs by deep geoelectrical soundings and seismic ground-noise surveys. These studies should be followed by shallow (200 metre) drilling into the fault zone to gain information on the geothermal gradient, and finally, if the results of the preceding investigations justify it, by deep (1500 m) geothermal drilling.

Since the Lochinvar springs are situated in a national park, and are easily accessible by road from the Lodge, they are frequently visited by tourists. A tourist guide to the hot springs has been published (Legg 1973), and information on the springs is being exhibited in the field museum at Lochinvar. The archaeological site and surrounding springs are a proclaimed national monument, and any detailed studies of the springs should be planned to have the minimum impact on the ecology and natural beauty of the springs and their surroundings.

FIG. 11

THE GWISHO SPRINGS

SCALE 1:10,000

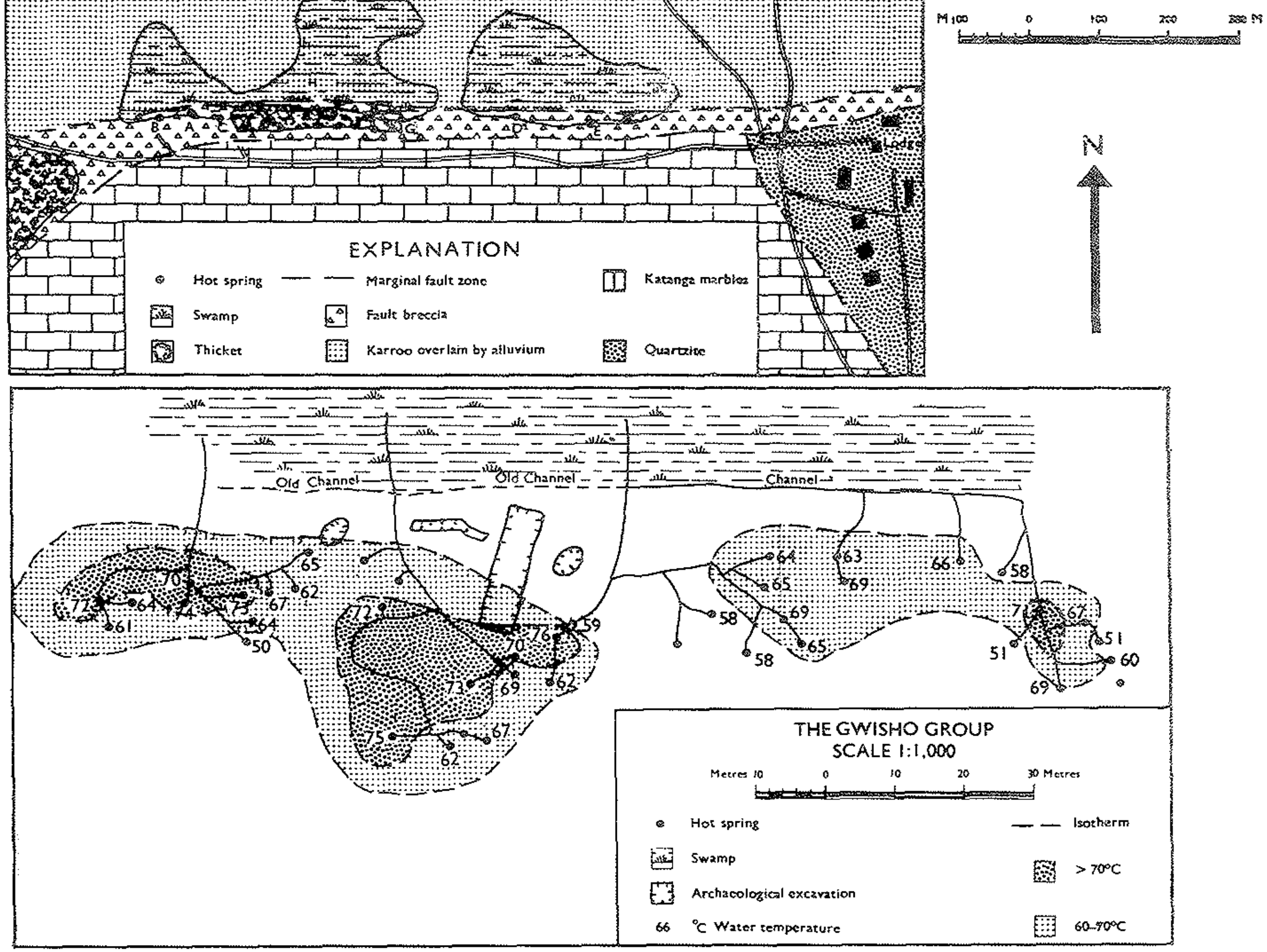
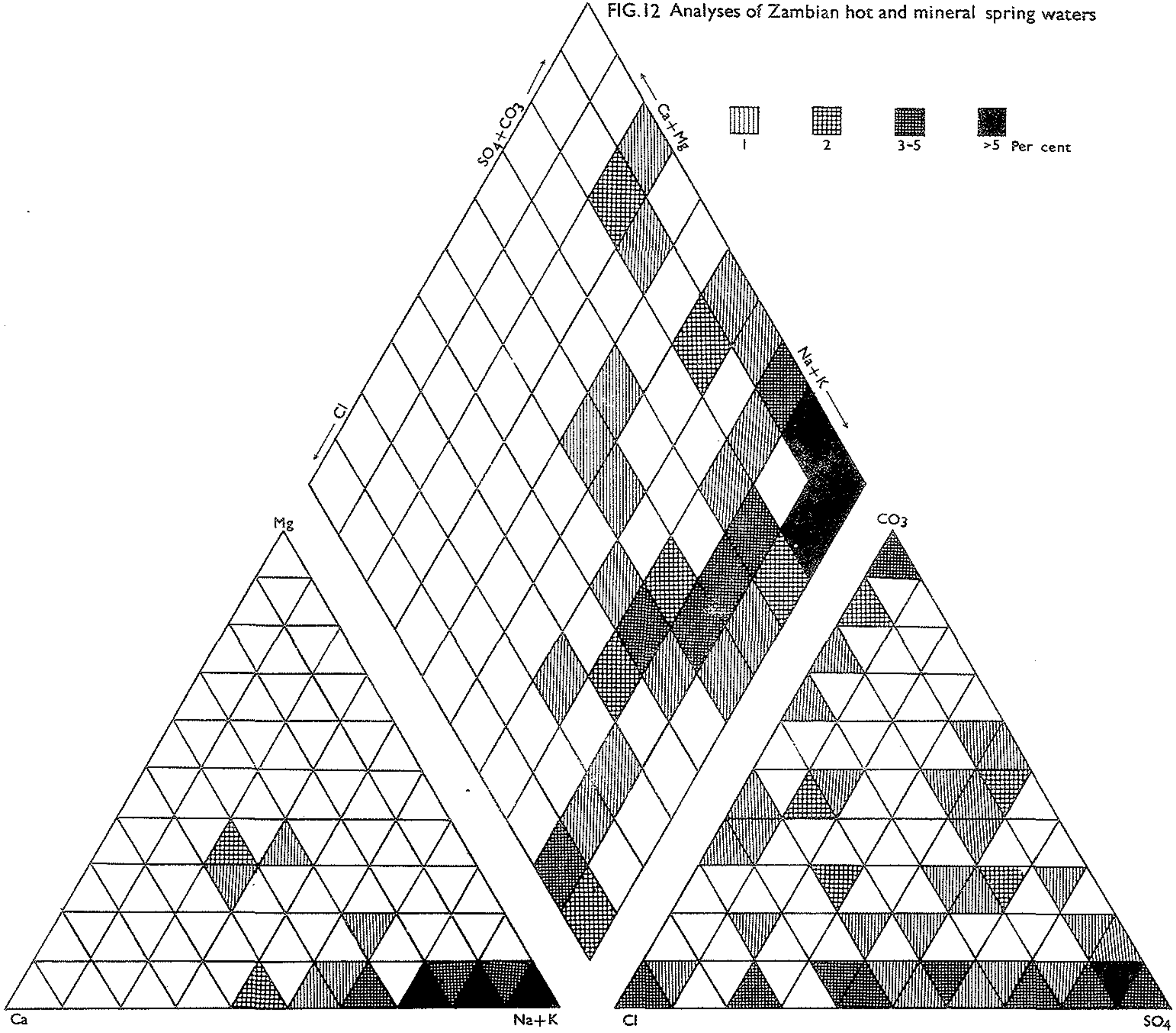
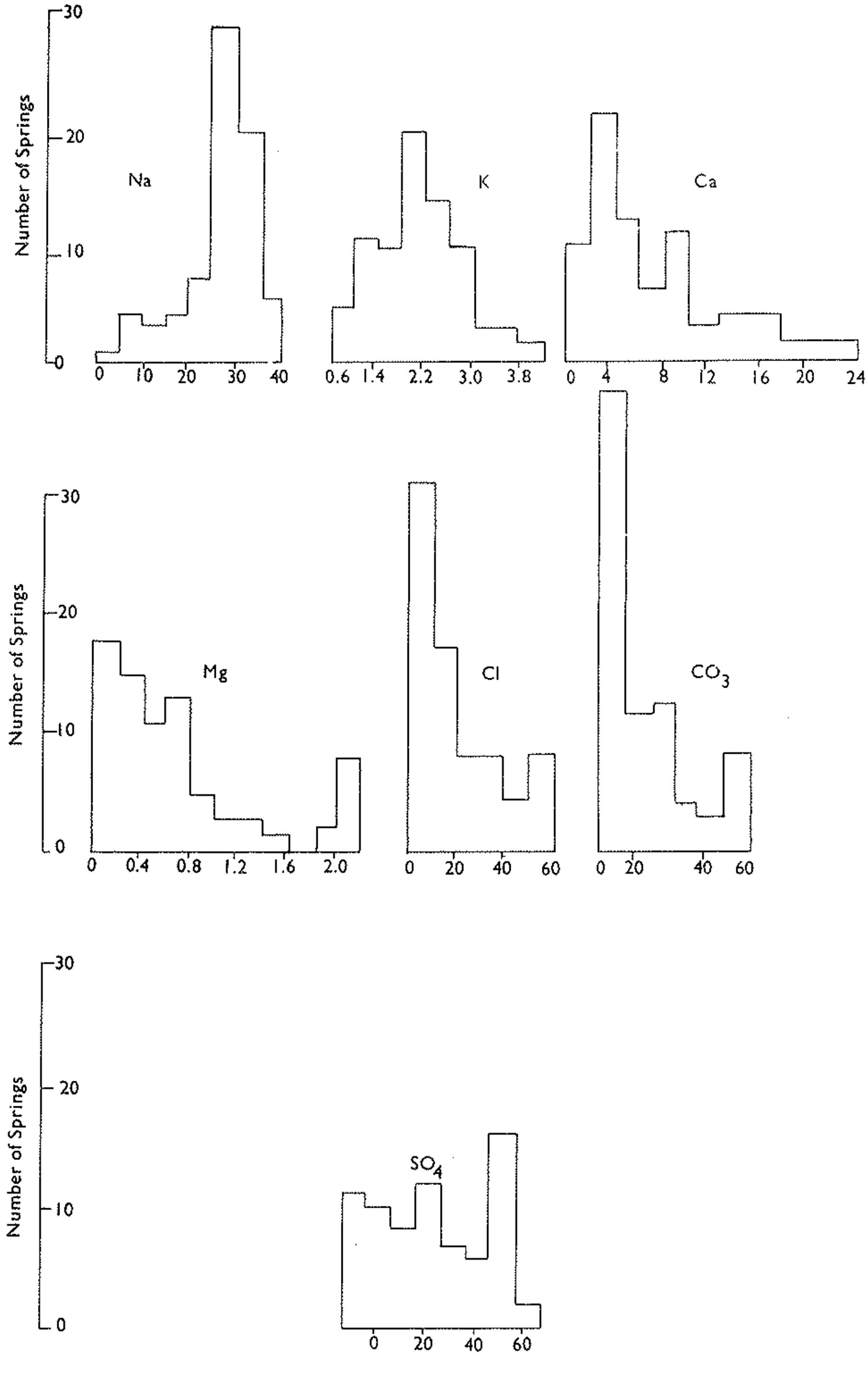


FIG. 12 Analyses of Zambian hot and mineral spring waters





HISTOGRAMS OF MAJOR CHEMICAL CONSTITUENTS OF SPRING WATERS. CONCENTRATIONS EXPRESSED AS PERCENTAGES OF TOTAL DISSOLVED SOLIDS

CHEMICAL CHARACTERISTICS OF ZAMBIAN HOT AND MINERAL SPRING WATERS

The distribution of the water compositions of all springs sampled in Zambia are shown on a modified Piper diagram (fig. 12). The majority of the spring waters have high contents of sodium and potassium relative to calcium and magnesium, and of chloride and sulphate relative to carbonate. The densest concentration on the diagram is at the sodium and potassium sulphate (plus carbonate) corner of the upper parallelogram. The Zambian springs differ from the thermal springs of Tanzania described by James (1967), which have predominantly carbonate-bicarbonate waters.

Histograms of the seven main chemical constituents are shown in fig. 13. Sodium shows a distribution strongly skewed towards higher relative concentration levels, with the peak at about 29 per cent of the total dissolved solids. Potassium shows an approximately normal distribution, peaking at 2.0 per cent of the total, while calcium and magnesium both show negatively skewed distributions of approximately lognormal type. The chloride and carbonate distributions have a strong negative skewness, and apparently a crude lognormal character, while sulphate appears to be a negatively skewed distribution with two peaks, at 25 and 55 per cent, superimposed.

The results of statistical analysis of the analytical data (table 19) demonstrate the high degree of variability between springs, or in other words, the relative chemical independence of individual springs. The coefficient of variation for most components ranges from 0.90 to 1.40, but is as low as 0.30 for silica and water temperature, and as high as 2.17 for chloride. The calculation of correlation coefficients between all the components listed in the table shows that few pairs exhibit any significant degree of interdependence. The only pairs showing correlation coefficients higher than 0.70 are Na-K, Na-Cl and Cl-Li, while pairs showing coefficients of between 0.50 and 0.70 are Ca-Mg, Na-Li, K-Cl, K-SO_4, K-Li and temperature-discharge.

Based on the histograms in fig. 13 the main components have been divided into groups (fig. 14 - 25). These maps show that, at least for some components, the variation between adjacent springs in restricted geographical groups is not as large as might be expected from table 19. The springs appear to be grouped into a number of chemical provinces, depending on the relative concentrations of different chemical components. These provinces are categorised as shown in fig. 26. The most clearly defined are the province with low Na/Li and K/Li ratios, including springs of the Northern Group, the Mansa-Copperbelt Group, and some springs of the Western Group; and the one with springs having relatively high sulphate contents, including most of the springs of the Luangwa Valley, and the Chirundu and Bilili springs. Other less well-defined and extensive provinces are indicated on the map. The sulphate-rich province includes mainly springs situated along basement-Karroo contacts, or underlain by Karroo, although all springs located in these settings are not sulphate-rich. Like many terrestrial sediments elsewhere, it appears that the Karroo rocks in Zambia are unusually rich in sodium and calcium sulphates, a fact which is supported by analyses of typical Karroo groundwaters, and by the occurrence of gypsum in the Karroo of the Luangwa Valley. Springs in the province with relatively high lithium contents occur in a wide variety of geological environments, ranging in age from older basement, through Plateau Series and the Katanga System, to Karroo, and including basic volcanics, granites,

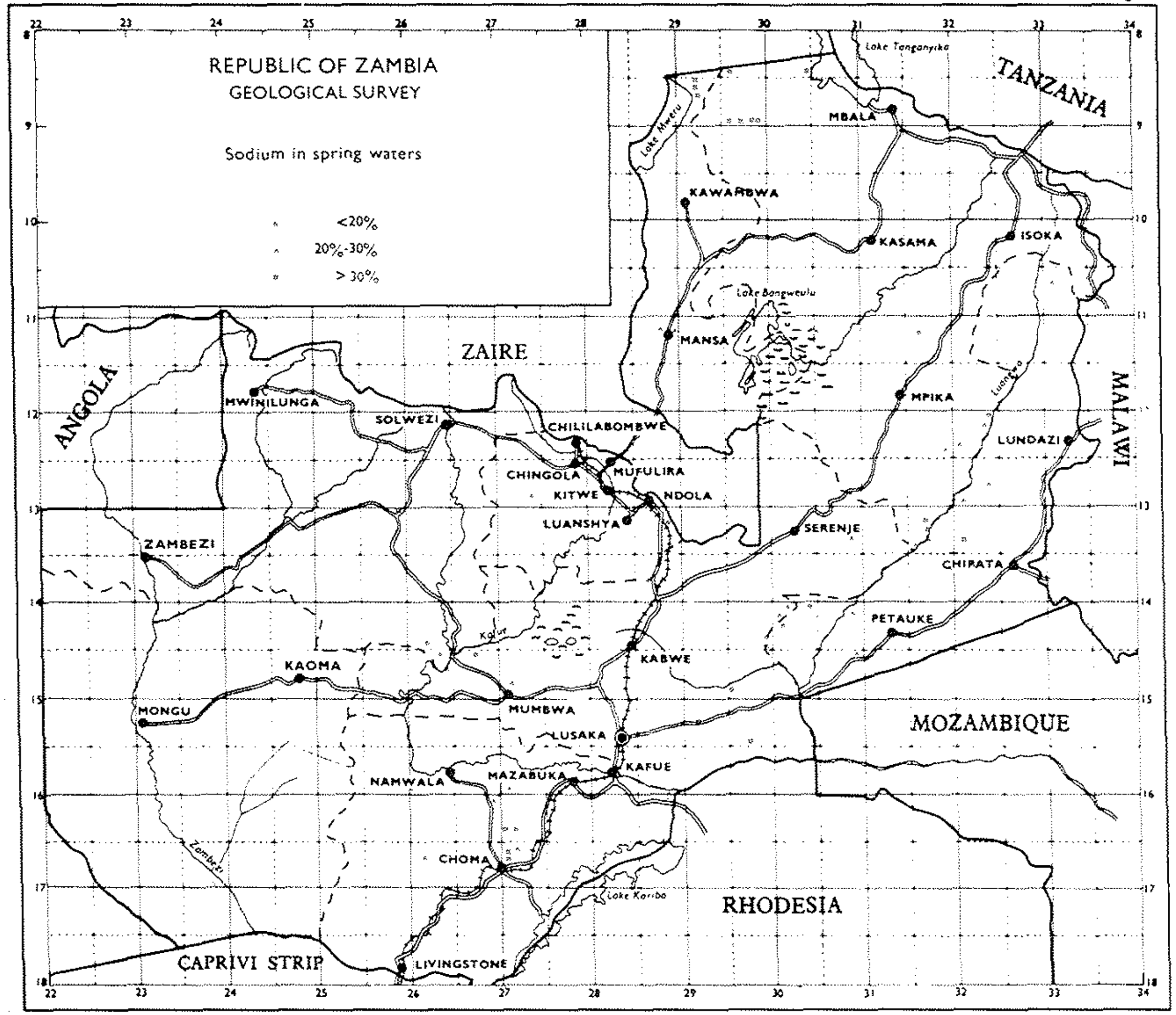
Table 19

Analysis of variance of main components of spring waters

	Ca	Mg	Na	K	CO_3	Cl	SO_4	SiO_2	Li	Temp	Discharge
Ca	78 / 1.30	0.62	0.37	0.33	-0.33	0.43	0.42	0.15	0.29	0.19	0.30
Mg		7.2 / 1.40	0.40	0.22	0.10	0.44	0.26	-0.14	0.29	0.02	0.12
Na			410 / 1.19	0.71	-0.10	0.92	0.33	0.29	0.64	0.001	0.08
K				22.5 / 0.94	-0.07	0.50	0.58	0.16	0.58	0.15	0.01
CO_3					64 / 0.98	0.007	-0.23	-0.02	0.08	-0.28	-0.08
Cl						368 / 2.17	0.003	-0.16	0.71	-0.06	-0.09
SO_4							489 / 0.99	0.30	0.07	0.32	0.29
SiO_2								34 / 0.37	-0.07	0.42	0.17
Li									1.09 / 1.34	-0.07	-0.03
Temp										52.6 / 0.30	0.68
Discharge											5.1 / 0.94

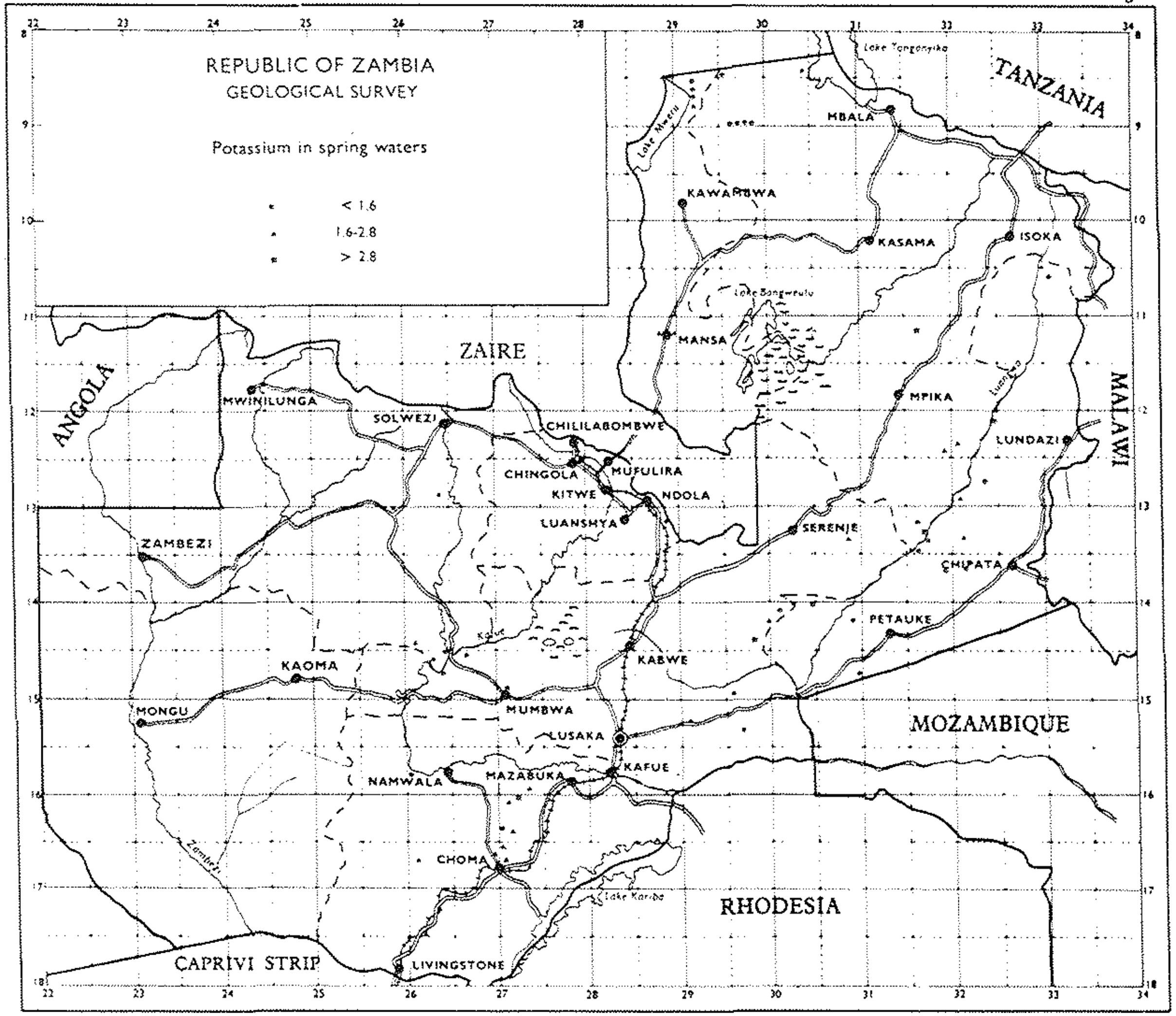
Mean and Coefficient of Variation underlined. Other figures are Correlation Coefficients between pairs.

Fig. 14



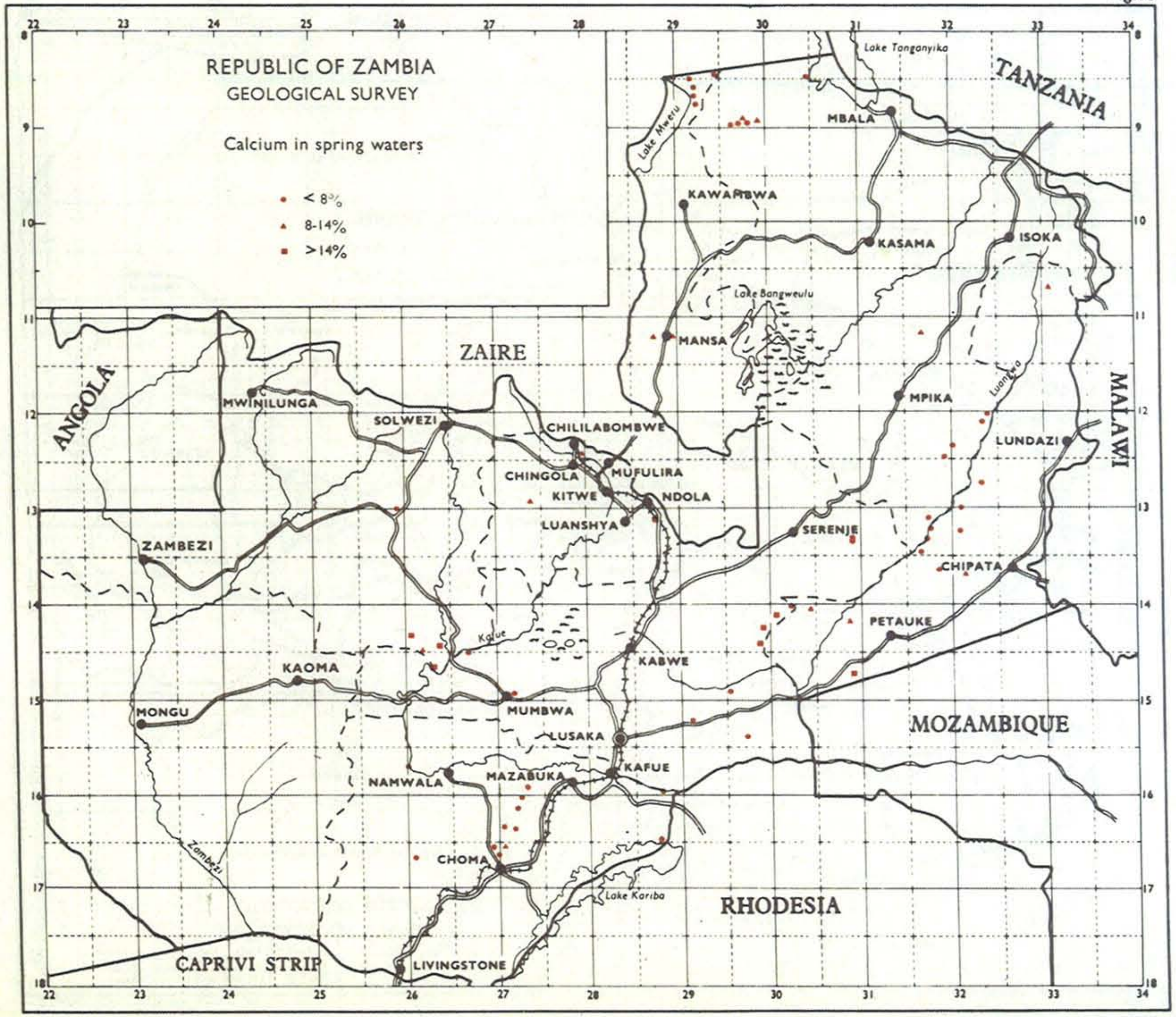
REPUBLIC OF ZAMBIA
GEOLOGICAL SURVEY
Sodium in spring waters
<20%
20%-30%
> 30%
TANZANIA
ZAIRE
ANGOLA
MALAWI
MOZAMBIQUE
RHODESIA
CAPRIVI STRIP
MBALA
KAWAMBWA
KASAMA
ISOKA
MANSA
MPIKA
MWINILUNGA
SOLWEZI
CHILILABOMBWE
CHINGOLA
MUFULIRA
KITWE
NDOLA
LUANSHYA
LUNDAZI
SERENJE
ZAMBEZI
CHIPATA
PETAUKE
KABWE
KAOMA
MONGU
MUMBWA
LUSAKA
KAFUE
NAMWALA
MAZABUKA
CHOMA
LIVINGSTONE
Lake Tanganyika
Lake Mweru
Lake Bangweulu
Lake Kariba

Fig. 15



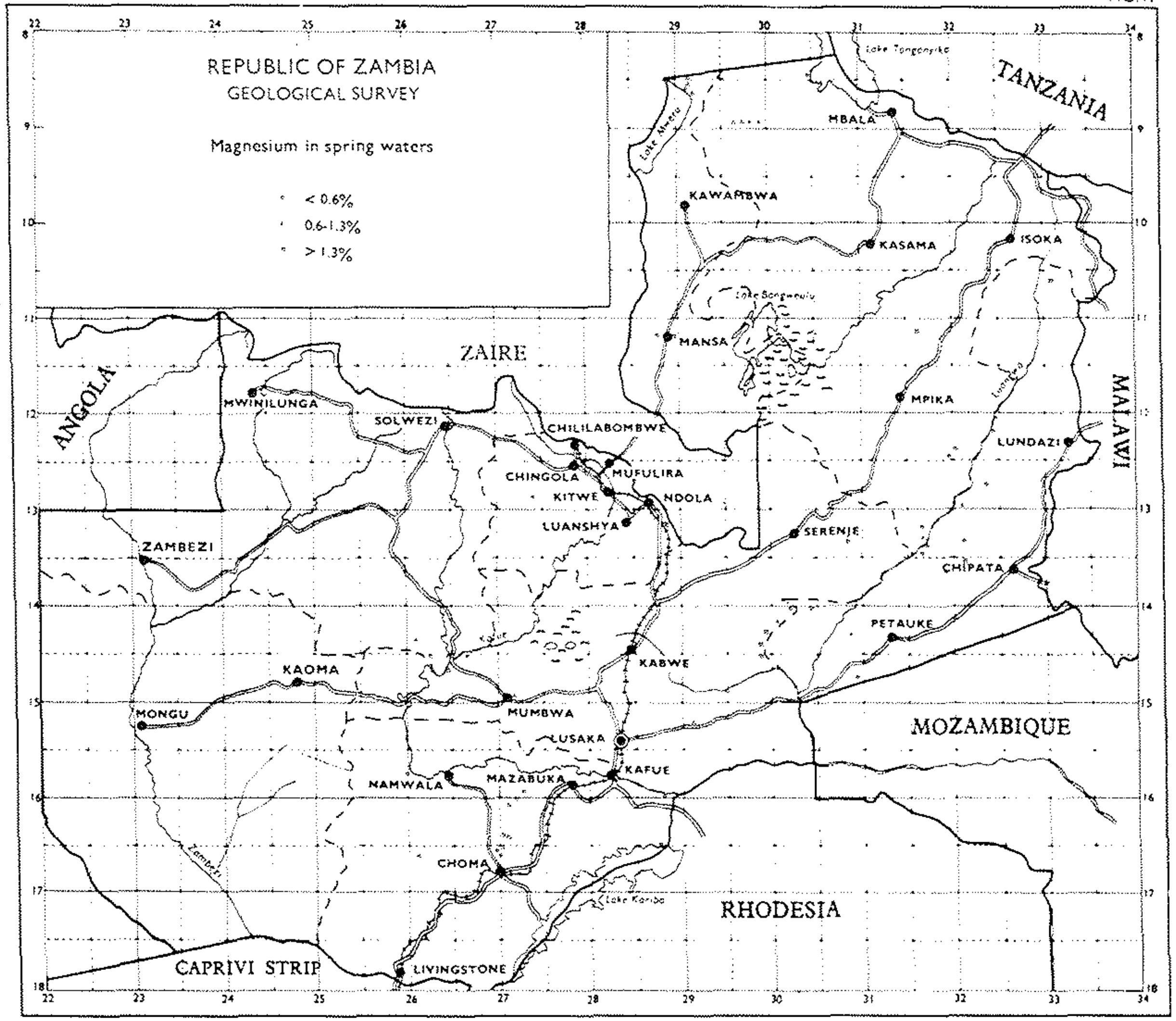
REPUBLIC OF ZAMBIA
GEOLOGICAL SURVEY
Potassium in spring waters
< 1.6
1.6-2.8
> 2.8
TANZANIA
ZAIRE
ANGOLA
MALAWI
MOZAMBIQUE
RHODESIA
CAPRIVI STRIP
MBALA
KAWAMBWA
KASAMA
ISOKA
MANSA
MPIKA
LUNDAZI
MWINILUNGA
SOLWEZI
CHILILABOMBWE
CHINGOLA
MUFULIRA
KITWE
NDOLA
LUANSHYA
SERENJE
ZAMBEZI
CHIPATA
PETAUKE
KABWE
KAOMA
MUMBWA
MONGU
LUSAKA
KAFUE
NAMWALA
MAZABUKA
CHOMA
LIVINGSTONE
Lake Tanganyika
Lake Mweru
Lake Bangweulu
Lake Kariba
Zambezi
Kafue
Luangwa

Fig.16



REPUBLIC OF ZAMBIA
GEOLOGICAL SURVEY
Calcium in spring waters
< 8%
8-14%
>14%
TANZANIA
ZAIRE
ANGOLA
MALAWI
MOZAMBIQUE
RHODESIA
CAPRIVI STRIP
Lake Tanganyika
Lake Mweru
Lake Bangweulu
Lake Kariba
Kafue
Zambezi
Luangwa
MBALA
KAWAMBWA
KASAMA
ISOKA
MANSA
MPIKA
LUNDAZI
MWINILUNGA
SOLWEZI
CHILILABOMBWE
CHINGOLA
MUFULIRA
KITWE
NDOLA
LUANSHYA
SERENJE
CHIPATA
ZAMBEZI
PETAUKE
KABWE
KAOMA
MUMBWA
MONGU
LUSAKA
KAFUE
NAMWALA
MAZABUKA
CHOMA
LIVINGSTONE

FIG. 17



REPUBLIC OF ZAMBIA
GEOLOGICAL SURVEY
Magnesium in spring waters
< 0.6%
0.6-1.3%
> 1.3%
TANZANIA
ZAIRE
ANGOLA
MALAWI
MOZAMBIQUE
RHODESIA
CAPRIVI STRIP
Lake Tanganyika
Lake Mweru
Lake Bangweulu
Lake Kariba
Zambezi
Kafue
MBALA
KAWAMBWA
KASAMA
ISOKA
MANSA
MPIKA
LUNDAZI
MWINILUNGA
SOLWEZI
CHILILABOMBWE
CHINGOLA
MUFULIRA
KITWE
NDOLA
LUANSHYA
SERENJE
ZAMBEZI
CHIPATA
PETAUKE
KABWE
KAOMA
MONGU
MUMBWA
LUSAKA
KAFUE
NAMWALA
MAZABUKA
CHOMA
LIVINGSTONE

Fig. 18

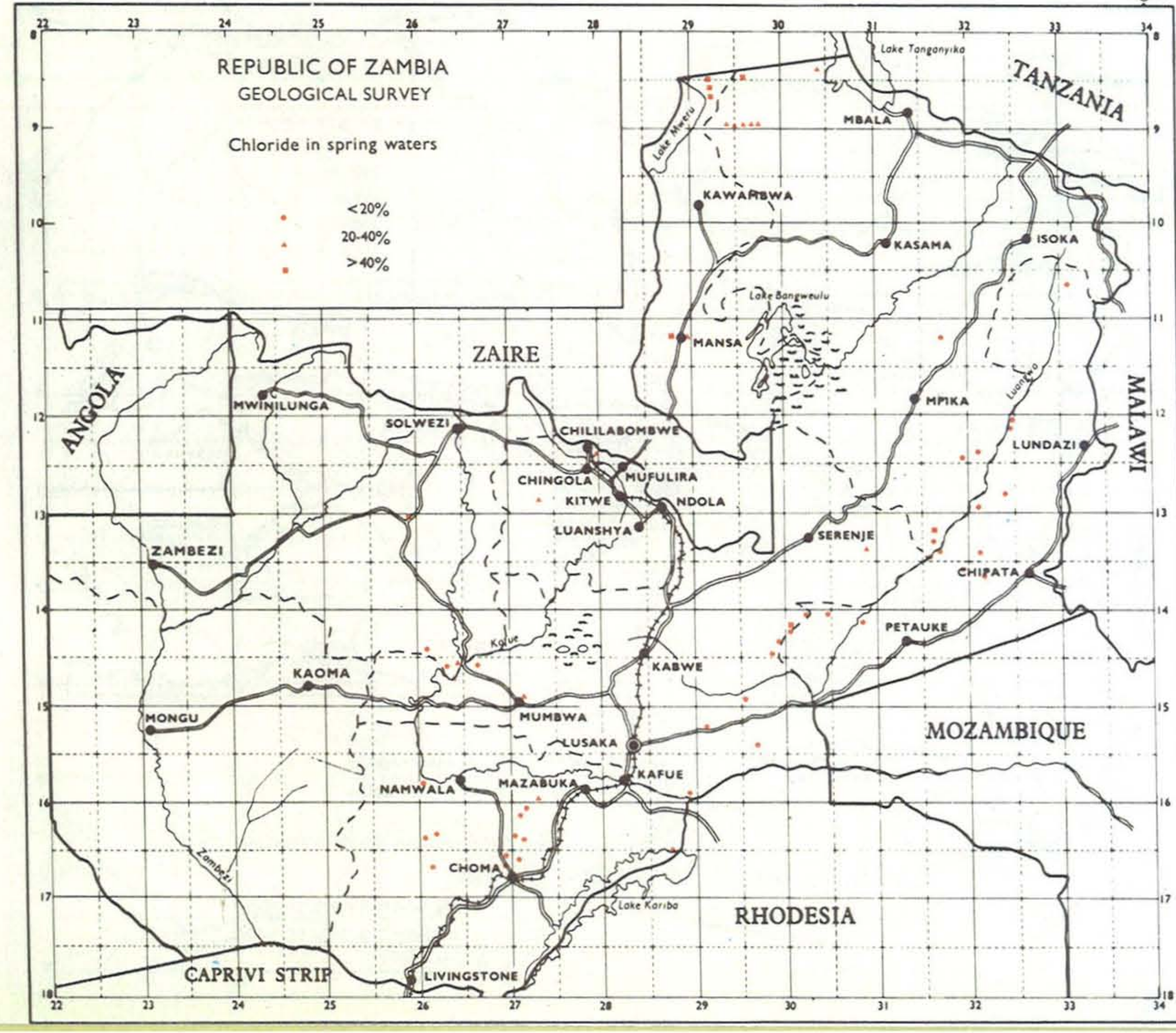
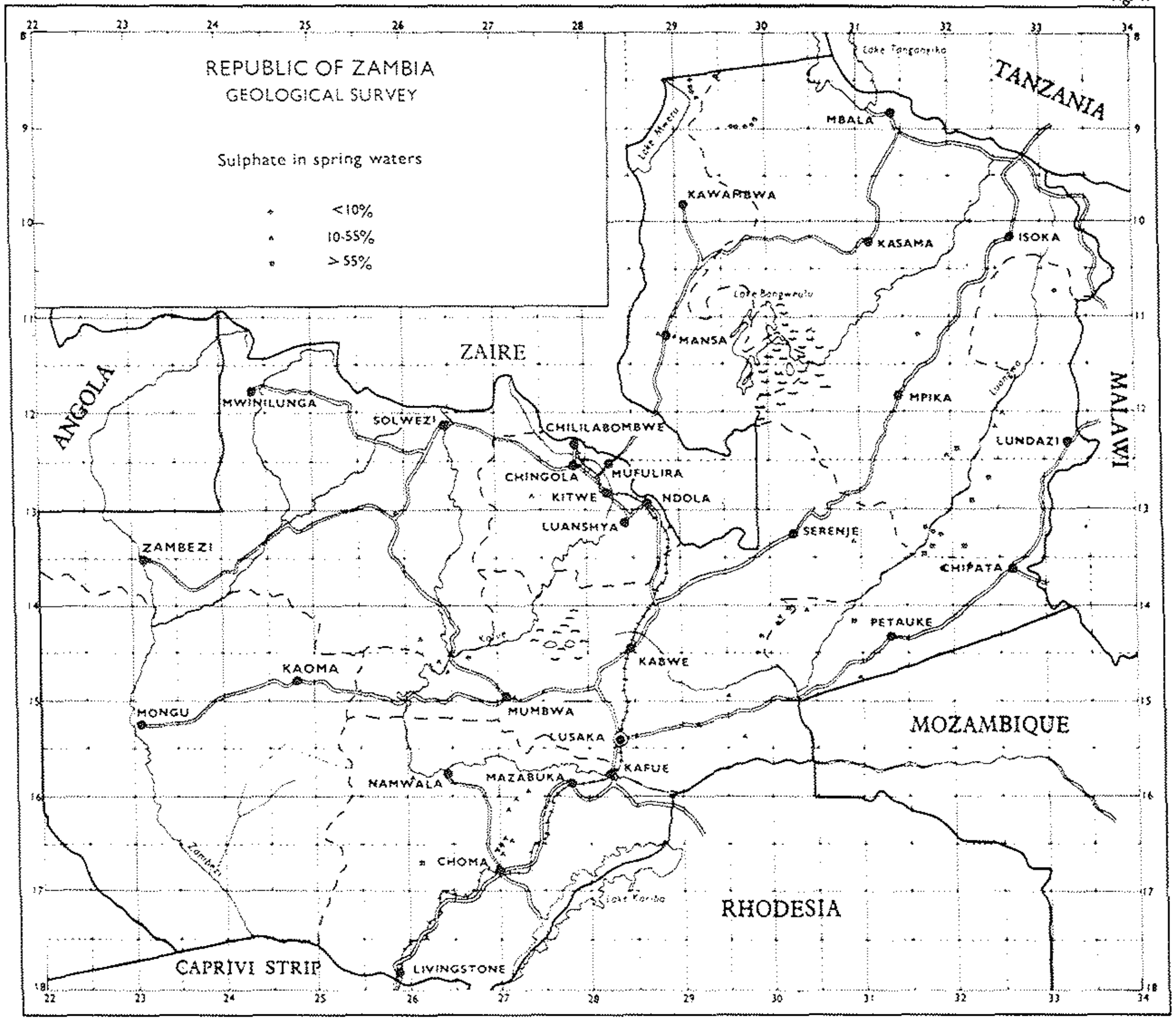

REPUBLIC OF ZAMBIA
GEOLOGICAL SURVEY
Chloride in spring waters
<20%
20-40%
>40%
ZAIRE
ANGOLA
TANZANIA
MALAWI
MOZAMBIQUE
RHODESIA
CAPRIVI STRIP
Lake Tanganyika
Lake Mweru
Lake Bangweulu
Lake Kariba
Zambezi
Kafue
Luangwa
MBALA
KAWAMBWA
KASAMA
ISOKA
MANSA
MPIKA
LUNDAZI
MWINILUNGA
SOLWEZI
CHILILABOMBWE
CHINGOLA
MUFULIRA
KITWE
NDOLA
LUANSHYA
SERENJE
CHIPATA
ZAMBEZI
PETAUKE
KABWE
KAOMA
MONGU
MUMBWA
LUSAKA
KAFUE
NAMWALA
MAZABUKA
CHOMA
LIVINGSTONE

Fig. 19



REPUBLIC OF ZAMBIA
GEOLOGICAL SURVEY
Sulphate in spring waters
<10%
10-55%
>55%
TANZANIA
ZAIRE
ANGOLA
MALAWI
MOZAMBIQUE
RHODESIA
CAPRIVI STRIP
MBALA
KAWAMBWA
KASAMA
ISOKA
MANSA
MPIKA
LUNDAZI
MWINILUNGA
SOLWEZI
CHILILABOMBWE
CHINGOLA
MUFULIRA
KITWE
NDOLA
LUANSHYA
SERENJE
ZAMBEZI
CHIPATA
PETAUKE
KABWE
KAOMA
MONGU
MUMBWA
LUSAKA
KAFUE
NAMWALA
MAZABUKA
CHOMA
LIVINGSTONE
Lake Tanganyika
Lake Mweru
Lake Bangweulu
Lake Kariba

Fig.20

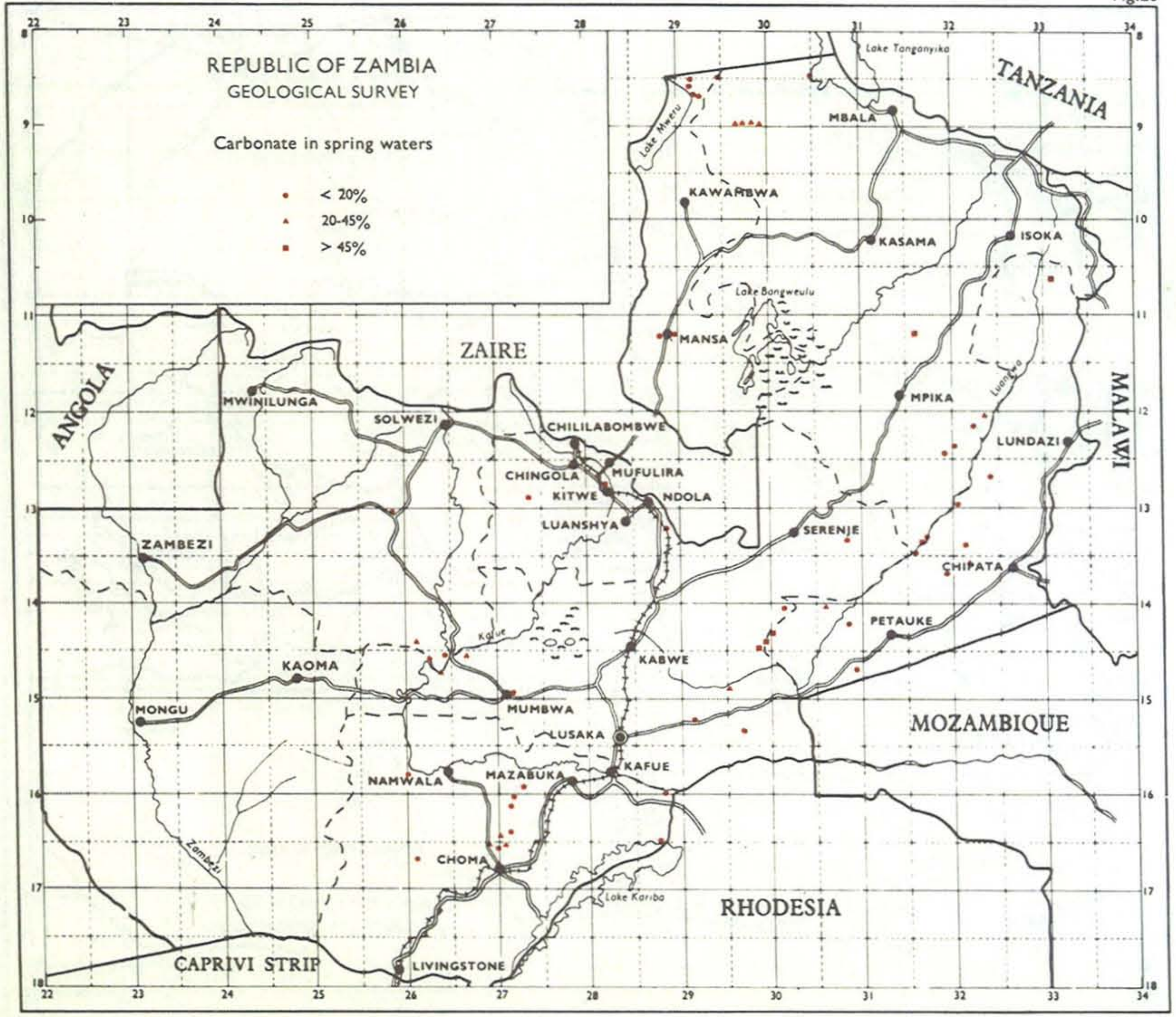

REPUBLIC OF ZAMBIA
GEOLOGICAL SURVEY
Carbonate in spring waters
< 20%
20-45%
> 45%
TANZANIA
ZAIRE
ANGOLA
MALAWI
MOZAMBIQUE
RHODESIA
CAPRIVI STRIP
Lake Tanganyika
Lake Mweru
Lake Bangweulu
Lake Kariba
MBALA
KAWAMBWA
KASAMA
ISOKA
MANSA
MPIKA
LUNDAZI
MWINILUNGA
SOLWEZI
CHILILABOMBWE
CHINGOLA
MUFULIRA
KITWE
NDOLA
LUANSHYA
SERENJE
ZAMBEZI
CHIPATA
PETAUKE
KABWE
KAOMA
MONGU
MUMBWA
LUSAKA
KAFUE
MAZABUKA
NAMWALA
CHOMA
LIVINGSTONE
Kafue
Luangwa
Zambezi

Fig.21

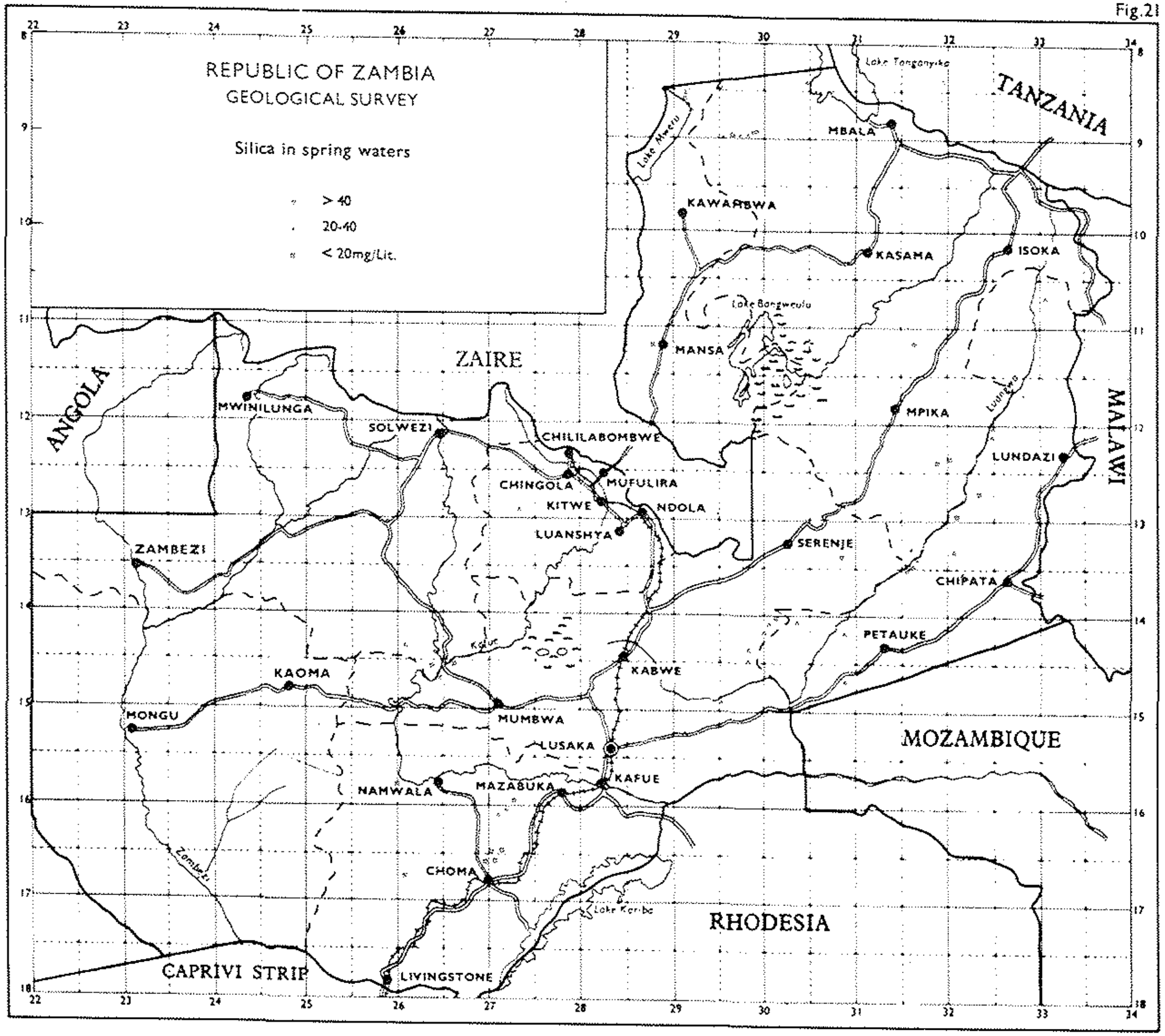

REPUBLIC OF ZAMBIA
GEOLOGICAL SURVEY
Silica in spring waters
> 40
20-40
< 20mg/Lit.
TANZANIA
ZAIRE
ANGOLA
MALAWI
MOZAMBIQUE
RHODESIA
CAPRIVI STRIP
MBALA
KAWAMBWA
KASAMA
ISOKA
MANSA
MPIKA
LUNDAZI
MWINILUNGA
SOLWEZI
CHILILABOMBWE
CHINGOLA
MUFULIRA
KITWE
NDOLA
LUANSHYA
SERENJE
ZAMBEZI
CHIPATA
PETAUKE
KABWE
KAOMA
MONGU
MUMBWA
LUSAKA
KAFUE
NAMWALA
MAZABUKA
CHOMA
LIVINGSTONE
Lake Tanganyika
Lake Mweru
Lake Bangweulu
Lake Kariba

Fig.22

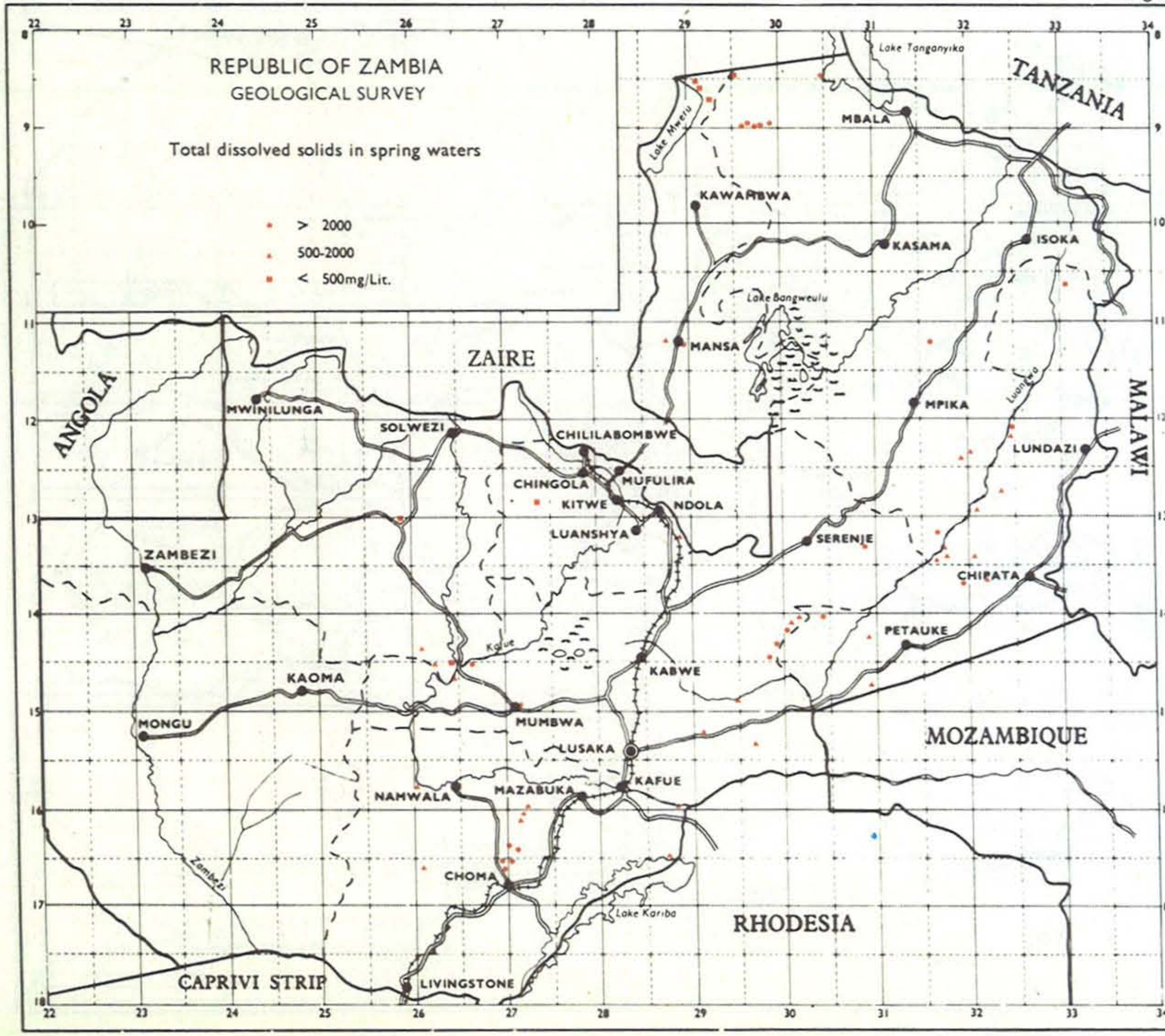
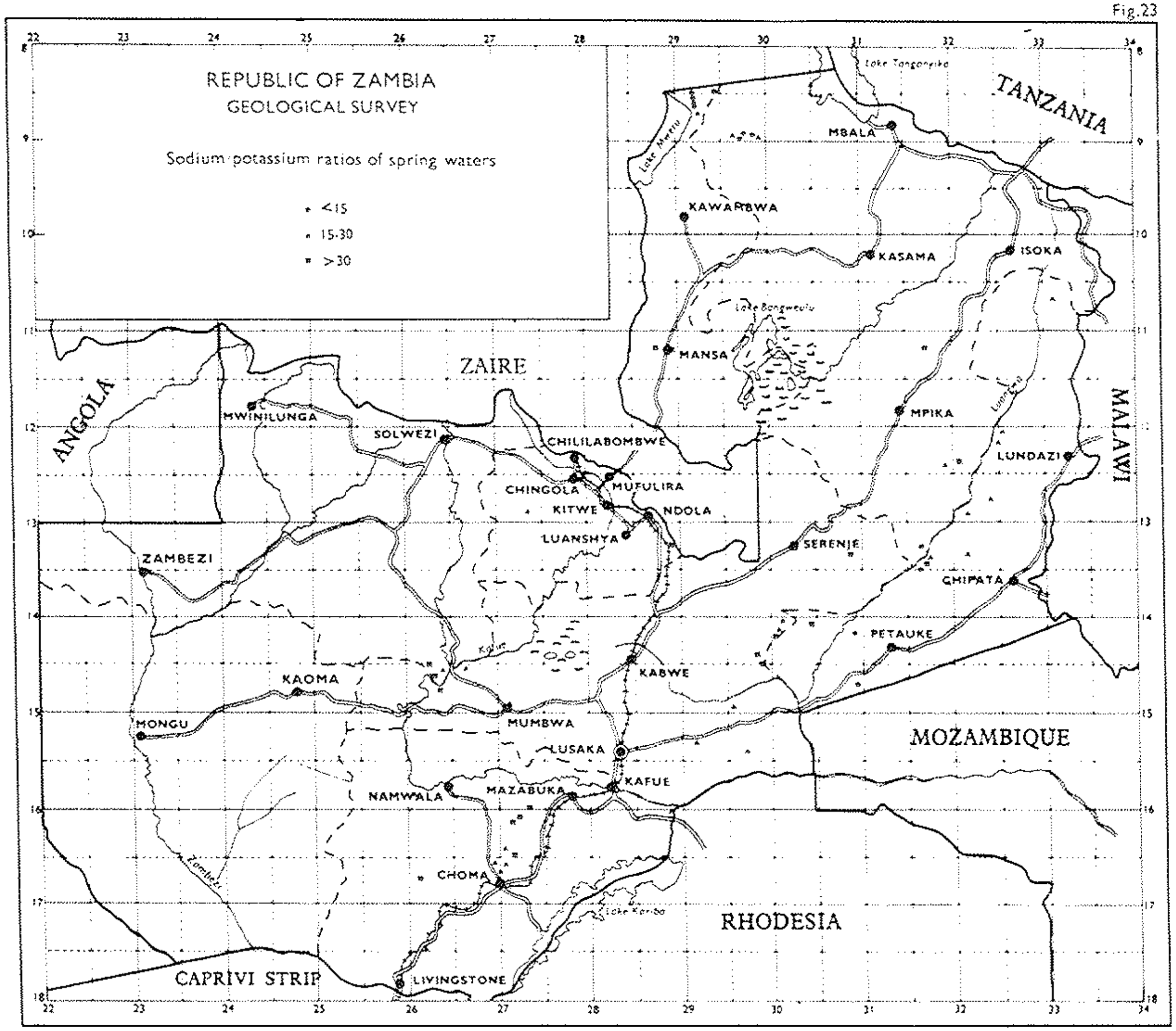

REPUBLIC OF ZAMBIA
GEOLOGICAL SURVEY
Total dissolved solids in spring waters
> 2000
500-2000
< 500mg/Lit.
TANZANIA
ZAIRE
ANGOLA
MALAWI
MOZAMBIQUE
RHODESIA
CAPRIVI STRIP
Lake Tanganyika
Lake Mweru
Lake Bangweulu
Lake Kariba
MBALA
KAWAMBWA
KASAMA
ISOKA
MANSA
MPIKA
LUNDAZI
MWINILUNGA
SOLWEZI
CHILILABOMBWE
CHINGOLA
MUFULIRA
KITWE
NDOLA
LUANSHYA
SERENJE
CHIPATA
ZAMBEZI
PETAUKE
KABWE
KAOMA
MONGU
MUMBWA
LUSAKA
KAFUE
NAMWALA
MAZABUKA
CHOMA
LIVINGSTONE
Kafue
Zambezi
Luangwa

Fig.23



REPUBLIC OF ZAMBIA
GEOLOGICAL SURVEY
Sodium/potassium ratios of spring waters
<15
15-30
>30
TANZANIA
ZAIRE
ANGOLA
MALAWI
MOZAMBIQUE
RHODESIA
CAPRIVI STRIP
MBALA
KAWAMBWA
KASAMA
ISOKA
MANSA
MPIKA
LUNDAZI
MWINILUNGA
SOLWEZI
CHILILABOMBWE
CHINGOLA
MUFULIRA
KITWE
NDOLA
LUANSHYA
SERENJE
CHIPATA
ZAMBEZI
PETAUKE
KABWE
KAOMA
MUMBWA
MONGU
LUSAKA
KAFUE
NAMWALA
MAZABUKA
CHOMA
LIVINGSTONE
Lake Tanganyika
Lake Bangweulu
Lake Kariba

Fig.24

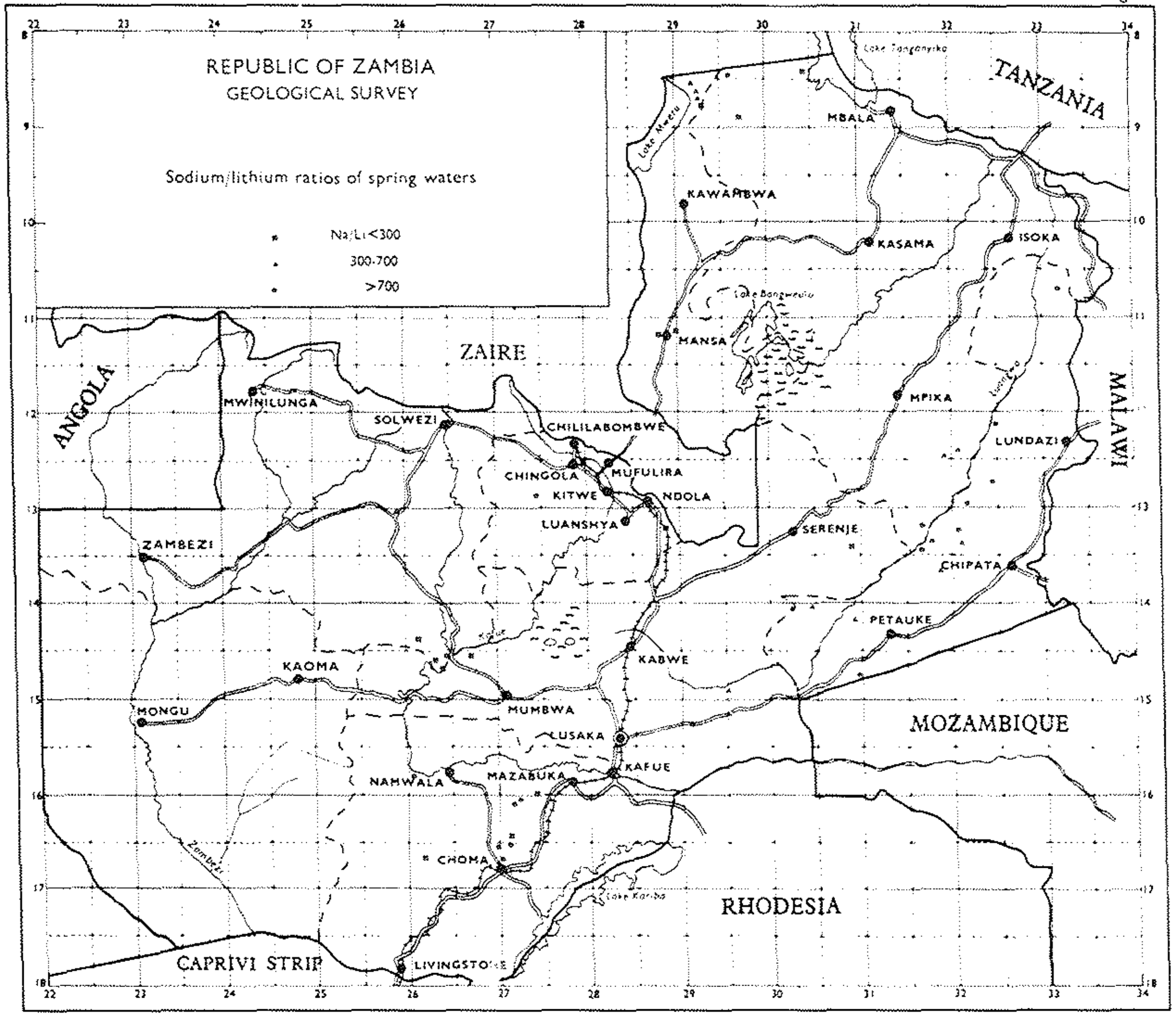

REPUBLIC OF ZAMBIA
GEOLOGICAL SURVEY
Sodium/lithium ratios of spring waters
Na/Li<300
300-700
>700
ZAIRE
ANGOLA
TANZANIA
MALAWI
MOZAMBIQUE
RHODESIA
CAPRIVI STRIP
Lake Tanganyika
Lake Mweru
Lake Bangweulu
Lake Kariba
Zambezi
MBALA
KAWAMBWA
KASAMA
ISOKA
MANSA
MPIKA
LUNDAZI
MWINILUNGA
SOLWEZI
CHILILABOMBWE
CHINGOLA
MUFULIRA
KITWE
NDOLA
LUANSHYA
SERENJE
ZAMBEZI
CHIPATA
PETAUKE
KABWE
KAOMA
MUMBWA
MONGU
LUSAKA
KAFUE
NAMWALA
MAZABUKA
CHOMA
LIVINGSTONE

Fig.25

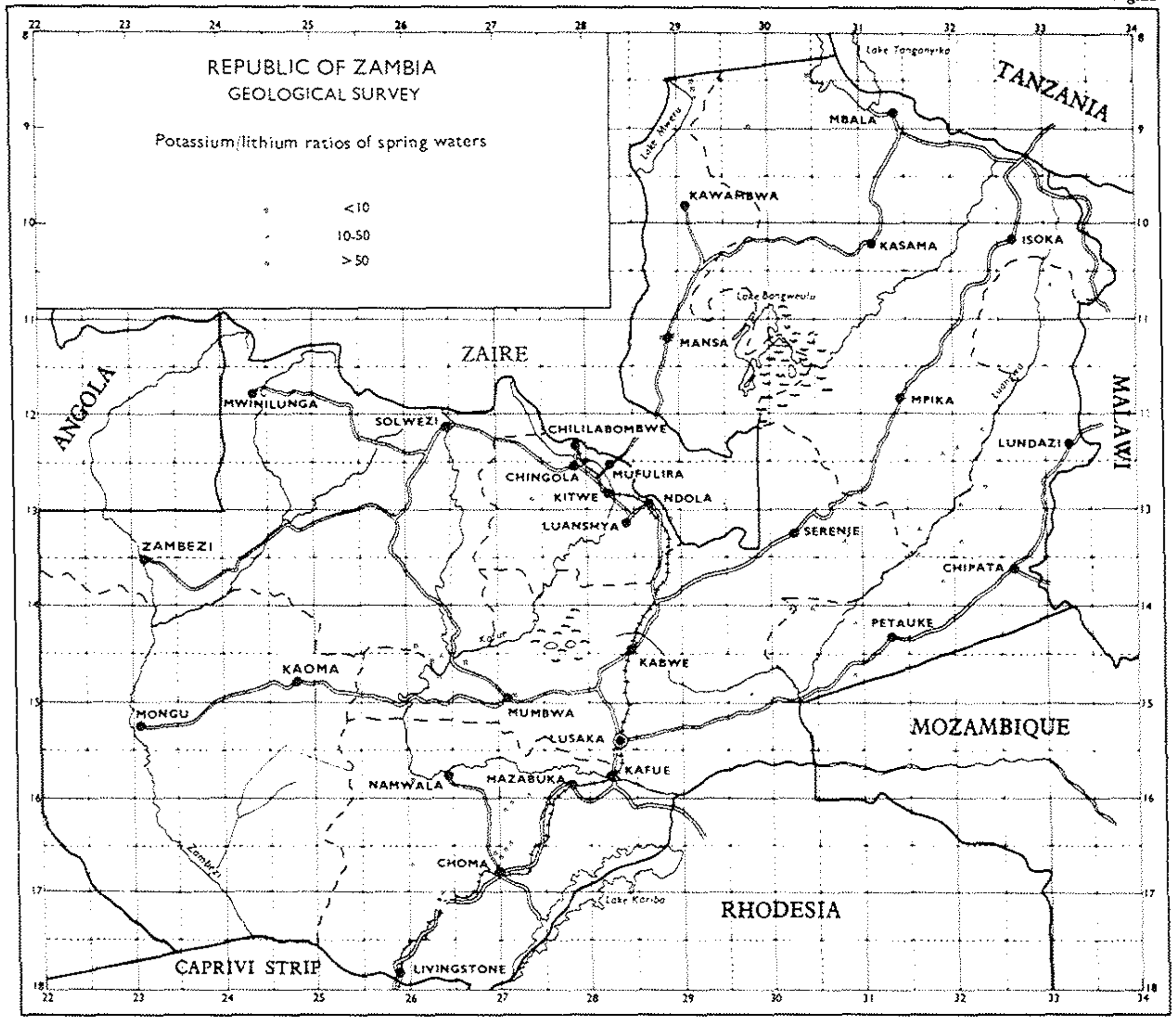
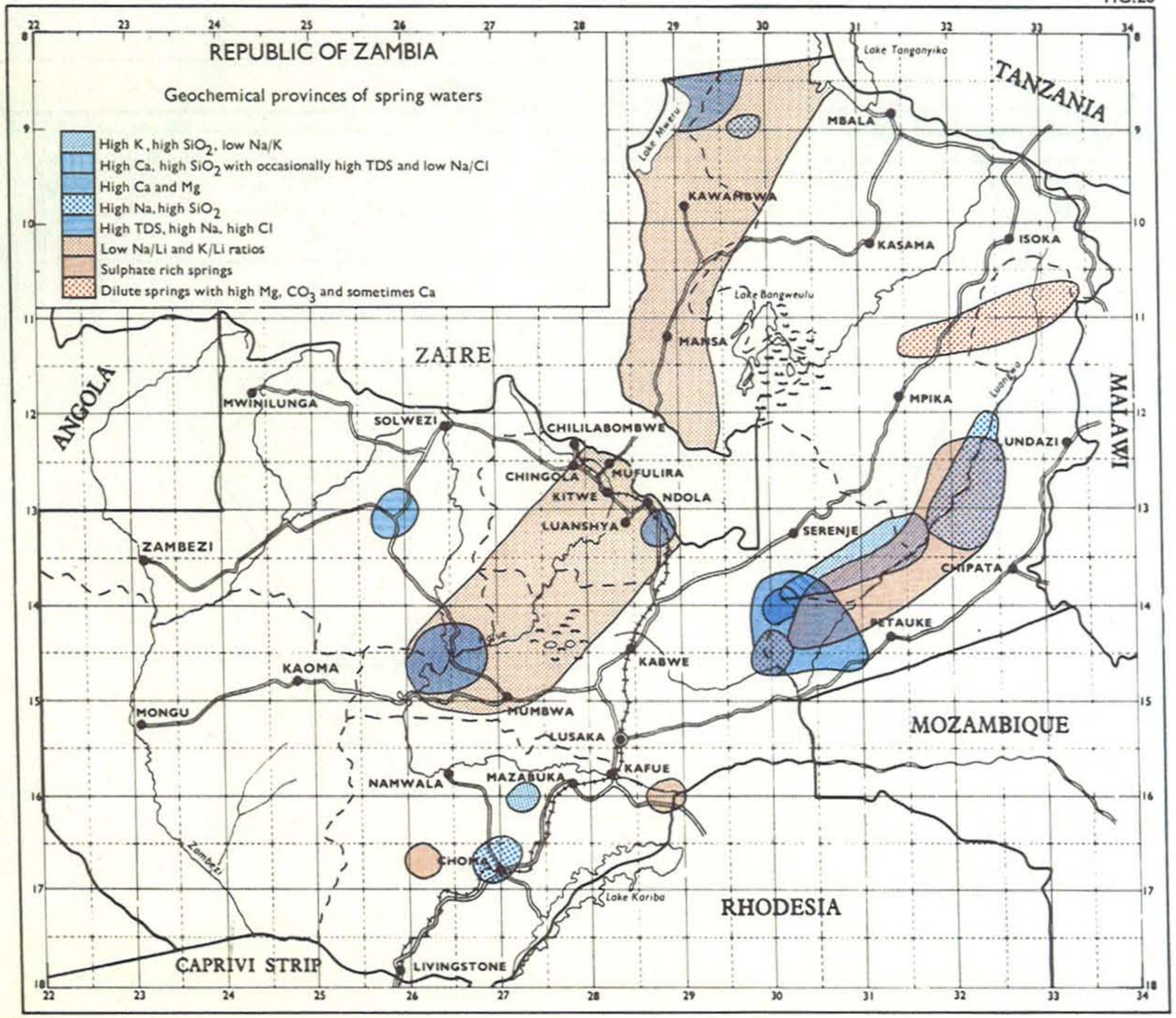
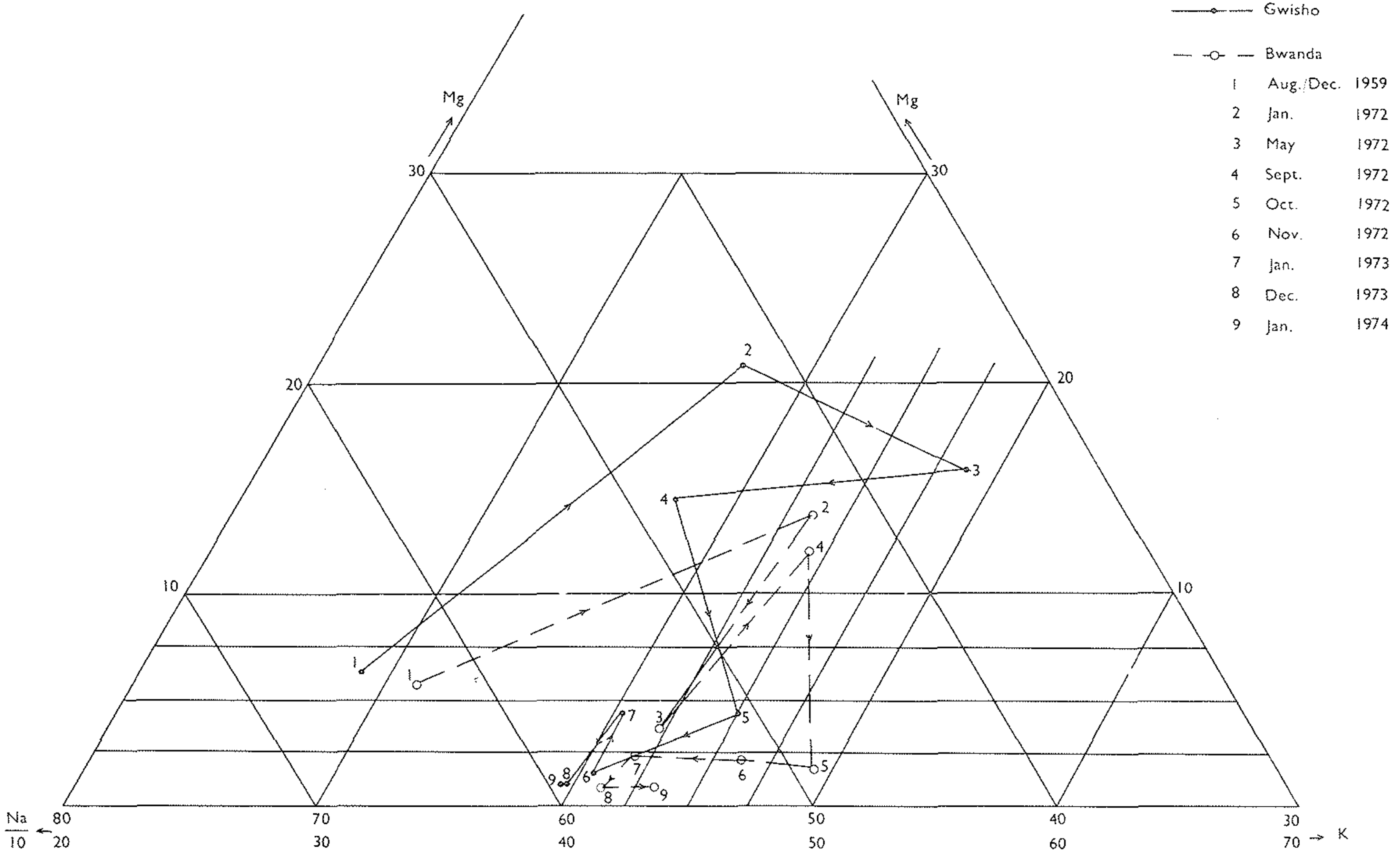

REPUBLIC OF ZAMBIA
GEOLOGICAL SURVEY
Potassium/lithium ratios of spring waters
<10
10-50
>50
TANZANIA
ZAIRE
ANGOLA
MALAWI
MOZAMBIQUE
RHODESIA
CAPRIVI STRIP
Lake Tanganyika
Lake Mweru
Lake Bangweulu
Lake Kariba
Zambezi
MBALA
KAWAMBWA
KASAMA
ISOKA
MANSA
MPIKA
MWINILUNGA
SOLWEZI
CHILILABOMBWE
CHINGOLA
MUFULIRA
KITWE
NDOLA
LUANSHYA
LUNDAZI
SERENJE
ZAMBEZI
CHIPATA
PETAUKE
KABWE
KAOMA
MUMBWA
MONGU
LUSAKA
KAFUE
NAMWALA
MAZABUKA
CHOMA
LIVINGSTONE

FIG.26



REPUBLIC OF ZAMBIA
Geochemical provinces of spring waters
High K, high SiO_2, low Na/K
High Ca, high SiO_2 with occasionally high TDS and low Na/Cl
High Ca and Mg
High Na, high SiO_2
High TDS, high Na, high Cl
Low Na/Li and K/Li ratios
Sulphate rich springs
Dilute springs with high Mg, CO_3 and sometimes Ca
TANZANIA
ZAIRE
ANGOLA
MALAWI
MOZAMBIQUE
RHODESIA
CAPRIVI STRIP
Lake Tanganyika
Lake Mweru
Lake Bangweulu
Lake Kariba
Zambezi
Luangwa
MBALA
KAWAMBWA
KASAMA
ISOKA
MANSA
MPIKA
MWINILUNGA
SOLWEZI
CHILILABOMBWE
CHINGOLA
MUFULIRA
KITWE
NDOLA
LUANSHYA
UNDAZI
SERENJE
CHIPATA
PETAUKE
ZAMBEZI
KABWE
KAOMA
MONGU
MUMBWA
LUSAKA
KAFUE
NAMWALA
MAZABUKA
CHOMA
LIVINGSTONE

FIG.27 Time-dependent variations in Lochinvar water composition



quartzites, schists and dolomites, sandstones and siltstones. It may be significant that this zone coincides with a major zone of strong negative Bouguer gravity anomalies, and to some extent with zones of unusually high seismicity (Topfer pers. comm.). It is possible that these zones of abnormal geophysical characteristics might represent an incipient rift structure, and the unusual water compositions might be a result of the addition of juvenile water from the mantle.

ORIGIN OF ZAMBIAN MINERAL AND THERMAL WATERS

The evidence suggests that the majority of mineral and thermal waters in Zambia are of meteoric origin, heated by deep circulation in major fault zones, and that the dissolved constituents are derived by leaching of the wallrocks adjacent to the faults. The oxygen isotope data from the Lubungu and Lochinvar spring waters supports a meteoric origin (Robson 1974), and the composition of most of the dissolved constituents are compatible with an origin by prolonged wallrock leaching. Mahon (1965), Kissin and Pakhomov (1967), Ellis (1968 and 1969), Helgeson (1969) and others have shown by laboratory and theoretical studies that waters of the composition of typical geothermal fluids can be derived by hot water-rock interactions, the relative concentrations of salts being controlled by rock-water equilibria, the formation of secondary hydrothermal minerals and limiting mineral solubilities. In the case of the sulphate-rich spring waters of Zambia, the probable origin of the dissolved salts is by leaching of Karroo sediments. The group of chloride- and lithium-rich springs extending from the area of Lake Mweru to the Kaimbwe spring near Kasempa are much more difficult to explain. None of the rocks occurring in the areas of the springs is known to be exceptionally rich in chloride. The high concentration of lithium in some of the spring waters makes it improbable that it was derived solely by leaching of the wallrocks. The Katete, Paulo, Chondwe, Moshi and Lubungu springs each has an output of lithium in excess of 0.5 tonne per year, which would require the leaching of 50 000 tonnes of basalt or 13 000 tonnes of granite or 6 500 tonnes of shale per year, based on average lithium contents of 10, 38 and 76 ppm respectively for these rocks (Heier and Billings 1970). The large volumes of rock which would be leached in a period of 10 000 years - a conservative time span for the life of a hydrothermal system - appears to be excessive, and an external source of concentrated brine, possibly from the mantle, for the chloride- and lithium-rich spring waters would appear to be a more likely explanation. The fact that these springs coincide with a major negative Bouguer gravity anomaly may support the idea of the existence of very deep fracture systems up which the chloride-rich brines could migrate. Mixing of the brines with downward percolating meteoric waters would produce the spring waters observed at the surface.

The geothermal gradient in basement rocks is of the order of 23°C per kilometre, which, assuming a mean surface temperature of 20°C, would give a temperature of 100°C at a depth of 3.5 kilometres. Because of the low thermal conductivity of Karroo sediments, the thermal gradient may be much higher and Bond (1953) suggests that gradients in excess of 50°C per kilometre could be reached, giving a temperature of 100°C at a depth of 1.6 kilometres. Since few of the Zambian hot springs approach boiling point, and most of them occur on major fractures which may extend to depths of up to 5 km, heating of water by downward percolation, followed by convective overturn and establishment of a continuous convection cell, appears to be the probable source of heat for these springs.

VARIATIONS OF HOT SPRING ACTIVITY WITH TIME

Variations of water temperature, rate of discharge and radioactivity take place over periods of a few hours. These have been studied only for the Lubungu spring. Variations, mainly in water composition, over periods of months or years have been examined only at the Lochinvar springs, where sampling has been carried out with sufficient frequency over a prolonged period to provide adequate information. However, data from the Lubungu and Chinyunyu springs is also of interest. Variations over periods of thousands or tens of thousands of years in the character of a hot spring can be inferred in a general way from the deposits associated with a few of the hot springs.

Detailed studies of the Lubungu hot spring were carried out in December 1971 and March 1972 (Legg, Topfer and Cowan in prep.), and are summarised below. Studies at the University of Zambia indicate that a variation of about 0.2°C in water temperature through two complete cycles a day may be related to earth tides. The effect of earth tides on water levels in hot spring systems is reported by White (1968), and a correlation between long term earth tidal forces and geyser activity by Rinehart (1972). Marked increases in radiation level, correlated with increasing water discharge and gas emission, were noted at Lubungu in December 1971 and March 1972, lasting for 4 days in March, with a rapid increase in about 12 hours, followed by a more gradual decrease. In March, the water pH also showed considerable fluctuations during this intense activity. In both cases these events followed about 24 hours after major thunderstorms, but unfortunately barometric pressure was not recorded.

Between 1959 and January 1972, both the Bwanda and Gwisho springs showed enrichment in potassium and magnesium relative to sodium. Since then the compositions of the two groups of springs have varied independently at some times, and sympathetically at others. No periodic or cyclic variation is discernable, and sampling at regular intervals for many years would probably be required before any systematic changes could be detected.

Although the Chinyunyu spring has been sampled on a number of occasions by many different people, probably at different points, so that the analyses are not directly comparable with each other, big variations in the ratio of sulphate to chloride are probably real, and can be compared with similar, but less marked variations in Lochinvar waters. Lubungu spring waters show a relatively constant composition judging from the few available analyses, except for the chloride/sulphate ratios in the first two samples, collected in October and December 1971 (table 4). In the first sample, the ratio is 3.7 to 1, while in the second it is 0.2 to 1. In all subsequent samples the ratio is about 0.8 to 1. A possible explanation of the considerable variations in the ratios between two major constituents is that they are of different origin. For example, if much or all of the chloride were of deep mantle origin, periodic injection of small amounts of chloride-rich brine could result in marked changes in the chloride/sulphate ratio.

Some springs show small variations in water composition, especially in the total dissolved solids content, at different times of the year, an effect which could be escribed to climate. Increased rainfall would result in some dilution of spring waters, unless the near-surface portions of the fault channels were completely sealed off against groundwater entry. However, there is insufficient information available to permit definite conclusions to be made.

The abundant encrustations and efflorescences which form around many springs during the dry season are quickly washed away during the rains. Some springs occur at the summits of mounds of organic-rich soil supporting abundant vegetation. These mounds appear to build up by the gradual accumulation of humus material and not by chemical precipitation. Some springs are associated with prominent zones of silicification, such as the Lochinvar fault zone. The material in these zones, which includes fluorite and pyrite, was apparently deposited from hydrothermal solutions - not necessarily the same as those emitted from the springs at the present time. The Lubungu spring is actively depositing travertine, consisting of calcium carbonate with associated iron and manganese oxides, and unusual heavy metal concentrations. Relict mounds of similar material occur near the Musaope spring in the Luangwa Valley, where there is evidence of silicification in a fault zone. The Chibemba spring has deposited a large mound of silica-rich material, without significant calcium carbonate or heavy metals. From the scanty evidence available, it appears that the evolutionary process commences with a period of active silica deposition at the surface or in the conduits or both. This may be followed by a period of travertine deposition, with or without heavy metals, and by a final stage during which only temporary deposits may form. All phases may not take place in every spring.

According to this model, most of the hot springs are at an advanced stage of development, a conclusion which is in accord with the age of most of the faulting. The youngest springs would appear to be those in the Kafue Hook area, which is an area of relatively high seismicity and may be a zone of incipient rift development.

POSSIBLE UTILISATION OF HOT AND MINERAL SPRINGS

Apart from sources of water supply, the three main ways in which the springs could be utilised include the production of salts, geothermal energy and for the promotion of tourism.

Salts

Some of the springs, particularly those in the Chiengi-Puta and Kaimbwe areas, form the basis of a traditional salt industry. With the possible exception of the Kaimbwe brine, the natural brines issuing at the surface are not sufficiently concentrated for salt production on a commercial scale. Drilling in other parts of the world has shown that more concentrated brines may be present at depth, but this is not invariably the case. Any drilling at Kaimbwe should be preceded by detailed geological and geophysical investigations. The cost of exploratory work and of salt production would be high, and it is improbable that the entire needs of the country, currently of the order of 5000 tons per month, would be met. The proposed development of the very large brine reserves of the Makgadikgadi pan in Botswana would have a considerable impact on the price of imported salt, and it is unlikely that salt production from Zambian hot springs would be competitive. However, any development would have important social implications, and may be justifiable from this point of view.

Geothermal energy

The absence of volcanic activity in Zambia since the Cretaceous renders the potential for high-temperature geothermal steam rather low, as under the prevailing natural geothermal gradients, water at temperatures in excess of 200 ^{o}C would be found only below depths of about 8 km, which is too deep for economic utilisation at the present time. However, potential for lower-temperature steam does exist in some areas, in particular the hot spring systems associated with deep Karroo basins, such as the Lochinvar springs, and some of the hotter and larger springs in the Luangwa Valley. Zambia's present energy requirements can be met largely from hydroelectric sources, and the opening of the Kariba North Bank power station and installation of the additional stages of the Kafue scheme should satisfy projected requirements for some time to come. Geothermal energy could be of local importance in isolated areas, however, such as the Luangwa Valley, where the cost of development and installation of a small-scale geothermal plant might be less than a powerline from the existing grid system. Exploration for geothermal energy should, as recommended by Robson (1974), commence with a detailed geochemical investigation of known hot springs, followed by detailed geological mapping and geophysical studies of the more promising areas. There is also potential in some areas for the utilisation of hot spring waters at temperatures below boiling point in specially designed refrigeration plants of the absorption type. A case in point is the Muckleneuk Main spring in the Choma district, where the farmer wishes to use the spring for refrigeration of beef and dairy products.

Tourism

Many of the springs are located in National Parks, and some are easily accessible to tourists. It is recommended that the Department of Wildlife, Fisheries and National Parks improve access to springs where necessary, and provide information at the more interesting sites. The fact that many of the springs, either because of their salt content or their supply of perennial water, are much frequented by game, increases their tourist potential. It is possible that some of the springs could be developed as spas, and recommendations as to the most suitable sites should be made by medical balynology specialists on the basis of the water analyses presented in this report.

RECOMMENDATIONS FOR FURTHER WORK

In addition to the recommendations made above, it is suggested that more information of a long-term character be obtained by repeated sampling and analysis of selected easily accessible springs. The personnel of the Department of Wildlife, Fisheries and National Parks may be able to assist in this respect during their frequent visits to some of the springs. Further detailed studies by the staff and students of the University of Zambia, similar to those carried out at Lubungu, would be of considerable value.

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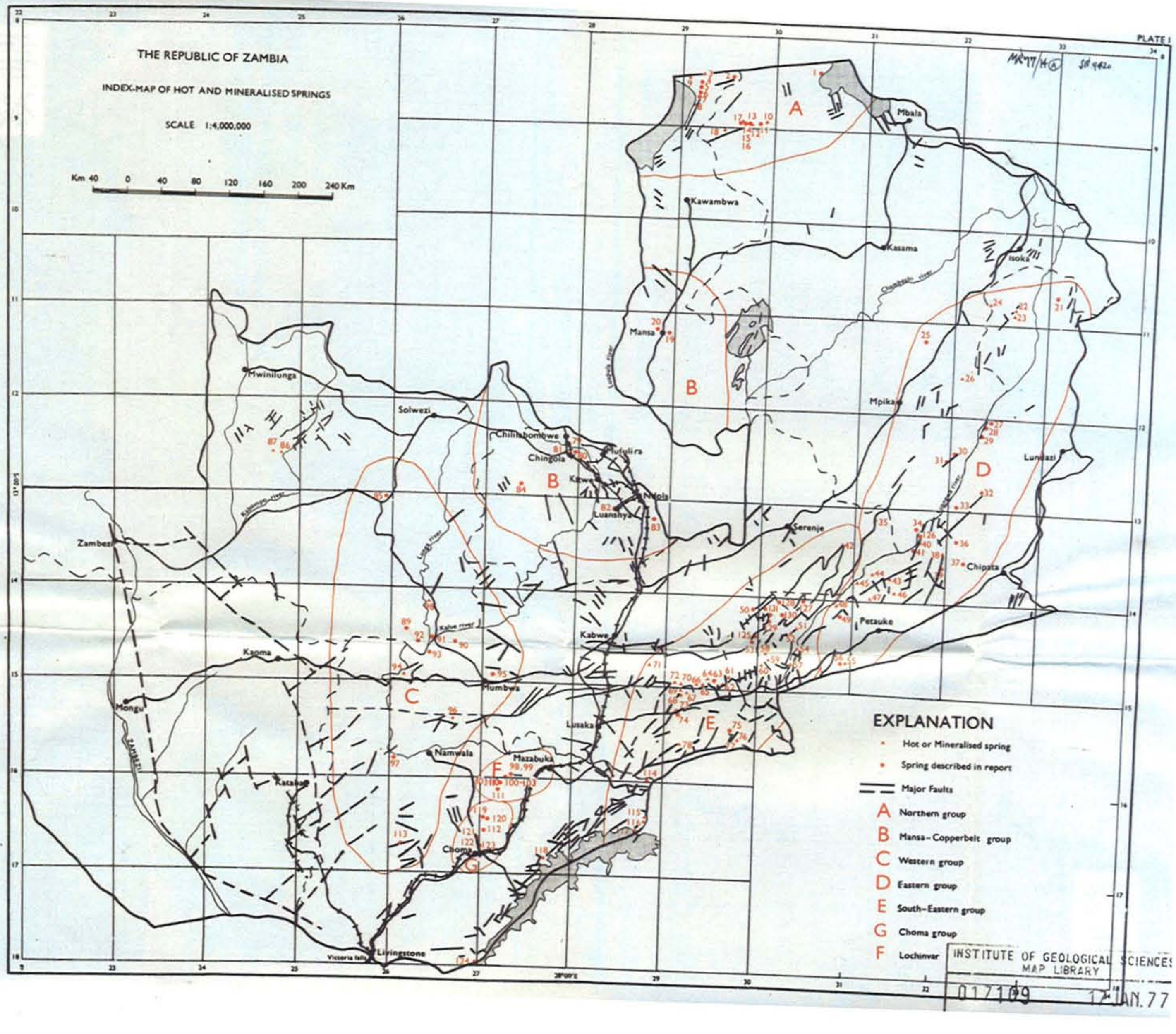


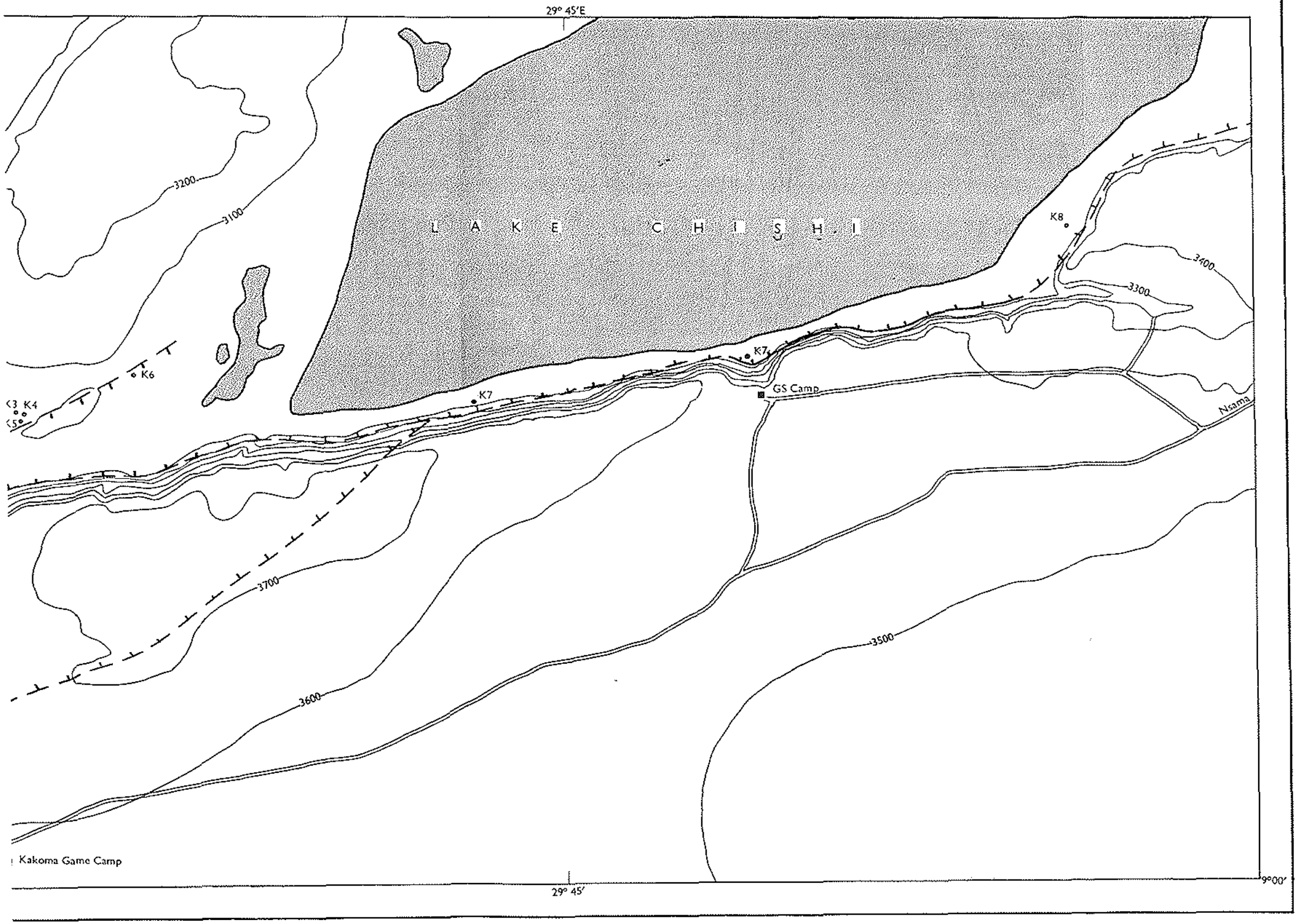
PLATE I
THE REPUBLIC OF ZAMBIA
INDEX-MAP OF HOT AND MINERALISED SPRINGS
SCALE 1:4,000,000
Km 40 0 40 80 120 160 200 240 Km
Mbala
Kawambwa
Kasama
Isoka
Mansa
Mpika
Mwinilunga
Solwezi
Chililabombwe
Chingola
Mufulira
Kitwe
Ndola
Luanshya
Lundazi
Serenje
Chipata
Zambezi
Kabwe
Petauke
Kaoma
Mongu
Mumbwa
Lusaka
Namwala
Mazabuka
Kalabo
Choma
Livingstone
Victoria falls
EXPLANATION
Hot or Mineralised spring
Spring described in report
Major Faults
A Northern group
B Mansa–Copperbelt group
C Western group
D Eastern group
E South-Eastern group
G Choma group
F Lochinvar

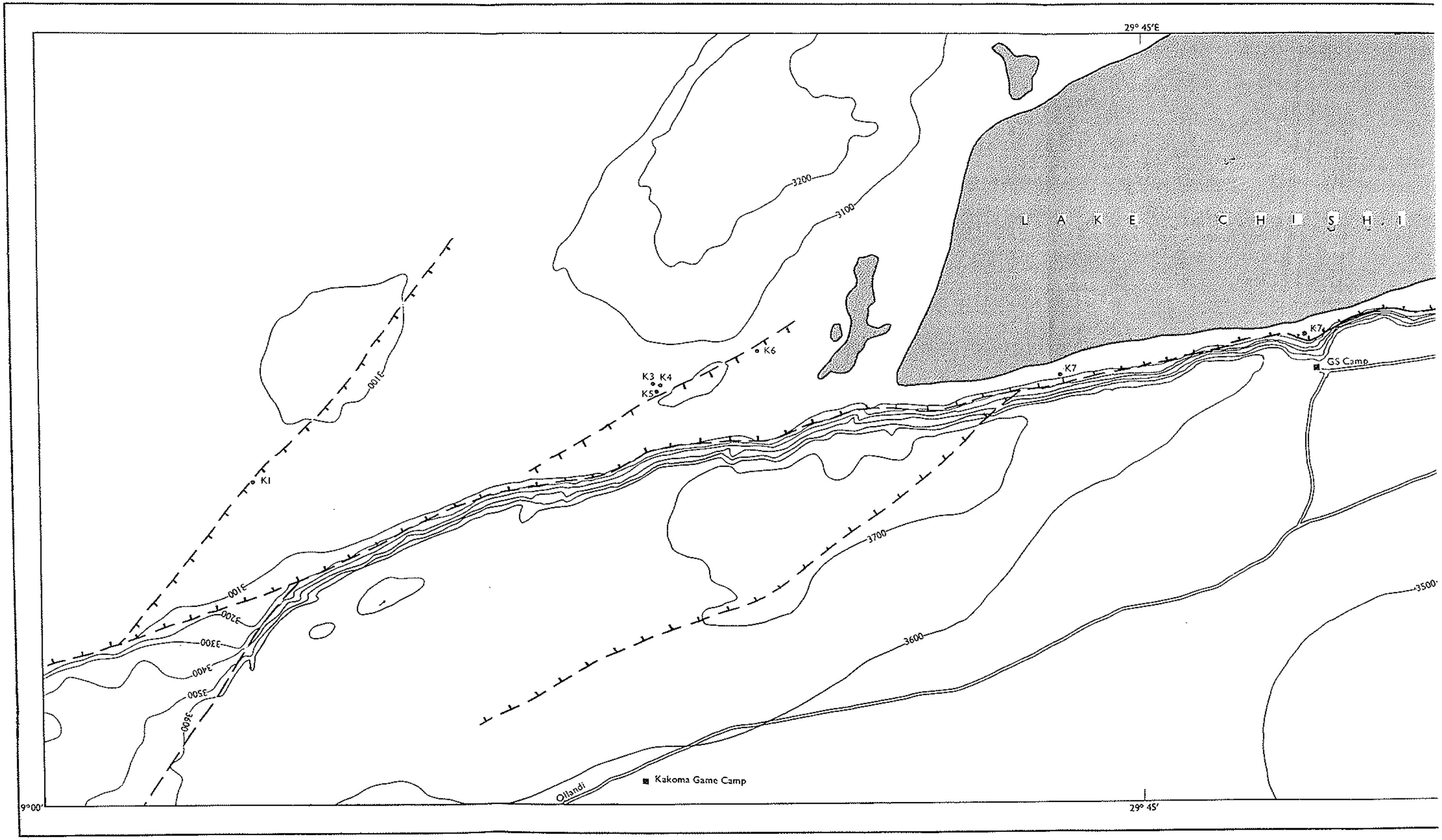
THE KALAYE GROUP OF HOT SPRINGS

SCALE 1:50,000

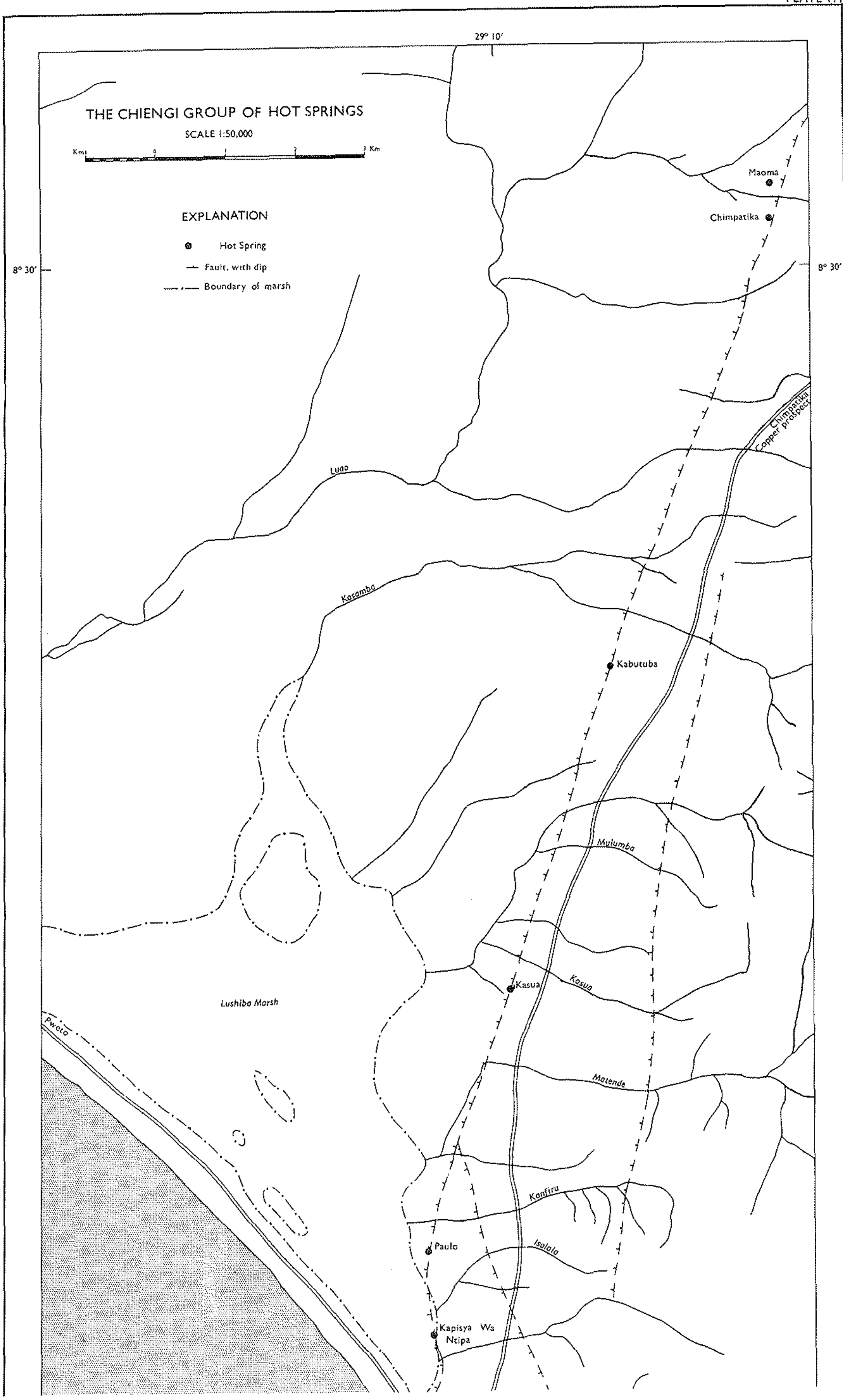
EXPLANATION

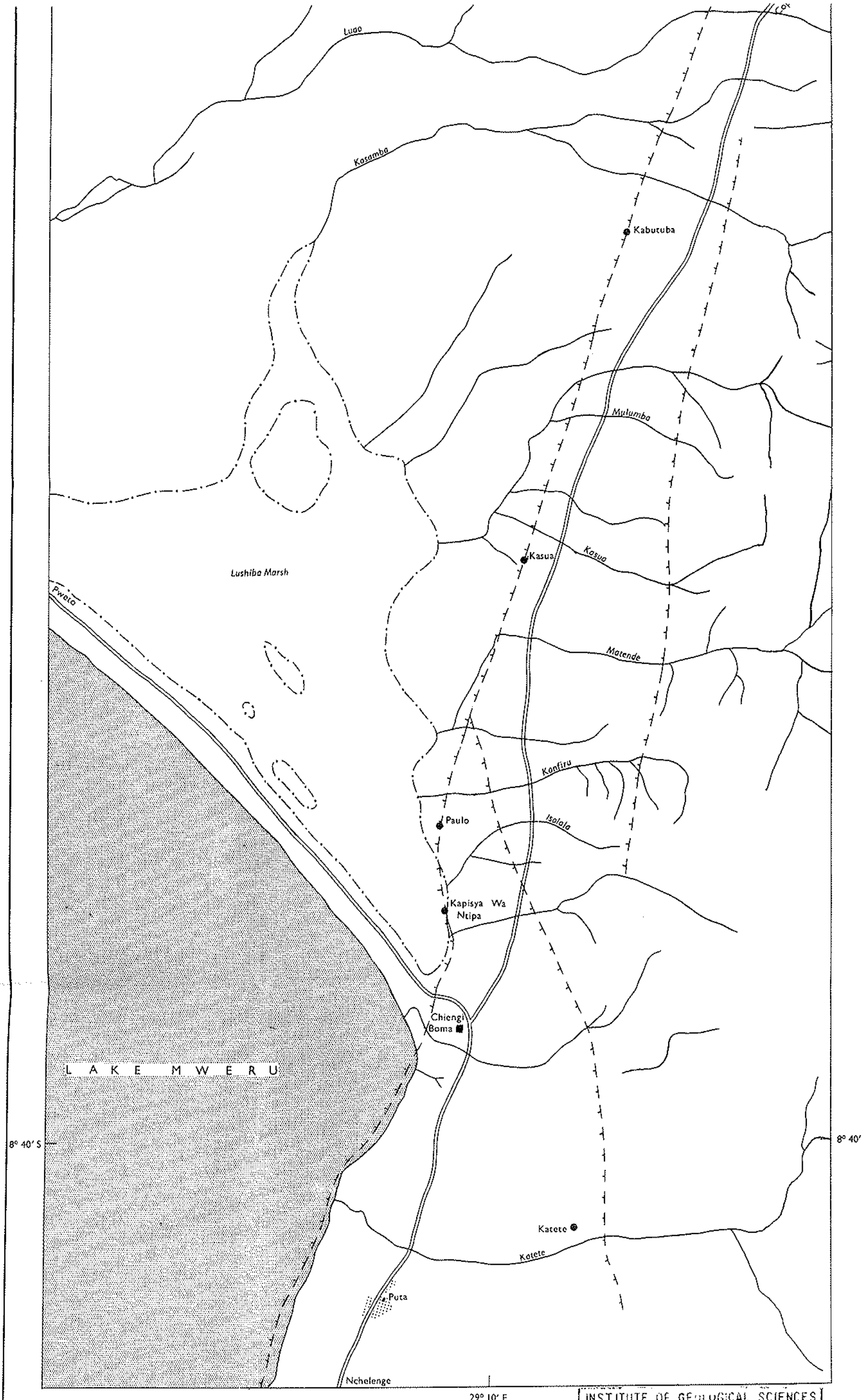
K4 Hot Spring
Fault with dip
3100 Contours in feet



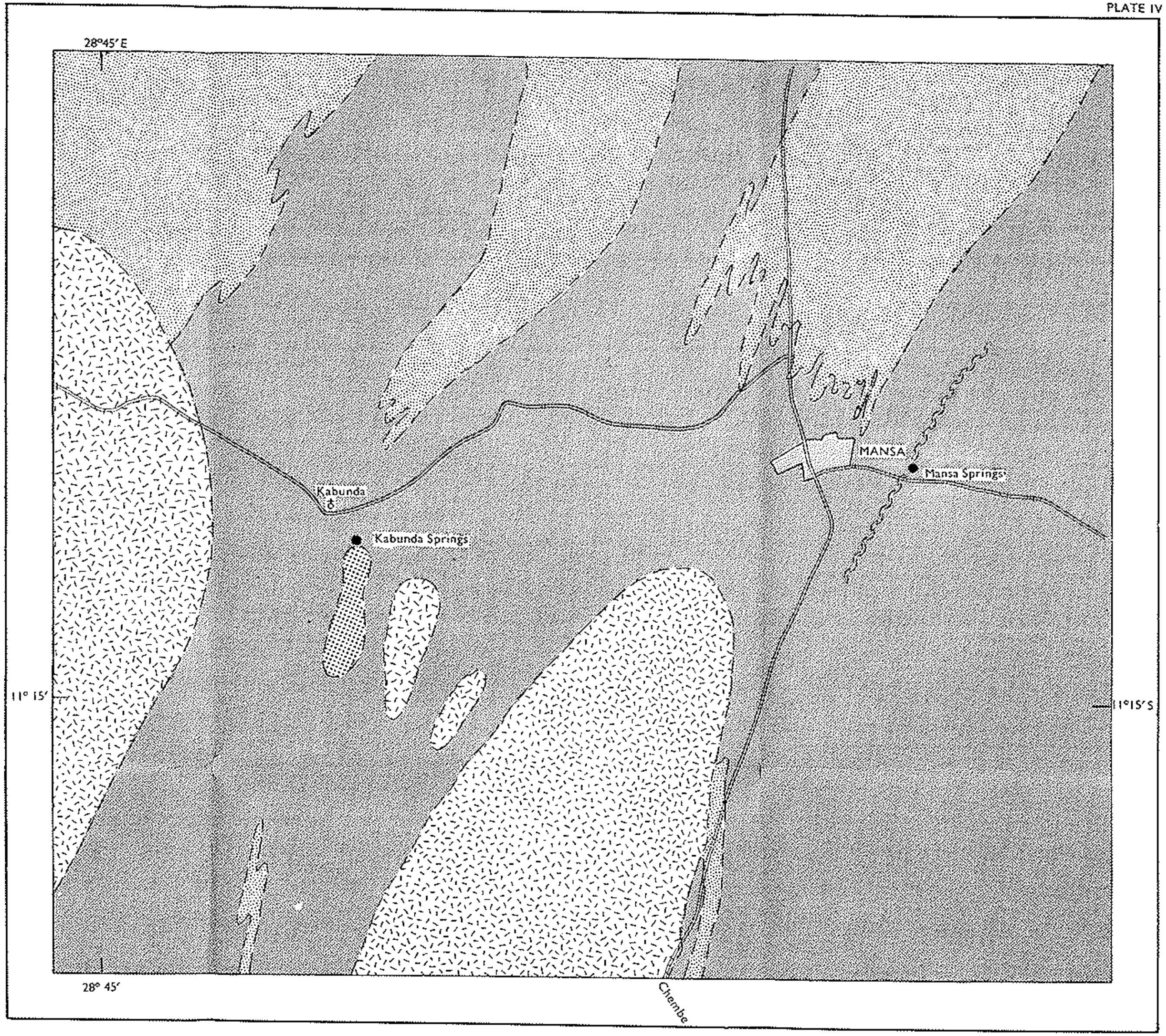


29° 45'E
LAKE CHISHI
3200
3100
3100
3100
3200
3300
3400
3500
3600
3700
3600
3500
K1
K3 K4
K5
K6
K7
K7
GS Camp
Kakoma Game Camp
Ollandi
9°00'
29° 45'


THE CHIENGI GROUP OF HOT SPRINGS
SCALE 1:50,000
Km 1
0
1
2
3 Km
EXPLANATION
Hot Spring
Fault, with dip
Boundary of marsh
29° 10′
8° 30′
8° 30′
Maoma
Chimpatika
Chimpatika Copper prospect
Luao
Kasamba
Kabutuba
Mulumba
Kasua
Kasua
Lushiba Marsh
Pwoto
Matende
Kanfiru
Paulo
Isalala
Kapisya Wa Ntipa


Luao
Kasamba
Kabutuba
Mulumba
Kasua
Kasua
Lushiba Marsh
Pweto
Matende
Kanfiru
Isalala
Paulo
Kapisya Wa
Ntipa
Chiengi
Boma
L A K E M W E R U
8° 40' S
8° 40'
Kateto
Katete
Puta
Nchelenge
29° 10' E

SPRINGS IN THE MANSA DISTRICT



SCALE 1:100,000

1 0 1 2 3 4 Km

Pyroclastics and lavas

Granodiorite

Medium-grained granite

Coarse porphyroblastic granite

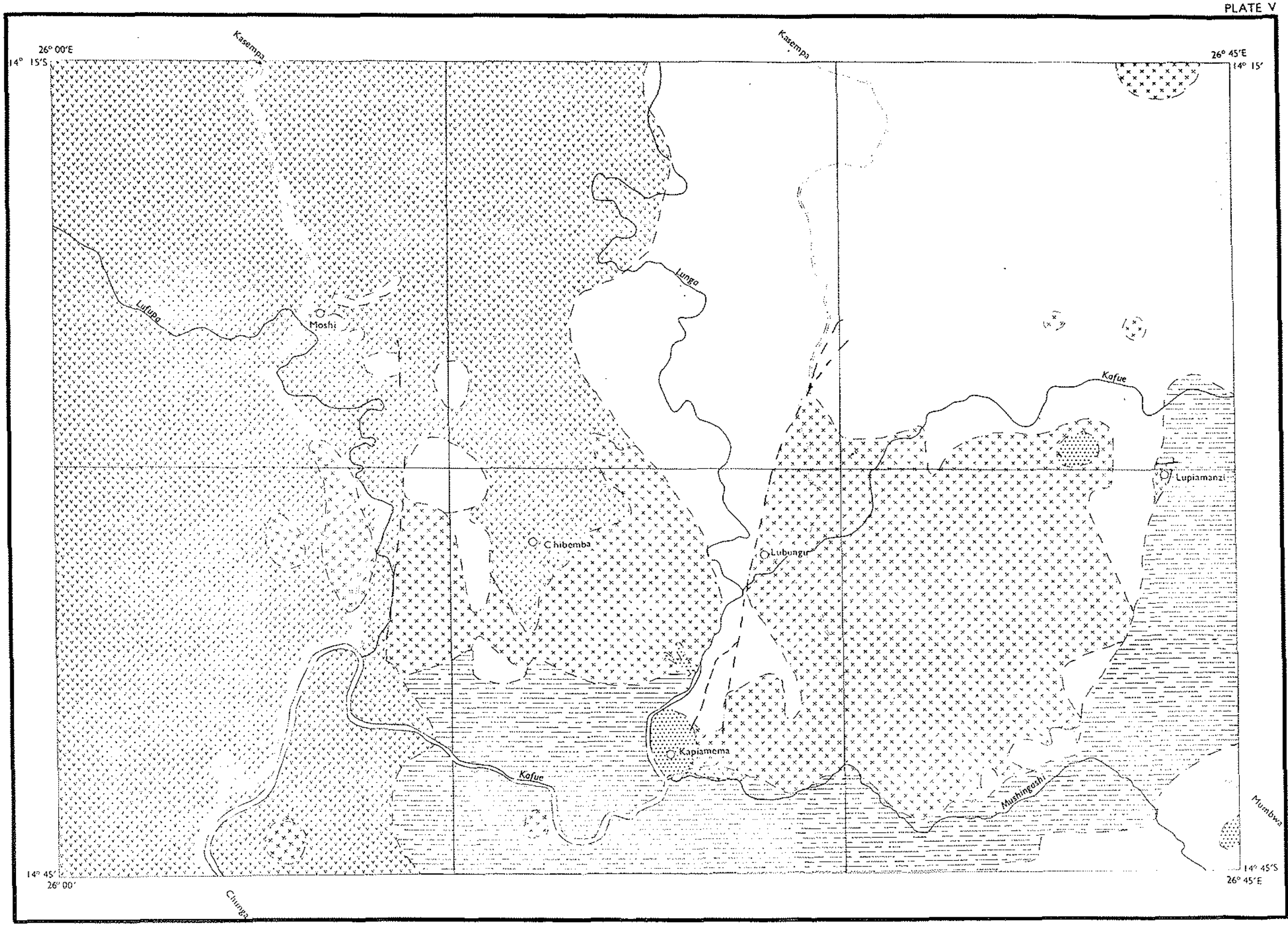
Geological boundary, inferred

Hot Spring

Shear zone

Geology after J.G. Thieme (1970)

HOT SPRINGS IN THE LU



SCALE 1:250,000

Geology after Cikin (1971) Page (in pre

EXPLANATION

Alluvium

Karroo

Katanga

Granodiorite, Syenite, Por

Granite

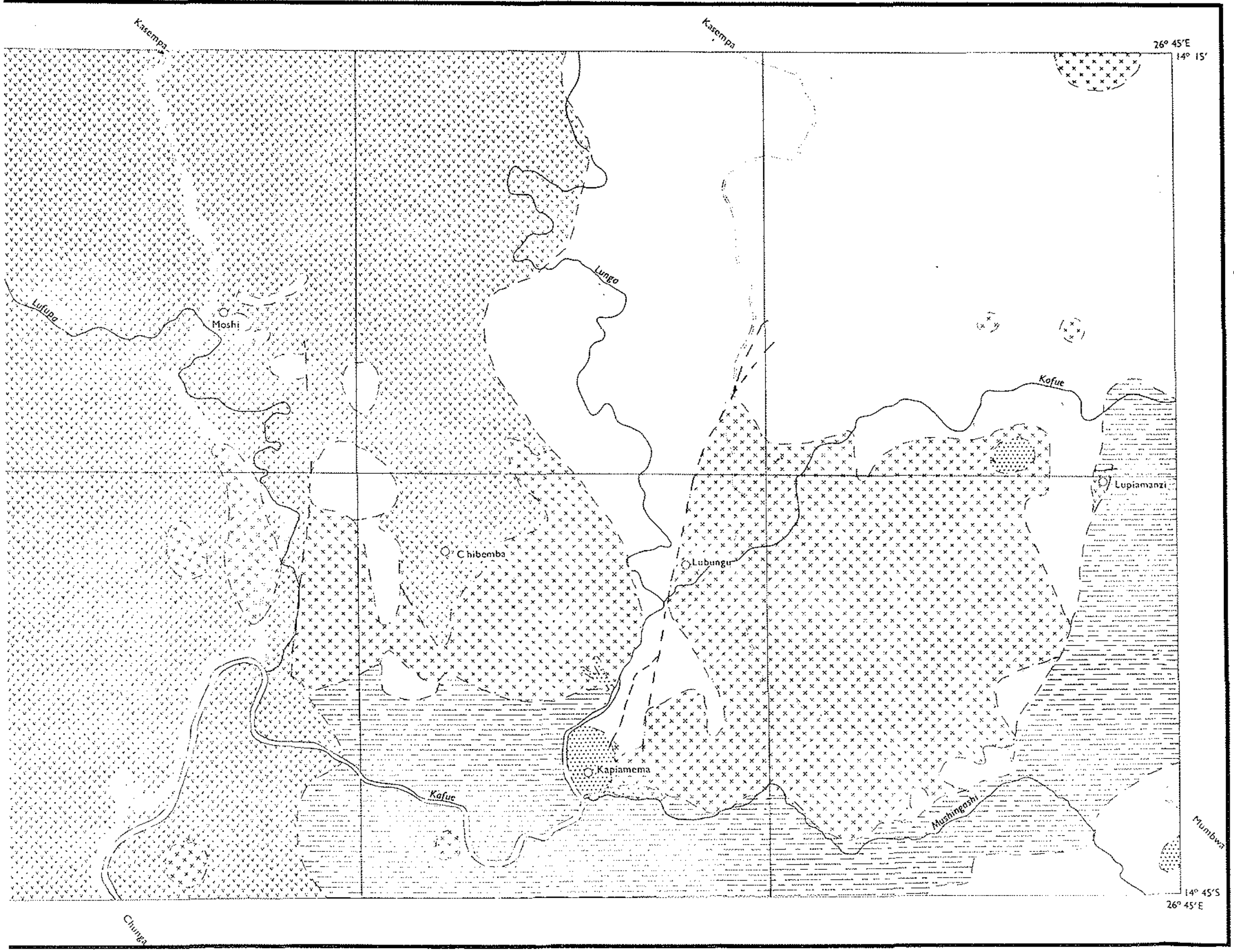
Motorable track

Hot Spring

Geological boundary, i

Fault, inferred

HOT SPRINGS IN THE LUBUNGU AREA



SCALE 1:250,000

Geology after Cikin (1971) Page (in press) and Pipping (in prep.)

EXPLANATION

- Alluvium
- Karroo
- Katanga
- Granodiorite, Syenite, Porphyry
- Granite
- Motorable track
- Hot Spring
- Geological boundary, inferred
- Fault, inferred

DETAILS OF THE LUBUNGU HOT SPRING

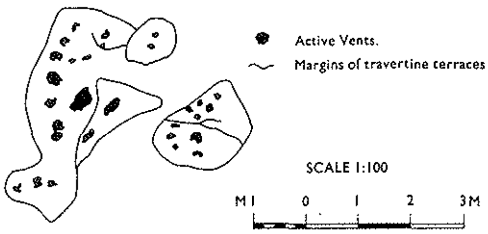
EXPLANATION

FOR

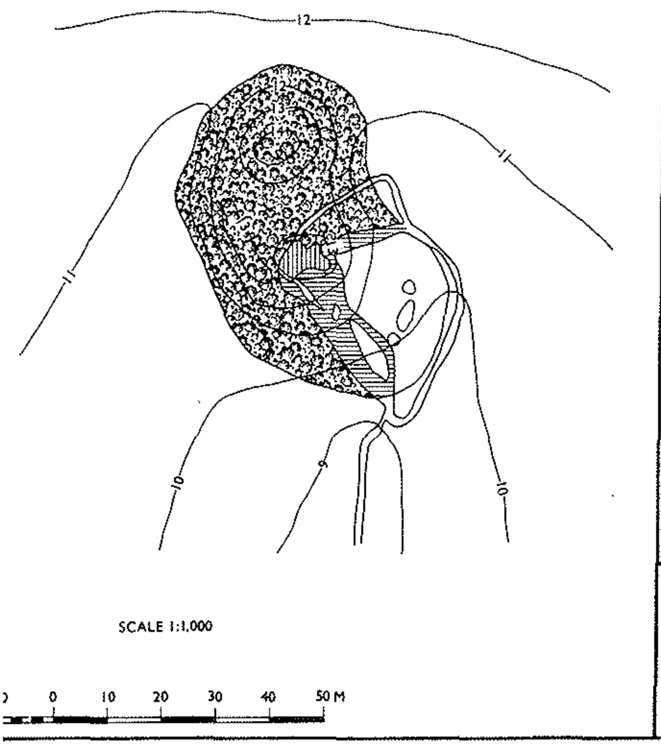
DETAIL OF SPRING AREA

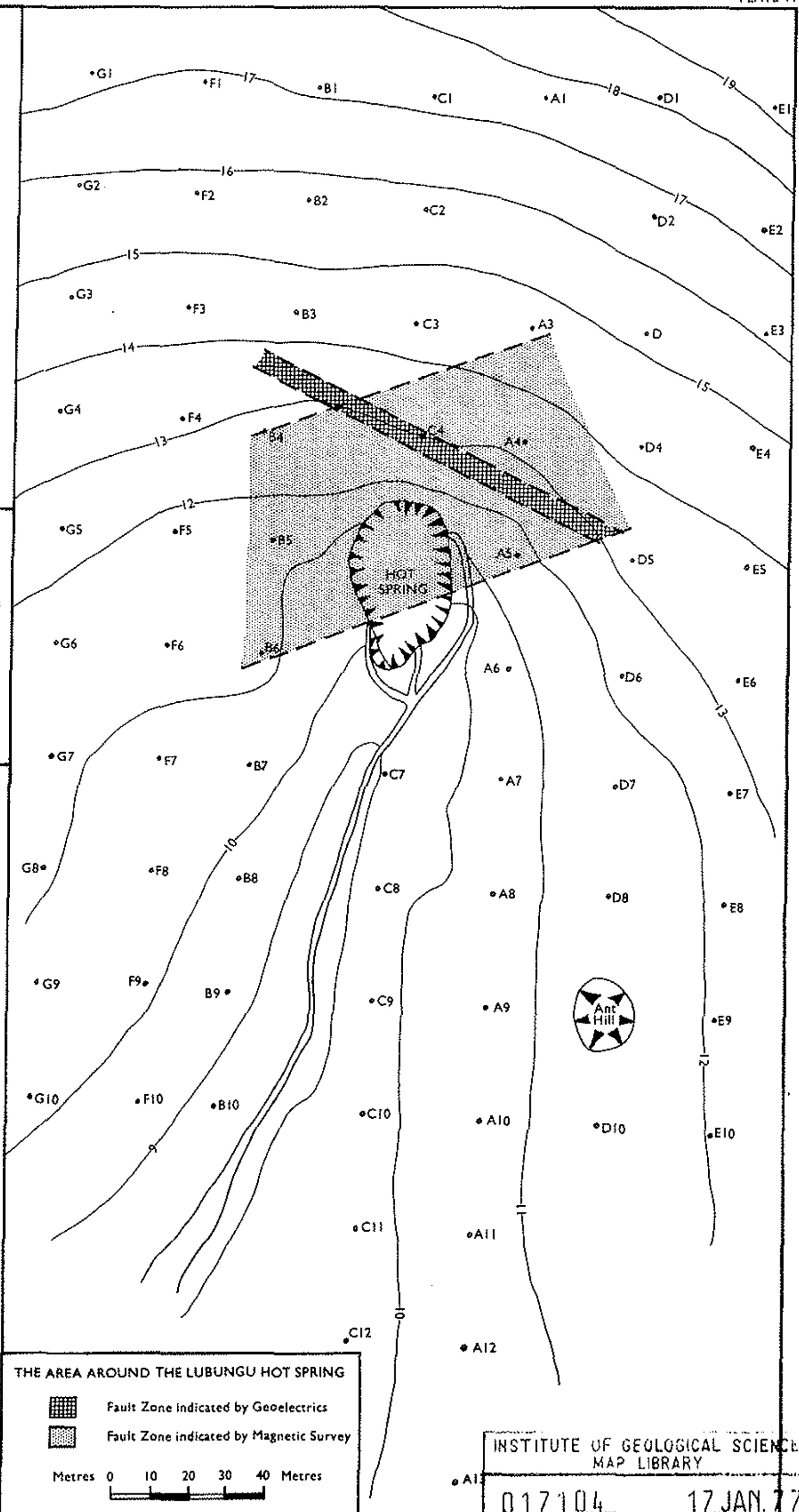
- Main vent area
- Active travertine deposition
- Dense vegetation
- Contours of 1 metre intervals

DETAIL OF ACTIVE VENT AREA



DETAIL OF SPRING AREA





THE AREA AROUND THE LUBUNGU HOT SPRING

- Fault Zone indicated by Geoelectrics
- Fault Zone indicated by Magnetic Survey

Metres 0 10 20 30 40 Metres

DETAILS OF THE LUBUNGU HOT SPRING

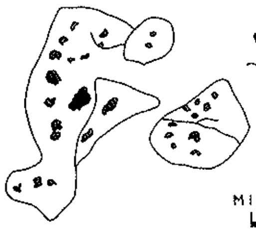
EXPLANATION

FOR

DETAIL OF SPRING AREA

- Main vent area
- Active travertine deposition
- Dense vegetation
- Contours of 1 metre intervals

DETAIL OF ACTIVE VENT AREA

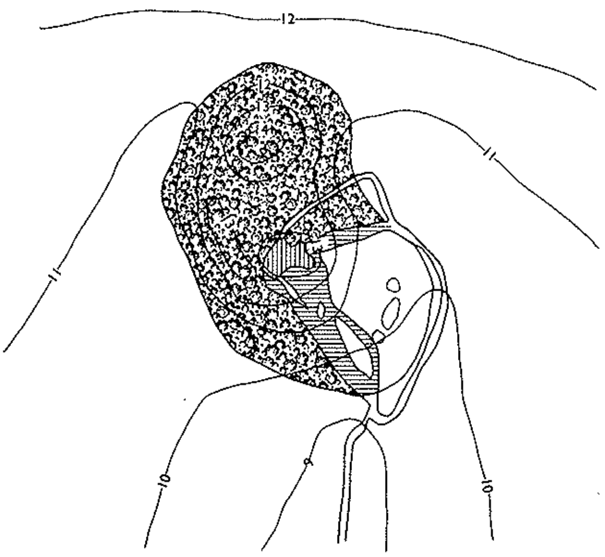


- Active Vents.
- Margins of travertine terraces

SCALE 1:100

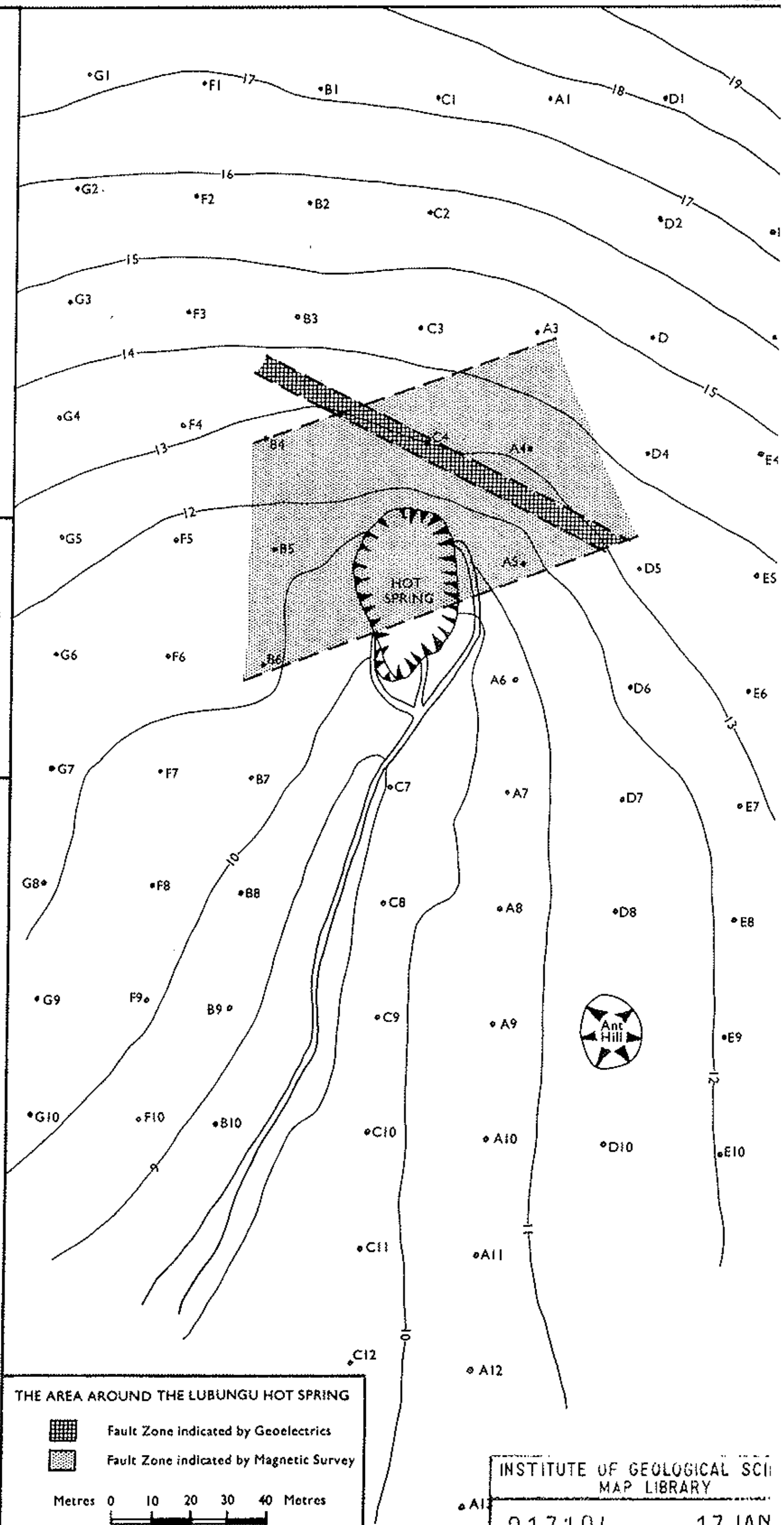
M 1 0 1 2 3 M

DETAIL OF SPRING AREA



SCALE 1:1,000

M 10 0 10 20 30 40 50 M

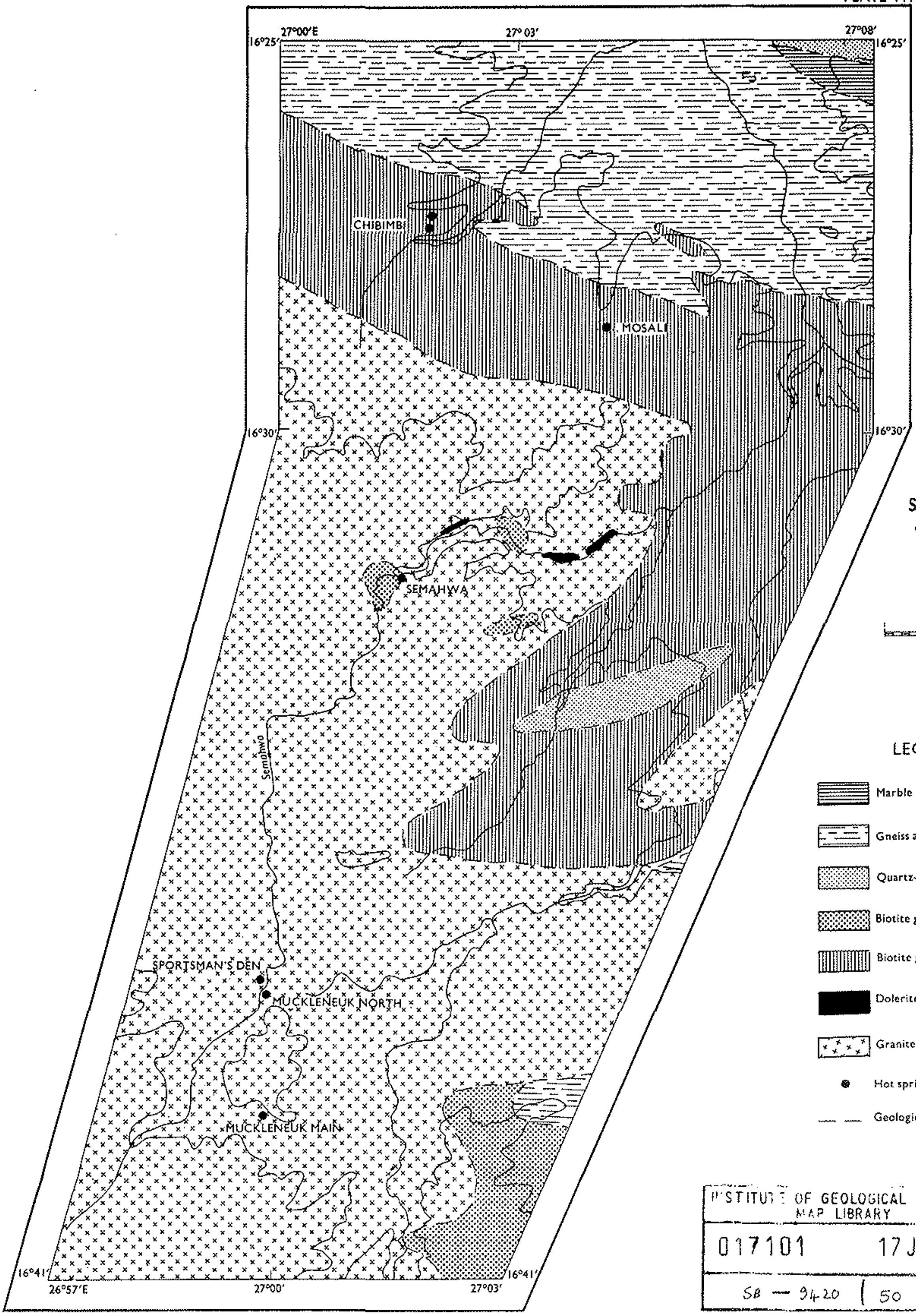


THE AREA AROUND THE LUBUNGU HOT SPRING

- Fault Zone indicated by Geoelectrics
- Fault Zone indicated by Magnetic Survey

Metres 0 10 20 30 40 Metres

PLATE VII



THE HOT SPRINGS NORTH OF CHOMA

Geology after Newton (1963) and Brown (1964.)

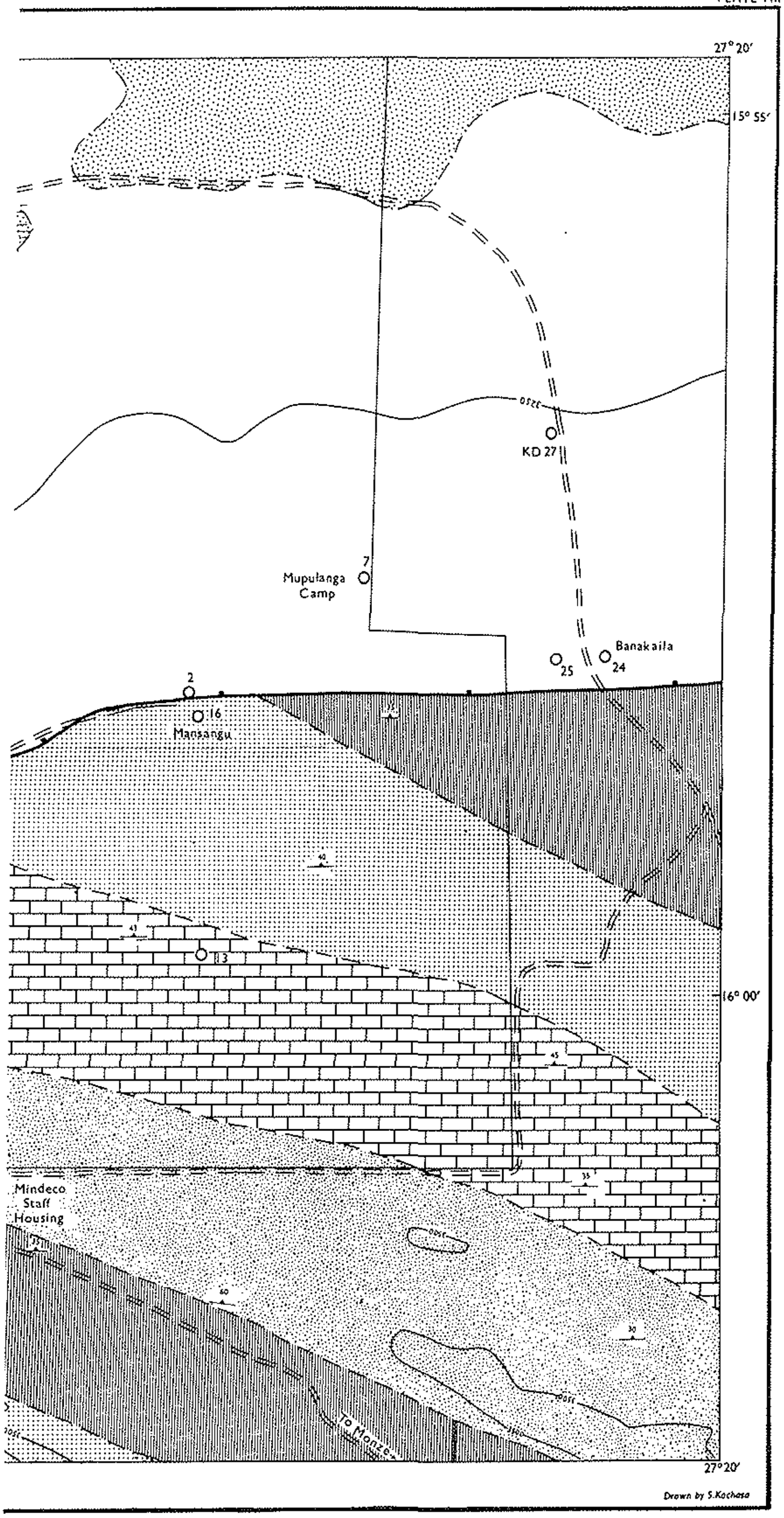
SCALE 1:100,000

1 0 1 2 3 4 Km

LEGEND

- Marble
- Gneiss and quartz-muscovite schist
- Quartz-muscovite schist and quartzite
- Biotite gneiss and granite-gneiss
- Biotite gneiss and granite-gneiss, feldspathised
- Dolerite
- Granite
- Hot spring
- Geological boundary, inferred

PLATE VIII



Drawn by S.Kachasa

THE AREA AROUND THE LOCHINVAR HOT SPRINGS

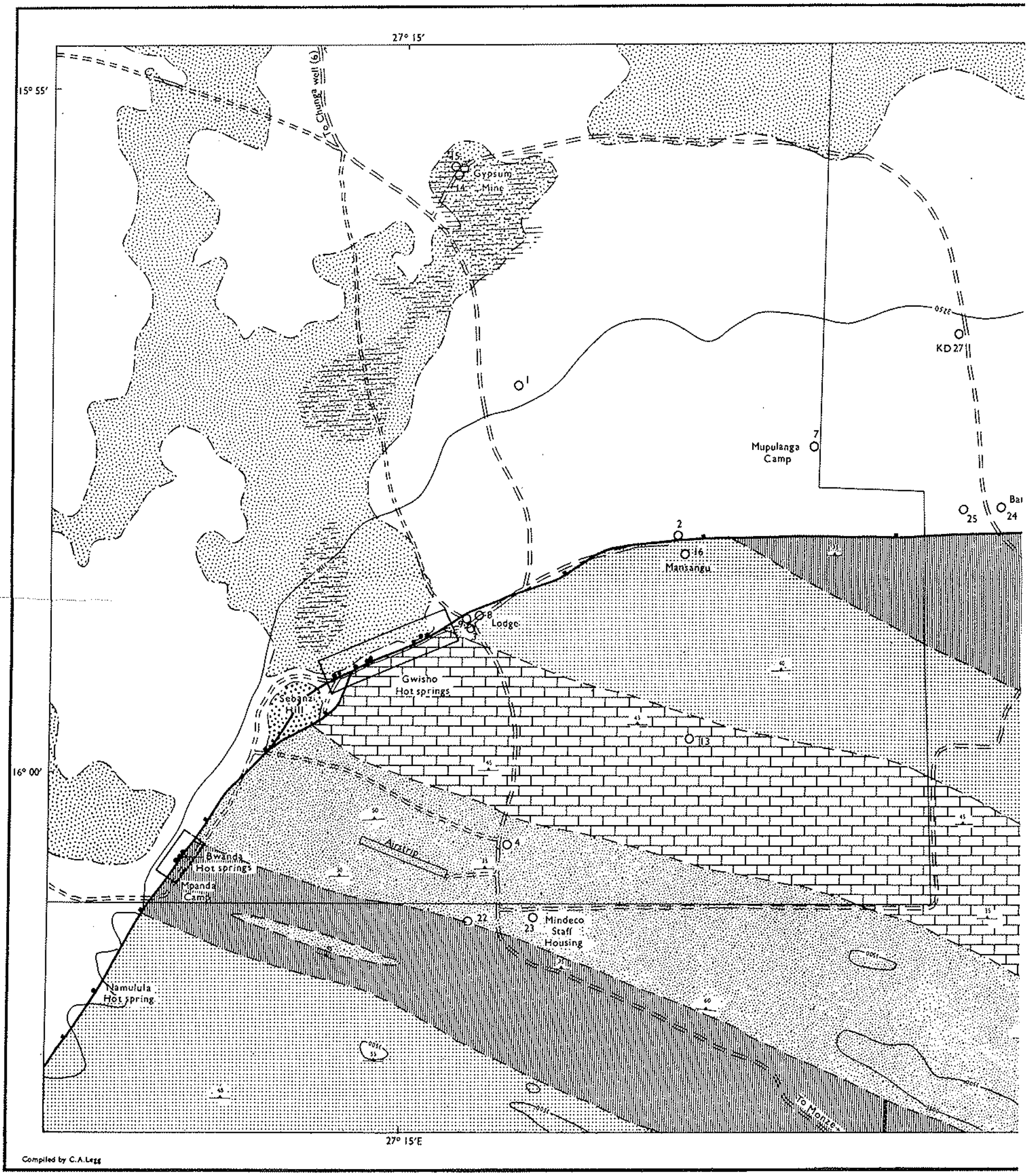
SCALE 1:50,000

Km 1 0 1 2 3Km

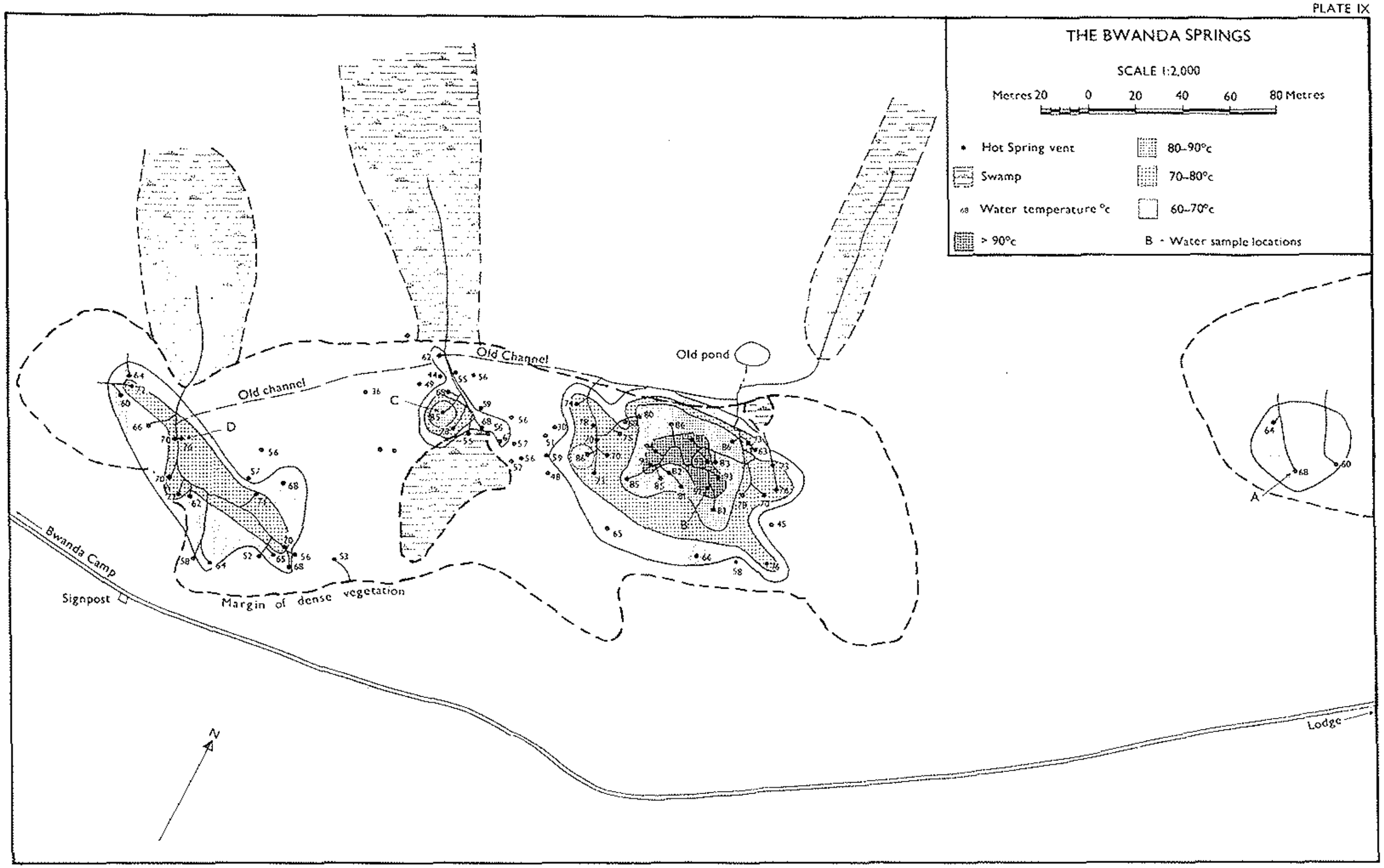
EXPLANATION

Main areas of Gypsum-rich clay		RECENT
Alluvium and Gypsiferous clays overlying Karroo Siltstones, Mudstones and Sandstones		RECENT
Karroo grit		KARROO SYSTEM
(Unconformity)		
Limestone, dolomitic limestone and dolomite		KATANGA SYSTEM
(Unconformity)		
Granite-gneiss and augen gneiss		BASEMENT COMPLEX
Feldspathic quartzite		BASEMENT COMPLEX
Quartz-muscovite schist		BASEMENT COMPLEX

- Geological boundary, inferred
- Foliation strike and dip
- Fault with downthrow
- Hot spring
- Borehole or Well
- All-weather road
- Motorable dry-season track
- High flood level
- Land liable to flooding
- Contour (heights in feet)



Compiled by C.A.Legg


THE BWANDA SPRINGS
SCALE 1:2,000
Metres 20 0 20 40 60 80 Metres
Hot Spring vent
Swamp
Water temperature °c
> 90°c
80–90°c
70–80°c
60–70°c
B - Water sample locations
Old channel
Old Channel
Old pond
Margin of dense vegetation
Bwanda Camp
Signpost
Lodge
N