Thermal Springs at Lilani, Natal, and Their Geologic Setting

by

T. W. Gevers, M.A., Dr. Phil., D.Sc.

[Plates I—X]

ABSTRACT

Six individual thermal springs issue over a distance of 800 yards from a major fault. Temperatures vary from 38.2 to 41.1 °C, and yields from 4,100 to 18,700 gallons per day. The total yield of all springs is 65,000 gallons per day. The content of dissolved salines ranges between 280 and 359 parts per million. By far the most abundant *cation* is sodium, the preponderating *anions* being bicarbonate, carbonate, and silicate. The waters are thus *siliceous alkaline*, one spring being in addition *sulphuretted*. Radioactivity is insignificant. The gases are almost pure nitrogen.

Below the horizontal Table Mountain Sandstone and the lowermost Karroo sediments there is a great variety of East-West trending and steeply dipping ancient crystalline rocks. They include: banded amphibolites, amphibolite-gneiss, and granulites, containing lenticular bodies of serpentine, talc, and crystalline limestone; massive felspathic amphibolite; hornblende-epidote quartz-diorite and granodiorite, as well as biotite-hornblende-epidote granite-gneiss; banded hybrid gneisses; leucocratic gneisses and granites; red aplitic granite; and innumerable aplites and pegmatites. All stages of migmatisation are represented, but many of the more acid rock types are intrusive.

The major Lilani fault is of the tensional, *trap-door* type with narrow subsidiary *graben*. The measurable vertical displacement of the Table Mountain Series is 900-1,000 feet. Evidence is adduced to show that the faulting follows an ancient east-west "line of weakness" characterised in the basement by intense shear in a mainly compressive stress-field, involving extensive flow, even injection, of crystalline limestones caught up in the zone of movement. Most limestones contain an abundance of wall-rock fragments. The zone of disturbance appears to have been initiated during the post-Insuzi orogeny (Precambrian) and movements along it were continued at intervals into post-Karroo times, the final tensional faulting being associated with the downwarp of the coastal belt in pre-Mid-Cretaceous times (Lebombo-Natal monocline), now interpreted to include extensive tilt-block step-faulting towards a major offshore dislocation.

CONTENTS

I. INTRODUCTION

Lilani is the oldest developed *spa* in Natal. Soon after the Zulu rebellion of 1906 a Greytown syndicate was granted a lease of two of the warm springs and a narrow track was constructed around the nose of the Tshane ridge, dropping nearly 2,000 feet in little more than a mile. Eventually a better graded road, subsequently widened for motor traffic, was cut out of the precipitous hillsides above the southern banks of the Lilani river. (Plate I). Its numerous cuttings reveal the most continuous exposures of petrologic and structural detail.

With the lovely setting of its warm pools, shaded by giant *umdoni* trees and surrounded by a colourful garden of flowering shrubs, against a magnificent mountainous background, Lilani is the most beautiful of all *spas* in Southern Africa. Steep and fluted ridges lead up to precipitous krantses of russet-tinted Table Mountain Sandstone, towering some 2,000 feet above the narrow valley floor (Plate I). Rainfall is high (37 inches p.a.) and the grassy slopes remain green throughout most of the year. Patches of dark forest nestle below the cliffs. Cascading streams and waterfalls abound.

The first reference to the geologic setting of the springs was made by A. L. du Toit in 1918 (1).

II. LOCALITY

The Lilani Hydro is situated 12 miles by road from Ahrens (formerly Hermannsburg) Station, on the Greytown-Kranskop railway, at an elevation of approximately 2,100 feet above sea level. The highest point on the road to Ahrens (3,996 feet) rises to 4,135 feet. The distance, as the crow flies, to the Indian Ocean (Umvoti mouth) is 35 miles.

III. TOPOGRAPHY

The difference in scenic aspect between the undulating wattle-covered plateau of horizontal sediments and dolerite sills, edged by cliffs of Table Mountain sandstone (T.M.S.), and the "Valley of a Thousand Hills" type of landscape developed on the steeply tilted and more massive ancient rocks below is striking (Plate I). Flowing in broad and shallow valleys on the uplands, the major streams, Umvoti and Hlimbitwa, take a sudden plunge through steep-walled gorges in the T.M.S. and then once more meander among a maze of fluted hills. Superimposed from overlying sediments and antecedent to the Late Tertiary uplift, they mostly take little heed of geological structure, though some loop sections of the Hlimbitwa *have* been cut along the foliation of banded gneisses (Plate I).

In tributaries structural control is often more pronounced. In the deep gorge of the Lilani river it is immediately apparent. (Plate I). Incised more or less parallel to the east-west strike of the ancient rocks, there is considerable contrast between its southern and northern flanks. South of the stream a dendritic pattern of tributaries, separated by diverging ridges, descends from below the T.M.S. cliffs of the Matimatolo mountains, whose edge is strongly indented in the normal way. North of the river, by contrast, the T.M.S. cliffs of the Tshane ridge, apart from minor indentations, are remarkably rectilinear and numerous parallel tributaries of great steepness course down to the main stream below. The separating ridges are correspondingly sharp and knife-edged (Plate I).

As will be shown later, the Lilani river has cut its way back into the T.M.S. plateau along a major fault-zona that trends parallel to the strike of the ancient rocks underlying the more or less horizontal T.M.S. The southern edge of the Tshane ridge is thus a *fault-line scarp*. The reason for its less rapid recession from the fault trace is probably to be sought in the more resistant rock types on the north side of the fault: aplitic granite and massive hornblende-biotite granite-gneiss. South of the river, by contrast, the T.M.S. is underlain by a broad belt of much more easily weathered banded amphibolitic gneisses.

Rather striking is the "chevron pattern" east of the Hlimbitwa river (eastern margin of Plate I) due to a steeply dipping sheet of platy, aplitic granite intersected by closely spaced gullies.

IV. THERMAL SPRINGS

Six individual spring orifices are strung out, over a distance of roughly 800 yards, in a straight line close to the northern bank of the Lilani river. The latter here flows slightly obliquely to the fault trace, so that the first, westernmost, spring is farthest from the river while the easternmost group is situated on the steep rock bank itself. (Plate I, overlay). All measurements of temperature and yield were carried out on 1 May, 1959.

A. "Radium Bath" Spring

This spring is located upstream some 450 yards to the west of the Hydro Hotel. It is a small elliptical pool, 6 x 5 yards wide, surrounded by trees and reeds and built up with stones to give a depth of approximately 3 feet of water. It is floored with dark mud except in the centre, where sand surrounds the spring orifice. Rather frequent bubbles of gas rise from the latter. There is normally no marked odour of sulphuretted hydrogen.

The surface *temperature* in the centre of the pool, where gas bubbles rise, was measured as 36·5 °C, when air temperature was 20·5 °C. On inserting the thermometer into the sand around the actual orifice on the floor of the pool, the temperature rose to 41·1 °C.

The *yield* at the overflow was measured as 540 gallons per hour or some 13,000 gallons per day.

A small cold spring trickles out of the ground only a few yards away from the pool.

B. Sulphur Spring

This spring, situated 50 yards east of the Hydro Hotel, has been cased in concrete to form a small, sealed enclosure, the walls and floor of which are coated with a greyish-white algal slime. Water for private baths is piped directly from the spring enclosure; mostly, however, it discharges into a small built-up bathing pool, from where it flows successively into two larger swimming pools.

The *temperature* within the sealed spring enclosure was measured consistently as 39·6 °C. When air temperature was 18·8 °C, the overflow from the first warm bathing pool was 34·3 °C and the discharge from the second into the third pool 28·8 °C. Du Toit gave the temperature of this spring in 1918 as 39·5 °C. (1).

No gas bubbles can be seen within the spring enclosure, but there is a pronounced odour of sulphuretted hydrogen. This is still marked in the first pool and distinctly noticeable at its overflow into the second. The latter often exhibits a marked bluish opalescent sheen, probably due to colloidal sulphur derived from the oxidation of dissolved H_2S. The bluish colour appears to vary in intensity, being much more marked at certain times than at others. This would indicate variations either in the H_2S content or in the abundance and activity of micro-organisms that aid in its oxidation or depend on H_2S for their metabolic processes (sulphur bacteria). Unfortunately it was not possible to carry out tests in this connection.

On entering the water a smooth silky, almost "soapy", feel on the skin immediately becomes apparent. In addition to colloidal sulphur, this is probably in part also due to colloidal silica and dissolved sodium silicate. (See chemical analyses Table I).

The *yield* was measured as 470 gallons per hour or 11,200 gallons per day.

C. "Zulu Baths" Springs

Approximately 220 yards farther east and right on the rocky banks of the Lilani river, there occur four more warm springs extensively used by the local Zulu inhabitants. A slight "whiff" of H_2S is often noticeable. The absence of visible gas bubbles may be due to the fact that three of these springs cascade down rocky slopes; but also in the fourth, stagnant, pool no gas bubbles were ever seen to rise.

1. "Washing Pool" Spring

Appearing from beneath a shallow covering of calcareous-siliceous sinter, this spring cascades over a vertical height of 5 feet into a pool, 6 x 8 yards wide and 2-3 feet deep, within the valley-fill on the edge of a rocky cliff. It is extensively used by Zulu women for washing clothes, subsequently rinsed in the rapidly flowing Lilani stream close by.

The *temperature* in the spring orifice was measured as 38·2 °C, that of the adjacent water in the pool being 37·4 °C, and where the latter discharges into the Lilani river, a few dozen yards away, 30-32 °C. The river water at this time, when air temperature stood at 24·3 °C, was only 20·4 °C.

The *yield* of this spring was measured as 575 gallons per hour or 13,800 per day.

2. "Small Spring"

Roughly 12 yards further east a small spring cascades down the rocky cliff. Its orifice is rather obscured. Where measured, at a distance of approximately 30 feet from its first appearance, the *temperature* of the water was still 35·2 °C.

The *yield* was ascertained to be 170 gallons per hour or 4,100 gallons per day.

3. "Girls' Bath" Spring

Some 30 yards eastwards and roughly 45 feet above the river bed, there is another strong spring frequented mainly by Zulu girls, the women performing their ablutions mostly in the same pool in which they wash clothes. The spring orifice is well exposed, the water gushing out of a narrow cavity in highly shattered, banded amphibolites into a small rocky pool, 2½ x 2 yards wide and only about one foot deep.

The *temperature* within the orifice was 39·5 °C, that of the water in the shallow pool being 38·2 °C.

The *yield* was measured as 780 gallons per hour or 18,700 gallons per day. This is the strongest of all six Lilani springs.

4. "Men's Bath" Spring

Some 25 yards eastwards, at a slightly higher elevation, there is the last of the Lilani thermal springs, frequented mostly by Zulu men and boys. A small pool, 4 x 2 yards wide and 2-3 feet deep, has been built up by stone walls against a low cliff of quartzose rock.

TABLE I

CHEMICAL ANALYSES OF LILANI SPRING WATERS

(according to standards of International Society of Medical Hydrology) in milligrams per litre or parts per million

LOCALITY		Lilani, Sulphur Spring? (old analysis)		Sulphur Spring		"Radium Bath" Spring		"Girls' Bath" Spring		Tugela "Shushu" below Kranskop	
Temperature		37–39.5°C		39.6°C		41.1°C		39.5°C		52–53°C	
pH at 20°C		n.d.		8.5		8.4		8.5		8.2	
Temporary Hardness as $CaCO_3$		n.d.		3		3		5		n.d.	
Permanent Hardness as $CaCO_3$		n.d.		nil		nil		nil		n.d.	
IONS		mg/l	N/1000	mg/l	N/1000	mg/l	N/1000	mg/l	N/1000	mg/l	N/1000
Saline Ammonia	$NH_4^{\cdot}$	1.98	.011	0.05	0.003	0.30	0.02	0.05	0.003	0.07	0.004
Lithium	$Li^{\cdot}$	n.d.	—	0.24	0.035	0.25	0.036	0.25	0.036	—	—
Sodium	$Na^{\cdot}$	102.58	4.46	94.00	4.08	101.00	4.40	94.00	4.08	231.40	10.06
Potassium	$K^{\cdot}$	23.01	0.59	3.30	0.085	3.30	0.085	3.30	0.085	8.50	0.217
Magnesium	$Mg^{\cdot\cdot}$	1.44	0.12	nil	—	nil	—	1.00	0.082	7.10	0.583
Calcium	$Ca^{\cdot\cdot}$	2.40	0.12	1.00	0.050	1.00	0.050	1.00	0.050	82.80	4.06**
Iron	$Fe^{\cdot\cdot}$	1.12	0.04	0.08	0.002	0.06	0.002	0.06	0.002	0.80	0.028
Aluminium	$Al^{\cdot\cdot\cdot}$	n.d.	—	<0.01	—	<0.01	—	<0.01	—	5.30	0.58
SUM OF CATIONS		132.53	5.44	98.67	4.255	105.91	4.593	99.66	4.338	335.97	15.528**
Fluoride	F'	n.d.	—	9.00	0.47	10.00	0.53	9.00	0.47	n.d.	—
Chloride	Cl'	35.14	0.99	5.00	0.14	28.00	0.79	5.00	0.14	188.00	5.30
Sulphate	SO_4''	46.08	0.96	31.00	0.64	36.00	0.72	34.00	0.70	385.80	8.037
Sulphite	SO_3''	2.78*	0.07	n.d.	—	n.d.	—	n.d.	—	n.d.	—
Phosphate	PO_4'''	trace	—	0.12	0.003	0.15	0.006	0.15	0.006	3.50	0.11
Bicarbonate	HCO_3'	—	—	49.00	0.80	61.00	1.00	67.00	1.05	34.10	0.559
Carbonate	CO_3''	27.51	0.92	42.00	1.40	42.00	1.40	36.00	1.20	—	—
Silicate (calculated)	SiO_3''	93.86	2.47	30.60	0.802	5.60	0.147	29.40	0.772	—	—
SUM OF ANIONS		205.47	5.41	166.72	4.255	182.75	4.593	180.55	4.338	611.40	14.007
Colloidal Silica SiO_2 (by balance)		—		15.55	.518	70.60	2.353	42.30	1.409	—	
(Total Silica SiO_2) (determined)		—		(40.00)	(1.320)	(75.00)	(2.500)	(65.00)	(2.140)	56.60	
Dissolved Sulphuretted hydrogen	H_2S	0.05–5.00†	—	3.90	—	—	—	—	—	0.70	
TOTAL SUM OF ITEMS		338.00	—	284.84	—	359.26	—	322.51	—	1003.97	—
$NaHCO_3$		n.d.	—	63.00	0.75	80.00	0.95	84.00	1.00	—	—
Na_2CO_3		—	—	74.00	1.40	74.00	1.40	64.00	1.20	—	—
Sought but not found:		NO_3', Br′, I′, $Ba^{\cdot\cdot}$		Nitrate (NO_3'); Nitrite (NO_2'); Manganese ($Mn^{\cdot\cdot}$); Barium ($Ba^{\cdot\cdot}$) Tin (Sn..)						NO_3', NO_2', Br′, I′, $Li^{\cdot}$, $Mn^{\cdot\cdot}$	
Analyst:		pre-1916: A. Heymann		1959: P. T. Viljoen Soil Research Institute, Dept. of Agricultural Technical Services Pretoria.						1942: J. Gray	

NOTES: $N/1000 = \text{millinormality} = \frac{\text{milligrams per litre}}{\text{equivalent weight}}$ n.d. = not determined.

* In addition 0.102 mgms per litre of thiosulphate S_2O_3'' are listed.

† As given by Kent (4).

** Erroneous calculation in original presentation (5) corrected.

The actual orifice is covered by water, but the latter is hottest in the NNE corner of the pool, where 40·6°C was measured some distance below the surface. At the opposite end of the pool the *temperature* was only 34·2°C. A small amount of cold water here trickles down into the pool from the rocks above.

Water seeps out of the latter from below the stone walling. This flow was measured as 170 gallons per hour or 4,000 gallons per day. Owing to additional, non-measurable, seepage, the actual *yield* is probably somewhat higher.

The total combined yield of all six springs is in the neighbourhood of 65000 gallons per day.

V. CHEMICAL ANALYSES

The only analysis hitherto available dates back to before 1916. It is included, in the form first presented by Rindl in 1936 (2, pp.18 and 22) and subsequently re-quoted by Kent in the 1952 re-issue (4), in the following table of new analyses. (Table I). For comparison, an analysis of the hot springs (*shushu*) on the floor of the Tugela Valley below Kranskop, some 30 miles away as the crow flies, is also listed (5).

TABLE III

QUALITATIVE SPECTROGRAPHIC ANALYSES OF SALINE RESIDUES

	"Radium Bath" Spring	*Sulphur Spring*
Major Elements	Na, K, Ca, Si	Na, K, Ca, Si
Minor Elements	Mg, Fe, Al, Strontium (Sr)	Mg, Fe, Al
Trace Elements	Boron (B), Vanadium (V), Titanium (Ti,) Copper (Cu), Chromium (Cr,) Barium (Ba)	Sr, B, V, Ti, Cu, Nickel (Ni), Cr, Ba

Note:—Fluorine, sulphur, carbon, selenium are not detectable by the method used.

Analyst: W. R. Liebenberg.

VI. DISCUSSION OF ANALYTICAL RESULTS

It will be seen that the old, pre-1916 analysis does not tally well with the new ones. Though Rindl (2) listed Lilani under *Sulphur Springs*, the analysis cited by him does not show any H_2S. It is possible, therefore, that the water analysed was not from the Sulphur spring. Its content of total dissolved salines (T.D.S.) is considerably higher than that shown by the new analysis of this spring. In T.D.S. and the much higher content of chloride, it shows greater resemblance to the "Radium Bath" spring. The very much greater potassium content shown is no doubt attributable to the inadequacies of the old Lawrence Smith method of alkali determination, when compared with the more reliable modern flame-photometer technique. If the, probably incorrect, amount of K is reduced to that consistently shown by the new analyses, then the T.D.S. would be intermediate between the Sulphur and "Radium Bath" springs, but the chloride content shown in the old analysis would still link it with the latter rather than the former. It is difficult to say whether these analytical differences over a period of more than 40 years indicate *actual* variations in composition of the same spring water.

The main significant features of chemical composition are the following: the waters are not highly mineralised, their T.D.S. content ranging between 280 and 359 parts per million, being approximately only one third of the salinity of the considerably hotter (52-53°C) Tugela *shushu* below Kranskop (1003·9 p.p.m.) (5).

The most abundant *cation* is sodium. Potassium, as usual, is very much lower, owing to the retention of K by absorption and base exchange in the clayey products of weathering. Calcium and magnesium are surprisingly low, in spite of the fact that crystalline limestones occur closely adjacent to the four easternmost springs and the richness of the banded amphibolites, traversed by all the waters, in both Ca and Mg. These two *ions*, by contrast, are much more abundant in the Tugela *shushu*, where the water rises through a wide fissure-filling of calcite and silica. At the latter locality, however, the gas bubbles, though not abundant, contain carbon dioxide and free CO_2 must therefore also be dissolved in the spring water. The reason for the paucity of Ca and Mg, of which only the bicarbonates are readily soluble, at Lilani is therefore probably to be sought in the absence of free CO_2. The gas bubbles from the "Radium Bath" spring gave no reaction for the latter whatsoever. Ca and Mg carbonates have such a low solubility in water poor in, or even devoid of, free CO_2 and the bicarbonates are so unstable that these salts, under the prevailing conditions, would be largely or entirely precipitated from solution before the water reaches the surface.

The sinter found along the spring-fault fissure at several places between the Sulphur and "Washing Pool" springs, is composed predominantly of carbonate, presumably mostly calcite. The free CO_2 content in previous times may thus have been higher, particularly since CO_2 developed from the oxidation of the abundant vegetable matter covering the sinter at this densely wooded locality would tend to remove $CaCO_3$ in solution far more readily than the silica which constitutes the rest of the sinter. Much of the latter is to be found above the present spring sites located within banded amphibolites and highly siliceous rock. It is possible, therefore, that much of this sinter was derived from springs, now defunct, that rose directly through the crystalline limestones outcropping somewhat higher up the slope and which are still located within the main fault zone.

Apart from silica, both silicate and colloidal, the most abundant *anions* are bicarbonate and carbonate, followed by sulphate. The chloride content is surprisingly low, only the "Radium Bath" spring showing somewhat higher values, being more than 5 times as rich in chloride as the Sulphur and "Girls' Bath" springs situated 450 to 700 yards farther east.

In the Tugela *shushu*, by contrast, total silica, both silicate and colloidal, as well as bicarbonate, are greatly exceeded by sulphate, the most abundant *anion*, and chloride.

The fluorine content is very high in all springs (9-10 p.p.m.), being 4 to 5 times the concentration usually considered safe (2p.p.m.) with regard to fluorosis ("mottled teeth") in young children. The thermal waters, however, are not used as a water-supply for the Lilani Hydro, the latter being obtained from a clear, very fresh stream coursing down from the Tshane ridge.

Since only the Sulphur spring normally emits a marked odour of sulphuretted hydrogen, only this water was analysed for H_2S, the latter being immediately "fixed" *in loco* by the addition of cadmium chloride. The new analysis shows only 3·9 p.p.m. of dissolved H_2S, the sample being taken at a time (May 1959) when the second swimming pool exhibited *no* pronounced bluish sheen of colloidal sulphur. Kent in his general description (4, p.7) cites 1·9 p.p.m. and in the Analytical Table 0·5 - 5 p.p.m. A determination carried out by the writer in 1941 (H_2S "fixed" *in loco* with $CdCl_2$) gave 2·4 p.p.m. (5, p.73). It would seem, therefore, that the H_2S content *is* actually variable, as already suggested. In 1941 the author noted a distinct odour of H_2S at *all* spring sites. According to Kent* similar variations in H_2S content are known from other South African sulphur springs.

The lithium content is low, but significant, in all three waters analyzed. This element is frequently strongly enriched in granites and pegmatites. In small amounts it occurs also in ordinary micas and amphiboles.

The "Radium Bath" spring also contains significant amounts of strontium, whereas in the sulphur spring it is only present in traces. This element constantly accompanies calcium in many minerals.

Concerning other trace-elements, small amounts of boron are often trapped in hydroxyl-bearing minerals, such as biotite and amphiboles. During chemical weathering it goes into solution as boric acid and borates. Titanium, too, is extensively incorporated in many mineral structures, of which titaniferous magnetite is the most common. The minerals ilmenite, leucoxene, and titanite are present in some of the Lilani rock types..

VII. COMPOSITION OF GASES

Only in the "Radium Bath" spring can bubbles of gas be seen to issue. Qualitative tests on the spot indicated the absence of carbon dioxide. A 400 cc sample of the gas was found to be almost entirely nitrogen, as shown by the following table:

TABLE IV

Analysis of gas from the "Radium Bath" Spring, Lilani

Hydrogen	H_2	nil
Carbon dioxide	CO_2	nil
Methane	CH_4	nil
Oxygen	O_2	0·05%
Nitrogen + inert gases (Helium, Argon, etc.)	N_2 + He, A, etc.	99·95%
TOTAL		100·00

Analyst: J. G. Mortimer, Chemical Lab., Johannesburg Municipality Gas Works.

This result is in keeping with the general finding throughout South Africa that the gas bubbling up from thermal springs in ancient crystalline rocks is composed of nitrogen with varying small proportions of oxygen. This fact indicates the gas to be ordinary air from which the oxygen has been abstracted to varying degrees by oxidation processes (Kent 3, p.244). In this particular case removal of O_2 has been practically complete.

VIII. RADIOACTIVITY

Extensive tests were carried out with a portable scintillometer of high sensitivity kindly lent to the author by Professor Sellschop of the Nuclear Physics Research Unit of the University of the Witwatersrand.

At the "Radium Bath" spring, at every setting of the instrument, even for highest sensitivity, there was no increase in response whatsoever against the general background. There was no difference when the probe was held close over gas bubbles rising from the centre of the pool or even when immersed right into them;

* Verbal communication.

also when the central portion of the floor was stirred to produce a multitude of gas bubbles. In spite of its name, this spring is not endowed with any significant radioactivity.

At the Sulphur spring there was a slight increase, against general background, over the opened-up spring enclosure and first warm bathing pool. Also over the four "Zulu Baths" springs there was a slight increase of activity. At the "Girls' Bath" spring, the strongest of all, the most definite significant increase was noted, not only against general background, but also when the probe was moved from the centre of the small pool over the gushing spring orifice and the water cascading from it into the pool. This fact suggests that small quantities of radon gas (radium emanation) are released through agitation of the water.

The degrees of radioactivity (beta and gamma radiation) in each case where a significant difference against background was noted are, however, only slight. In no case was there anything like the activity of the instrument shown over some of the pegmatites outcropping in the vicinity of the thermal springs. Decomposed pegmatite used as path gravel between the Hydro Hotel and Sulphur spring, as well as to the "Radium Bath", invariably caused a much greater degree of response than any of the thermal waters.

IX. CLASSIFICATION OF LILANI THERMAL SPRINGS

Rindl (2) classed Lilani as a sulphur spring. This would apply, however, only to one spring, which Kent (3) listed in his only "slightly sulphuretted" group containing 1-5 mgms of H_2S per litre (3, p.238). According to Kent's suggestions only waters with more than 10 mgms per litre of H_2S+HS' should be classed as truly sulphuretted.

In the old pre-1916 analysis silicate is shown as the most abundant *anion*, its content being twice that of sulphate, almost three times that of chloride, and almost four times that of carbonate. Kent (3) accordingly listed Lilani under *siliceous waters*.

All the new analyses, however, show bicarbonate + carbonate to be the most abundant *anions*, their content being roughly twice that of total silica in the Sulphur and "Girls' Bath" springs and considerably higher also in the more siliceous "Radium Bath" spring. The pH of all three waters is rather high (8·4-8·5).

The Lilani waters, according to their present composition, should therefore be classed as *siliceous alkaline* the "Sulphur spring" being in addition *sulphuretted*.

X. THERAPEUTIC VALUE OF LILANI WATERS

Very few visitors drink these waters, whose saline content in any case is low. Deducting colloidal silica (SiO_2), dissolved salines only amount to 265-288 mgms per litre. The water of the Sulphur spring has a slightly astringent taste, possibly due to a small amount of iron sulphate,

The main therapeutic benefits derived from these waters are through immersion. There is no doubt of the highly beneficial effect of colloidal sulphur on the skin. *Solar dermititis* and *keratosis* for instance, so prevalent in sunny South Africa through an overdose of ultraviolet rays, the writer found to be rapidly improved after periods of regular daily bathing extending over no more than 10-12 days.

Apart from relaxing in unusually beautiful surroundings, most visitors use these waters for rheumatic, arthritic and general neuritic complaints. Many notable cures, or at least prolonged alleviations, have been achieved. The "Radium Bath" spring is claimed to be particularly effective in this respect. It is certainly true that complete immersion in this spring for as brief a period as 15 minutes produces a far greater degree of fatigue, coupled with perspiration in some people, than 3-4 times the duration of bathing in the uppermost warm pool of the Sulphur spring. The overall temperature of the latter is somewhat below that of the human body and has a most pleasant relaxing effect. The "Radium Bath" is several degrees warmer, at least in the centre of the pool. This purely physical difference may well be the main cause of the greater induced fatigue, as well as of the greater efficacy claimed for rheumatic complaints. The somewhat greater concentration of salines, particularly of chlorides and sulphates which act as skin stimulants, may possibly also be part of the cause. The considerably higher silica content is not likely to be involved. The gas bubbles of nitrogen are quite inert. Whatever the actual cause, it certainly is not a high degree of radioactivity (beta and gamma radiation).

XI. SINTER DEPOSITS

At several localities on the wooded path between the Sulphur spring and "Zulu Baths" springs, as well as immediately above the "Washing Pool" spring, there are occurrences of yellowish-white sinter, with a grey surface, up to a few feet thick. A sample from the most extensive deposit on treatment with hot dilute HCl indicated 75·8% carbonate, presumably calcite. The residue was mostly cryptocrystalline silica; a few rounded grains of quartz were also present.

XII. GEOLOGY

A. Rock Seccession

1. Table Mountain Series

The cover of Karroo rocks, Dwyka Tillite and Lower Ecca shales, with intrusive dolerites, lying unconformably on the Table Mountain Series, need not concern us here. The latter, however, forms an integral part of the geologic picture and its visible dislocations are the main factor in elucidating the tectonic structure responsible for the occurrence of the thermal springs.

Though subjected to erosion prior to the deposition of the overlying Karroo sediments, some 500 feet of T.M.S. are still preserved on the Tshane ridge. In the Matimatolo mountains on the opposite side of the gorge the preserved thickness is roughly similar.

The T.M.S. cliffs, often several hundred feet high, are frequently distinctly terraced, a lower and upper cliff face being separated by a sloping ledge of lesser gradient. (Sections: Plate X). Within the latter, red shales, in part sandy, often predominate over argillaceous sandstones and soft micaceous sandstones, while the cliff-forming rocks both above and below are mostly rather pure quartzitic sandstones.

Du Toit (6, p.80) noted that south of a line drawn from Mfongosi, in the Tugela valley, to Melmoth in Zululand the basement-rocks underlying the T.M.S. mostly had been eroded to a rather even surface, whereas to the north of this line the floor of alternating Insuzi quartzites, shales and lavas is often very irregular, with ridges and valleys within which very coarse basal conglomerates were deposited.

None of the latter are found in the Lilani area and the T.M.S. floor is, on the whole, rather even. Irregularities, however, are indicated locally, e.g. below the nose of the Tshane ridge and particularly along the northern headstream of the Lilani river. Here differences in elevation of some 100 feet are indicated within a few hundred yards, but faulting, not shown on the geologic map, appears to be at least in part responsible. Exposures are insufficient for details to be unravelled. There is, however, a good deal of variation in rock type and unit thickness in these localities, as well as generally within the lowermost beds.

In a vertical section taken up the central cliffs of the Tshane ridge, the lowermost rock is a soft, argillaceous sandstone, only a few feet thick and containing in its basal portion smallish angular fragments of highly weathered felspathic amphibolite, which here forms the floor. This is followed by well-bedded, hard, quartzitic sandstones, usually somewhat felspathic and of pale red colour. On fresh exposures, however, the true colour is mostly pale yellow. The thickness of this *basal* group of *cliff-forming quartzites* is up to 100 feet, but locally may dwindle to much less. In the upper part of the Lilani gorge and north of the nose of the Tshane ridge, quartzites become inconspicuous and are largely replaced by softer, reddish, felspathic sandstones with layers of whitish, felspathic grits, as well as red sandy shales. This transition into more easily weathering softer sediments is found also elsewhere, e.g. at the base of the Matimatolo mountains above the asbestos "mine". The basal cliff then disappears, as clearly visible on the air-photo (Plate I).

The overlying *shale band*, up to 150 feet thick, is also subject to considerable variation in thickness and lithology, particularly in the upper reaches of the Lilani river where it is well exposed only in the road cuttings. Here the dominant rocks are soft, deep red shales, with intercalations of sandy types and narrow layers of fine-grained, yellowish-white sandstones (Plate VIII, Fig. 2). Well-bedded argillaceous, in part micaceous, red sandstones also occur and may locally predominate over shales.

A striking feature in the two main headstreams of the Lilani river is the presence in the uppermost portion of the *shale band* of small-pebble conglomerate layers separated by red, argillaceous sandstones. Individual conglomerate bands may be up to 8 feet thick. The pebbles, practically entirely of white quartz and up to 1 inch in diameter, are closely packed and, though far from angular, are on the whole not perfectly rounded. Apart from a few outcrops forming low cliffs, this zone can usually be picked up by the profusion of small quartz pebbles scattered over and embedded within the soil. The main rock type above this conglomerate horizon is a pale reddish, medium-grained, felspathic grit with fairly numerous, recurring, narrow layers of red shale, seldom thicker than a few inches.

That the most strongly developed *oligomictic* orthoconglomerates of *intact* framework (12, p.253-256), with advanced rounding of pebbles, should be found in a predominantly argillaceous environment is an unusul feature. Conglomerates, the coarser residues, are normally associated with finer, but *related* residues, viz. well-washed sands. The fact that the pebbles of these conglomerates are practically exclusively quartz would assign them to Pettijohn's *supermature* category (12, p.225), though the somewhat imperfect rounding is not in agreement with this. In general, *oligomictic* orthoconglomerates are not coarse, pebbles less than an inch in diameter being more typical than larger sizes. They are normally transported by highly turbulent water, either high-velocity streams or beach surf. No marked erosion of the underlying shales was noted anywhere in the Lilani area, though the argillaceous nature of the sandstones associated with the conglomerates does indicate some stirring up of clayey material. The fact that conglomerates are very subordinate in the entire succession and at the same time very mature, i.e. composed only of chemically inert residues, viz. quartz, indicates environmental conditions of low relief, as already deduced from general sub-T.M.S. floor features.

Of special interest, therefore, is the occurrence within the *shale band*, in a spectacular outcrop produced by slump and gully erosion on the west side of the northern headstream of the Lilani river near the boundary gate of the Bantu Reserve, of scattered angular fragments of quartz throughout a thickness of 12-15 feet of well-bedded shales. One zone in particular is characterised by these inclusions; but isolated, similar fragments occur also above and below it. They vary in size from 10 inches down to grit particles. The majority are small, less than 2 inches. They are all very angular, often with sharp points and edges. While mostly of vein-quartz, a few chunks of completely weathered felspathic amphibolite were also seen. The latter underlies the T.M.S. in this area and quartz veins are ubiquitous within the basement-rocks.

The matrix of the main layer is very fine-grained, with a smooth, silky texture without tangible quartz grains. The bedding is completely regular, with no suggestion of disturbance or erosion "wash-outs". Higher up, however, scattered, angular, quartz fragments occur also in a more sandy layer showing cross-bedding.

Regarding origin, the completely undisturbed bedding of the shale matrix rules out slump and mud flow. The glacial horizon within the T.M.S. of the south-western Cape Province naturally comes to mind; but the exceedingly angular quartz fragments show no typically smooth-facetted surfaces. Rock fragments transported subglacially over any appreciable distance, furthermore, do not exhibit such sharp edges and points. Quite obviously the rock fragments in question have not travelled far.

The puzzle was solved by digging operations adjacent to and below a pocket of closely spaced, very large fragments containing, in addition to quartz, a high proportion of completely weathered felspathic amphibolite. What was at first taken to be an only partially exposed particularly large fragment of the latter, turned out to be continuous over many yards, obviously forming part of a protuberance of the massive rock exposed in the stream bed below. The large fragments are thus merely partially dislodged scree on the slopes of a hillock projecting above the pre-T.M.S. land surface, against which the lower beds abut. That the large chunks, up to 1 foot in diameter, practically stayed on the hillslope and progressively smaller fragments were not washed out for more than a few dozen yards, testifies to the quiet conditions of sedimentation. The complete absence of erosional features in the enclosing shales is probably due to their compact "stickiness" under immersion and the fact that ordinary rainwash was responsible for the transport of scree fragments.

Owing to the small scale of the map it was impossible to show the sedimentational and structural details of this complex locality with any degree of clarity.

The *upper cliff-forming quartzites*, overlying the shale band, are much thicker (often several hundred feet) and far more persistent than the basal group. They represent the most quartzitic rocks, with the lowest felspar content, of the entire T.M.S. succession. Where the felspar content increases, the rocks usually at the same time becoming more gritty, their cliff-forming propensities recede, particularly when softer intercalations of reddish, argillaceous sandstone and narrow layers of red shale are also present. Isolated and discontinuous narrow conglomerate layers, with small, mostly well-rounded pebbles of quartz up to half an inch in diameter, are usually associated with felspathic grits.

Above these quartzitic sandstones the T.M.S. sediments are normally more felspathic, often gritty, and on the whole more thickly and less regularly bedded. Cross-bedding is found in all horizons of the T.M.S. outside the more purely argillaceous shale bands.

The development of the Natal rocks correlated with the T.M.S. of the south-western Cape Province is in many ways rather different from that of the type-area. Generally the rocks are far more felspathic and arkosic grits of frequent occurrence. A mainly granitic provenance is obviously indicated. The basal "red bed" facies appears to be best developed where iron-rich rocks (amphibolites etc. of the Tugela and Mfongosi Series) are most widespread among the granites and gneisses.

2. Ancient Crystalline Rocks

A study of the innumerable boulders, often of large size, within the beds of the Lilani and Hlimbitwa rivers already suffices to indicate the great variety of rock types present in the basement below the T.M.S.

Owing to the high rainfall and warm summer temperatures, however, weathering has progressed to great depths, even on the slopes of steep ridges where only the more massive and homogeneous gneisses and granites make scattered outcrops. The banded amphibolites and platy amphibolite-gneisses, on the other hand, are always highly decomposed to form a deep, reddish soil and are well exposed only in some stream courses. Only few outcrops are to be found in the bouldery bed of Lilani river incised parallel to their strike along the main fault trace and often flanked by precipitous walls of alluvium up to 40 feet high. The deeply entrenched meanders of the Hlimbitwa, crossing the E-W trend of the ancient rocks more or less at right angles, have, however, fortunately laid bare superb exposures of most rock types, though here again outcrops of banded amphibolites are scarcest.

A large amount of highly informative detail concerning metamorphism, felspathisation and "granitisation", i.e. the *in situ* generation of gneisses, granites and pegmatites, as well as of the mobilisation of magma thus formed, is available in these magnificent stream-scoured outcrops (Plates IV—VI). For the purpose of this paper a brief description will suffice. The complexity of individual exposures and the degree of intermingling of different rock types is so great, that the geologic picture presented on the map, overlaid on the air-photo, perforce had to be greatly simplified. Often only the predominant rock type is indicated, admixed though it may be with considerable proportions of other materials.

As in the Tugela valley farther north (7, p.10 *et seq.*) the most important rock types occur in belts, of varying width, trending parallel to one another along the dominant E-W tectonic direction. For simplicity, and brevity, the various belts are described in cross-section proceeding outwards, both south- and northwards, from the central belt of banded amphibolite-gneisses within which the main fault, with the thermal springs, is located.

(*a*) *Banded Amphibolites and banded Amphibolite-Gneisses*

In their rather weathered condition in the numerous cuttings along the Lilani road, this group at first sight appears to be a rather monotonous succession of dark femic bands of hornblende amphibolite alternating in endless array with bands of light felsic material, largely of pegmatitic and aplitic texture. Fresh stream and gully outcrops, however, indicate much greater variety, both in composition and and structure. (Plate II, Fig. 2).

The width of individual bands is variable. Occasicnally of *lit-par-lit* dimensions, mostly the banding is considerably coarser and measurable in inches and feet. The dark bands often break out as black slabs. Their grain size varies from fine to medium, the latter usually showing glistening needles of hornblende on slab surfaces. In dense varieties no light minerals may be recognisable; in the coarser they are usually apparent.

Occasionally bright green actinolite zones are visible, mainly along pegmatite margins. One specimen collected was found under the microscope to be composed almost entirely of the orthorhombic Mg-Fe amphibole anthophyllite.

The colour of the felsic bands is mostly white, but pale red aplites and pink pegmatites also occur. The majority are parallel to the foliation, but many, both narrow and wide, also cross-cut the latter. Many water-washed exposures show a veritable network of parallel and criss-crossing veins.

In addition to granitic material, quartz veins are also present, sometimes in abundance. They, too, range from narrow veinlets to bodies several feet in diameter.

The microscope shows the dark amphibolite bands to be composed largely of more or less parallel needles of green hornblende that enclose small quartz grains poikilitically in variable quantity. The mesostasis, apart from quartz, consists of minute unidentifiable flakes and grains, probably largely alteration products ("saussurite" and paragonite) of plagioclase.

(*b*) *Granulites*

Whereas composite amphibolite-gneisses by far predominate in this belt, there also occur bands and thicker layers less femic in composition, varying in colour from grey to pale brownish and red. Within these, foliation is often less marked but usually still present, somewhat darker layers alternating with lighter. They are best classed as granulites. Some are garnet-bearing and may be designated as *garnet granulites*. Rocks of this nature may be several dozen yards wide and in certain zones predominate over amphibolite (Plate I, Overlay).

(*c*) Fine-grained *sericite schists*, usually reddish and deeply decomposed, have been found in several zones within the banded amphibolites.

(*d*) *Sheared banded quartzose* rocks are met with in isolated, usually narrow, layers. Some are undoubtedly massive, sheared quartz veins. Within the fault-zone some highly siliceous rock types are due to secondary silicification. No quartzites of definitely sedimentary origin were identified.

(*e*) *Crystalline Limestones*

Unless duplicated by isoclinal folding, there appear to be several horizons of crystalline limestones, over a width of several hundred yards, within the banded amphibolite-gneisses. Very thin and discontinuous bodies are not shown on the map. Fairly thick bands (up to 30 feet wide) occur in the immediate vicinity of the four "Zulu Baths" springs, both above and below their points of issue. In this thickly wooded area, however, exposures are poor and the rocks mostly weathered. The preponderant rock type appears to be a coarse white marble, with scattered minute specks of pyrite. Another variety is banded white and light grey. At somewhat less obscured exposures the steeply dipping limestone can be seen to contain fragments of adjacent rocks: amphibolite, granulite, aplite, pegmatite, and banded siliceous rock.

Roughly a third of a mile downstream there is an excellent exposure in the bed of the Lilani river. Rather broken and fractured banded amphibolite-gneisses and granulites here contain a band of white to light grey crystalline limestone, 12-15 feet wide, surrounded by several smaller contorted lenses and pods, whose discontinuous nature may be due to *boudinage.* Within the limestones occur numerous fragments of the adjacent rocks, varying in dimensions from a few feet to small chips. The crystalline limestone is mostly banded and shows strong contortions due to flow. One flat slab of banded, highly siliceous rock, several feet long, has been bent into a completely compressed sigmoid fold.

The most interesting exposures of all are to be found on a bare eroded patch near the summit of a hill several hundred feet above the "Zulu Baths". Within the more or less vertical banded amphibolite-gneisses there occur, over a strike-length of several hundred and a width of approximately 50 yards, numerous short lenses and pods of grey crystalline limestone, all with a very rough surface as if containing harder grains. Under the microscope these were found to be mostly broken fragments of tremolite together with shattered grains of quartz, felspar, and hornblende.

Northwards these discontinuous lenses, apparently due to *boudinage,* become progressively more numerous, thicker (up to 3 feet) and longer (several dozen feet), until a large lens up to 12 feet wide and 40 feet long appears. It pinches and swells and ends abruptly in a stumpy bulge that sends elongate tongues into the surrounding rocks. Higher up the slope progressively smaller lenses and pods continue for several dozen yards, the banding of the amphibolite-gneisses curving around them.

The most interesting feature is the abundance within these limestones not only of small fractured grains, but also of large chunks of wall-rock up to a foot wide and several feet long. Pegmatite material predominates. Much of the rock thus represents a breccia with a limestone matrix. (Plate VII, Figs. 1 and 2). Under the microscope small broken fragments of practically every mineral occurring in the adjacent rocks are to be found.

The largest lens actually consists of two vertical portions: a thicker zone, up to 8 feet wide, rey in colour and full of foreign fragments, and a thinner layer, 4-5 feet wide, distinctly banded in light grey and white, with no inclusions. The banding not only bears similarity to that of the adjacent banded amphibolite-gneiss, but also exhibits the same contortions and small drag-folds. The two portions are separated from one another by a bluish quartz vein several inches wide.

Many features here thus point to a secondary replacement origin for the banded variety, and fault-fissure filling for the predominant breccia-form type of limestone. Against this explanation, however, is the widespread occurrence of small, fractured grains of tremolite of contact-metamorphic origin. The limestone must thus have been in existence before at least the final phase of metamorphism, migmatisation, and granite intrusion. Furthermore, the widespread effects of intense tectonic deformation (*boudinage*) point to its existence at least prior to the *tensional* faulting, of post-Karroo age, that displaces the T.M.S. at the north end of the Lilani gorge. Finally, the limestones, greyish to pink in colour, exposed along the main fault in the latter area contain not only broken fragments, but also contorted siliceous bands that may originally have been chert (Plate VIII, Fig. 1).

It would seem, therefore, that these limestone bands and lenses, no matter of what primary origin, are part and parcel of the rock succession and were subsequently caught up, as a zone of weakness, in intense tectonic movements that caused them to flow and incorporate adjacent rock material. Du Toit (6, p.38) mentions a band of crystalline limestone, 1,600 feet long but only 30 feet thick, as occurring within banded amphibolite-gneisses of his Tugela Series near Middle Drift, some 25 miles away. Whilst mentioning contortion of banded layers, he makes no reference to foreign inclusions. This particular limestone band appears to be in now way associated with a fault-zone, thus indicating membership of the ordinary rock succession. Du Toit considers it to be of sedimentary origin.

Four analyses given by Du Toit (1, p.116) show the magnesia content of these limestones to be low.

(*f*) *Talc and Serpentine*

Apart from isolated, narrow bands of talc within the belt of banded amphibolite-gneisses, somewhat larger bodies of talcose rock were found also within the massive amphibolite to be described later. (Plate I, Overlay). Exposures, however, are poor and the relationship with the enclosing rock types could not be determined. Some more massive outcrops showed blebs of amphibole within a talcose matrix. These, therefore, represent altered peridotites originally containing, in addition to olivine and/or orthorhombic pyroxene, also clinopyroxene.

At the asbestos "mine" below the Matimatolo mountains (Plate I, Overlay), a lenticular body of well-preserved serpentine, roughly 100 yards wide and approximately 300 yards long, has been prospected for chrysotile. The serpentine varies in colour from dark bluish-black through brown to greyish-green, with a bright apple green type developed along shear-zones. Marginally the serpentine has been talcified; bright green, brittle, micaceous flakes have also been developed. Contacts against the enclosing banded amphibolites are steep and, where exposed, conformable. All features suggest a lenticular intrusion of dunite.

(*g*) *Massive Banded Gneisses and Leucogranites*

Within the banded amphibolites and granulites exposed south of the Lilani river in the gullies leading up to the Matimatolo mountains, pegmatites, mostly of white colour but also pale pink, become progressively more numerous and thicker, until below the T.M.S. cliffs massive greyish-white granites of varying grain size appear (Plate I, Overlay). Near the margin some types are distinctly pegmatitic and contain muscovite; but the greater part of the rock is medium-grained and often somewhat porphyritic. Biotitic *schlieren* and banded migmatic zones of amphibolite in various stages of potash metasomatism are common.

Outcrops high up on the slopes towards the upper reaches of the Igoaga stream are entirely of these harder, weather-resisting granitic rocks; but deep below in the bed of the Hlimbitwa river magnificent exposures indicate a far more complex picture of predominating hybrid and mixed rocks containing a profusion of bands of leucogranite. Only in one zone, several hundred yards wide, does the latter actually form the main bulk of the rocks; for the most part these granites are subordinate to hybrid, banded gneisses with hornblende and/or biotite. Predominantly greyish, the actual local colour of the gneisses depends on the degree of felspathisation of banded amphibolites and occasional intercalated biotite-schists. Light coloured, felspar-rich zones alternate with darker, more femic; individual bands vary in width from less than an inch to several feet. The bands are frequently intensely contorted due to drag-folding with axes oblique to the general E-W tectonic trend (Plate III Fig. 2).

These exposures, recurrently washed by the floodwaters of the Hlimbitwa, are among the most superb known to the author and would well repay detailed study of migmatisation processes (Plate III, Figs. 1 and 2, and Plate IV, Figs. 1 and 2). All stages in the process of "granitisation" can be followed, from isolated felspar porphyroblasts to their gradual massing into truly granitic layers. In some granitic zones, up to a few yards wide, the drag-fold contortions of the less highly granitised rocks can still be seen in "ghost" form. Some granitic bodies, on the other hand, cut obliquely across the foliation, thus indicating injection.

The microscope shows hornblende in the more mafic bands often to be replaced by biotite, which in turn is sometimes chloritised. Epidote is common. The felspar is largely altered oligoclase-andesine. The larger felspar porphyroblasts are potassic. In the leucogranites microcline predominates. There can thus be no doubt of the introduction of alkalies, particularly potassium, into the original rocks.

(*h*) *Massive Amphibolites (often felspathic), and Hornblende Diorite and Granodiorite*

Northwards of the broad belt of banded amphibolite-gneisses and granulites cut by the Lilani fault-zone, geologic conditions are just as complex. Also in this direction there is a marked increase in *igneous* activity, both metasomatic and intrusive in character. The final results are even more varied than those along the southern margin of this belt, not only in cross-section but also laterally.

The amphibolite here is mostly massive and unbanded. Much of it is fine-grained and very black, but all stages of felspathisation can be seen, though gradational contacts between larger masses of the different rock types are not exposed. The details of the general process can be studied in many exposures.

A striking feature is that in this very massive amphibolite incipient felspathisation is often not in bands, as described from farther south, but proceeds from intersecting fractures. The rock is not only seamed with irregular, narrow veinlets of essentially felsic nature, but also by fine-grained hybrid material extending gradationally into the black amphibolite. All stages of increasing felspar content can be seen, resulting in "replacement breccias" of angular fragments of dark amphibolite often showing corrosion embayments, set in a grey felspathic matrix of coarser grain and variable felspar content (Plate V, Fig. 1). The wider and more abundant this matrix becomes, the richer it is in felsic constituents and the lighter its colour.

Under the microscope incipient alteration of green hornblende to biotite can be observed. Epidote is common. Felspar is present in very variable amounts and is largely altered. Where albite twinning is still preserved, oligoclase-andesine is indicated. Most slides also show quartz in grains and veinlets. Grain size often varies; where coarser, there is usually more felsic material and hornblende is less, but in larger aggregates. Some of the larger felspars enclose hornblende poikilitically.

On a larger scale the outcrops here show all stages of increasing felspar content and recrystallisation, varying from black, fine-grained amphibolite through white-speckled and felspathic varieties and hornblende quartz diorite of medium grain to coarse, grey, hornblende-epidote granodiorite (Plate V, Fig. 2) and hornblende-biotite-epidote-granite-gneiss (Plate VI, Fig. 1). The degree of alteration is very variable both across the E-W tectonic trend and parallel to it, resulting in widespread and often rapid variation of lithologic types along the same line of strike.

Thus, whilst the rocky cliffs on the eastern slopes of the deeply entrenched Hlimbitwa river show outcrops mainly of coarse-and medium-grained hornblende-epidote granodiorite and hornblende-biotite-epidote granite-gneiss, albeit with large numbers of zones and patches of felspathic amphibolite, on the opposite, steep, western slopes outcrops are almost entirely of the latter rock. While the felspar content and degree of recrystallisation also here are subject to wide fluctuation, actual granodiorite and granite-gneiss are present only on a very restricted scale (Plate I, Overlay).

(*i*) *Massive hornblende-biotite and biotite-hornblende-epidote Granite-Gneiss*

One sheet of fully "granitised" rock, up to 200 yards wide, however, persists along the E-W tectonic trend from the valley of the Hlimbitwa for several miles westwards. It is the major rock type outcropping high above the Lilani road below the eastern end of the T.M.S.-capped Tshane ridge. It does not, however, persist as far as the head of the Lilani gorge, where it is in part once more replaced by felspathic amphibolites, but in part appears to grade into more acid hybrid gneisses. (Plate I, Overlay).

Another apparently broader belt, comprising both granodiorite- and granite-gneiss of this type, extends both east- and westwards in the region of the Hlimbitwa rapids below the nose of the Tshane ridge. It is here, however, so heavily laced with white and pale pink aplitic granite and aplite, that the latter rocks frequently preponderate over the gneiss.

The granite-gneiss is normally coarse (Plate VI, Fig. 1), though medium-grained varieties also occur. Its overall colour is mottled grey, but owing to the abundant development of epidote it frequently has a distinct greenish-yellow tinge. It often encloses rafts of felspathic amphibolite and in places may also contain *schlieren* and nodular patches of biotite. Some types may be distinctly foliated, but some are almost granitic in texture.

Under the microscope several interesting features may be observed. In a specimen from the Hlimbitwa river, apparently representing a transition from highly felspathic, massive amphibolite, the predominant femic mineral is green hornblende, poikilitically enclosing quartz and apatite. Biotite is quite subordinate and can be seen to replace hornblende. The felspar is largely turbid (paragonite, etc.); clear portions are twinned oligoclase. As far as can be ascertained, the felspar is thus predominantly sodic plagioclase. Quartz is less abundant than in the specimens to be mentioned later. Mineralogically the rock can thus be described as hornblende granodiorite, portions being quartz diorite.

Westwards, overlooking the Lilani road below the Tshane ridge, similar, though somewhat coarser, rocks show biotite to predominate over hornblende, usually very considerably. In some types hornblende is only seen as residual remnants within the biotite. The latter still often encloses quartz and apatite poikilitically, and small grains of zircon, surrounded by pleochroic haloes, are now present. The amount of femic minerals is considerably reduced, biotite often occurring in clusters or, together with residual hornblende, in elongate *schlieren*. Quartz is more abundant and often present in large patches or lenticles of sutured, highly undulose grains. The felspar is now predominantly microcline and perthite, often partially altered to sericite. Oligoclase is now quite subordinate. Epidote is still common. Pale pink garnet (almandine) occurs sporadically. Sphene, though present only in small amounts, appears to be far more common than in the felspathic amphibolites.

The final rocks are thus true granites in mineralogical composition, the only abnormal feature being the abundance of epidote.

(*i*) *Pale red, yellow and grey Gneisses*

Between the sheet of red aplitic granite and the belt of biotite-hornblende granite-gneiss below the eastern end of the Tshane ridge, there is a poorly exposed zone of pale red, fine-grained "streaky" gneiss. Situated within an ancient fault-zone, part of this rock may be highly sheared aplitic granite; but where intersected by the road further west, outcrops indicate a higher femic content than normally possessed by the latter.

Still farther west, and more or less in the same line of strike as the belt of biotite-hornblende granite-gneiss, there is a considerable development of coarser types of pale red, yellow, and grey gneisses, which are particularly well exposed in the bed of the northern headstream of the Lilani river. (Plate I, Overlay). Here these gneisses are of an extremely "mixed" type and seamed with an abundance of aplite veins. Bands rich in biotite, as well as rafts of banded amphibolite, are common.

Under the microscope, these rocks are mostly composed of quartz and turbid felspar, among which microcline and subordinate sodic plagioclase can still be identified. The only femic mineral present is biotite, scattered rather sparingly, together with ore, in little nests throughout the felspar-quartz matrix. Closer to the fault zone highly cataclastic varieties show the biotite to be mostly replaced by chlorite and secondary iron ore. The latter minerals, together with some epidote, often line fractures or occur within intensely granulated, almost mylonitised, shear-planes.

(*k*) *Massive grey Leucogranite*

Above the first cataract of the northern Lilani headstream, below the eucalyptus plantations, there outcrops, within mixed gneiss and felspathic amphibolite, a massive, light grey leucogranite composed of quartz, potassic felspar, and very sparing biotite, in part chloritised.

(*l*) *Aplites and Pegmatites*

As already outlined, there is a profusion of these within practically all rock types except the red, aplitic granite. Another conspicuous exception is the body of serpentine below the Matimatolo mountains. Du Toit (6, p.68) attributes this to the toughness of peridotites, which merely became serpentinised and talcified in the process of migmatisation.

The predominant colour is white, but pink and pale red also occur, as well as occasional blood-red varieties. The pegmatites often contain muscovite, not infrequently also pink almandine garnet. Tourmaline is rare. The felspars are potassic.

Several sequences of emplacement are indicated, these rocks often cutting each other in bewildering fashion. Some pegmatites, however, can clearly be seen to have been generated *in situ*. Details may be observed in several of the magnificent exposures washed by the Hlimbitwa river. Large and frequently idiomorphic porphyroblasts of potassic felspar (microcline) of the *dent de cheval* type are found in zones within banded amphibolite, usually parallel to the foliation. Often only sparse, they may increase in number and finally mass together to form a pegmatite with varying amounts of hornblende-quartz mesostasis. The hornblende is frequently altered to biotite, in part chloritised, while the microcline porphyroblasts are often very sericitic. Some of the resulting pegmatites, several feet wide, exhibit the dark residual mesostasis right through their entire widths (Plate IV, Fig. 2). In others it has disappeared in the central, but is still evident in the marginal portions. The boundaries between pegmatite and amphibolite are often quite diffuse, large microcline porphyroblasts, up to 1 inch in diameter, bordering the predominantly pegmatitic rock (Plate IV, Fig. 2).

Mobilisation is indicated by several of these pegmatites, still showing residual dark femic mesostasis between the large microcline and quartz grains, cutting across the foliation. The larger pegmatites may then also include true xenoliths of black amphibolite in their marginal portions.

These particular outcrops indicate the narrow white pegmatitic veins intercalated with bands of amphibolite and containing much sodic plagioclase to have been formed first, since they are frequently cut by the larger potassic pegmatites, which at one place are cut in turn by narrow fine-grained aplites. Other definitely intrusive pegmatites, however, may have aplitic cores, while several wide aplites may have pegmatitic margins. Conditions thus are extremely complex.

In the neighbourhood of the great Hlimbitwa cataract, below the end of the Tshane ridge, medium-grained white aplites, occurring in great profusion together with pegmatites within hornblende-biotite gneiss, are cut by numerous very fine-grained white aplites, every rock type being finally sliced by a dull red "felsitic" aplite no doubt associated with the red aplitic granite.

(*m*) *Red Aplitic Granite*

The main body of this rock type occurs as a persistent sheet, up to 300 yards wide along the northern margin of the broad belt of banded amphibolite-gneiss and granulites. It is heralded on either side by narrower sheets and lenses too numerous to be shown on the map. Where not excessively sheared, it is weather-resisting and forms knob-like protuberances on the steep knife-edge ridges leading down from the Tshane ridge.

The best exposure is at the cataract formed by the Hlimbitwa river where it crosses the main, E-W trending, sheet. Where smoothed and polished by the stream, the rock appears extremely dense and fine-grained, practically felsitic. The colour is mostly pale red, though somewhat deeper tints also occur, as well as occasional pale grey bands and *schlieren* due to a slightly greater chlorite content.

In contrast with the gneisses, inclusions of amphibolite are rare away from the margins, where locally they may be abundant and large. Such foreign bodies are obvious *xenoliths* and not *residuals* as in the gneisses.

Everywhere the rock has a peculiar platy cleavage and often breaks into slabs. Particularly the marginal portions of the rock are often "streaky", i.e. exhibit a distinct but fine linear foliation. The occurrence of pale red, fine-grained, "streaky" gneisses along the northern margin of the main sheet has already been mentioned.

Under the microscope the predominant felspar is potassic, mainly microcline, with subordinate amounts of oligoclase. Femic minerals are extremely sparse;

apart from isolated residual flakes of biotite, only chlorite is present in small amounts, often accompanied by secondary iron ore. Even when not macroscopically "streaky", the microscope reveals some measure of linear variation in grain size, apparently due to shearing. Occurring as it does within the main dislocation zone, much of the main sheet is in an extremely cataclastic condition.

This rock contains only occasional narrow veinlets of even finer-grained red aplite. Nowhere was it seen to be cut by the innumerable white aplites and coarse pegmatites that abound within the other rock types. It thus appears to be the latest felsic igneous rock within the area.

(*n*) *Summary Account of Basement Complex*

The banded amphibolites, amphibolite-gneisses and granulites with intercalations of narrow bands of sericite schists, limestone, and talc, closely resemble the rocks grouped by Du Toit under his *Tugela Series* (6, p.35-38). These he considered to be intensely metamorphosed, migmatised and "granite-impregnated" representatives of volcanic tuffs and lavas, ultrabasic intrusions, and intercalated subordinate sediments of the *Mfongosi Series* (6, p.38).

It would seem that the highly banded amphibolites and amphibolite-gneisses, with their isolated bands of intercalated sediments, were originally in the main volcanic tuffs. The massive amphibolites probably represent altered basic intrusions, associated with subordinate ultrabasics. Boulders within the Hlimbitwa river of a striking, very fine-grained, porphyritic amphibolite, nowhere seen in place, were no doubt derived from a lava horizon.

Regarding metamorphism, migmatisation and igneous intrusion, Matthews (7, p.15 *et seq*) has recently somewhat modified the sequence of events suggested by Du Toit in that he has shown the major portion of the granites found north of the Tugela river to be of post-Insuzi age. Nevertheless, the bulk of the extensive migmatisation is still considered by him to be related to a major orogeny antedating the deposition and subsequent folding of the Insuzi sediments and lavas of suggested Dominion Reef age. He states (7, p.18) that the main migmatisation of the basement was characterised by the introduction of soda, the dominant felspar being an acid or intermediate plagioclase, whereas the later post-Insuzi granite is strongly potassic in composition, the dominant felspar being microcline.

Whilst it is generally true that also in the Lilani area initial felspathisation was sodic, nevertheless potassic felspars are not only widely distributed but mostly dominate within many of the rock types described as being developed from banded and massive amphibolites. The gradual replacement of hornblende by biotite and increase of potassic felspars within the hornblende-biotite-epidote granite-gneiss, for instance, clearly indicates progressive introduction of potassium. Also in the leucogranites, often with "ghosts" of contorted gneissose banding, the predominant felspars are potassic. Finally, in all the innumerable larger aplites and pegmatites, including those of *in situ* origin, the predominating felspar is microcline. *Dent de cheval* porphyroblasts within banded amphibolite on examination were always found to be microcline.

Unless it is assumed that all this extensive potassium migmatisation and granitisation in the Lilani area belongs to the later Post-Insuzi orogenic cycle, of which there is no proof and which in the general nature of orogenies is unlikely, it can only be deduced that the permeating fluids were only initially sodic and later, throughout the greater duration of metamorphism, became predominantly potassic.

It is quite possible, however, that the highly potassic red aplitic granite and its derivatives, which are the latest felsic rocks in the area and cut across all other rock types with intrusive contacts, belong to the later post-Insuzi orogeny.

Rather puzzling features are presented by isolated dyke-like bodies of fine-grained amphibolitic rock, varying in width from narrow veins to a few feet, seen within the gneisses at a few localities. When parallel to the foliation, they are easily confused with xenolithic rafts of amphibolite; but they can sometimes be seen to split and fan out in tongues, and also to cut across the foliation, inclusive of pegmatite and aplite veins. Furthermore, one large such occurrence near the Hlimbitwa cataract below the nose of the Tshane ridge contains gneissic and aplitic xenolithic strips in its marginal portions (Plate VI, Fig. 2). In the northern headstream of the Lilani river, a rather small vein of this type, whilst cutting the gneiss and larger aplites, is in turn cut by several narrow aplitic veins. Most likely these amphibolite bodies represent altered basic intrusives later than the main period of migmatisation, but older than the very last phases. Basic intrusives of post-Insuzi age are known from the Tugela region (6, p.74).

3. Post-Basement Igneous Rocks

(*a*) *Lamprophyre*

High above the "Zulu Baths" and cutting banded amphibolite gneiss, crystalline limestone, pegmatites, etc., was found a 4-6 feet wide, mostly highly weathered, basic dyke. It heads for the warm springs, for the site of which it would appear to be in part responsible. Fresh chunks are extremely fine grained and of dark black colour. It does not cut through the sheet of red aplitic granite, but shoots off at an angle, thins and apparently peters out. Higher up the slope, within biotite-hornblende granite-gneiss and felspathic amphibolites, it is, however, again present. This evidence is interpreted *not* that the dyke is older than the red aplitic granite, but that the fracture filled by it did not penetrate this particularly massive resistant rock. Indeed, higher up the slope, it cuts narrow bodies of red aplitic granite. It was nowhere seen within the overlying T.M.S. on the track leading down around the Tshane nose; exposures in line with the dyke, however, are not particularly good. The upper age of the rock is thus unknown, though in the field it was taken to be a Karroo dolerite.

Under the microscope, however, it bears little relation to any known type of Karroo dolerite. It is composed of minute laths, some of which appear to be plagioclase, often arranged in radiating clusters, intergrown with a matrix so fine-grained as to be utterly irresolvable. Isolated minute phenocrysts, colourless and often corroded, were shown by X-ray examination to be serpentine. From their shape it would appear that both olivine and orthorhombic pyroxene were originally present.

Until a chemical analysis is available this rock is best classed under the general term *lamprophyre*. No other occurrence was found in the area.

(*b*) *Karroo dolerite*

Rather light grey rocks outcropping in the broad source-valley of the northern headstream of the Lilani river, below the eucalyptus plantations, were found under the microscope to be almost completely chloritised dolerite. Whereas labradoritic plagioclase laths of the ophitic texture are still identifiable, though largely turbid and containing some secondary calcite and epidote, the clinopyroxene is practically completely altered to chlorite.

Within the wattle plantations further along the Ahrens road, spheroidal boulders, located above the T.M.S. in the horizon of Dwyka Tillite, were found to be medium-grained dolerite of unusually light colour. The pyroxene, ophitically intergrown with labradorite, is very pale, orthorhombic being present in addition to preponderant monoclinic.

Apart from chloritisation, the two rock types are very similar in texture and structure and there thus can be little doubt that the chloritic rock found near the contact between the basement-rocks and overlying T.M.S., is in fact altered Karroo dolerite.

B. Tectonic Structure

1. Fault Pattern

That the rectilinear Lilani gorge has been incised along a fault can be seen at a glance when rounding the first road bend cut into the shale band (Plate II, Fig. 1). Not only does the normally more or less horizontal T.M.S. dip down, at angles of 10-15°, towards the river all along the road cuttings, but its base in the Matimatolo mountains, towering on the opposite side, stands at a very much higher elevation. Details of the faulting are shown on the geological map and the two sections (Plate X).

In the upper part of the gorge the main fault trends obliquely towards the western end of the Matimatolo mountains, where aneroid readings indicate a downthrow on the northern side of 900-1,000 feet. On the southern slopes of the main Lilani gorge isolated patches of T.M.S., contained within the main and subsidiary fault, abut on banded amphibolite gneiss, crystalline limestone, and sheared aplitic granite. At the end of the Matimatolo cliffs a small displacement of T.M.S. stratigraphic horizons is visible. Here two small faults, of up to 50 feet throw, parallel the subsidiary fault in step-like fashion (Plate I, Overlay). Farther west, in the wattle plantations on the high plateau, a north-facing scarp appears to mark the trace of the main fault (Plate II, Fig. 1).

North of the Lilani river several subsidiary faults of varying smaller throw parallel the main dislocation. (Plate I, Overlay). The southernmost of these has been responsible for the incision of the southern Lilani headstream. In the narrow gully that continues the main gorge straight westwards, T.M.S. abuts on sheared red aplitic granite with a downthrow of approximately 80-100 feet on the south side. In the northern headstream, down which the Ahrens road first meanders, basal T.M.S. horizons are at somewhat different elevations on opposite sides of the deep gully. Furthermore, felspathic amphibolite, deeply weathered, suddenly appears on the road from below the shale band. Exposures, however, here are insufficient to indicate the fault pattern in complete detail.

As is to be expected, no exposures of the main fault are to be seen in the boulder- and alluvium-filled floor of the Lilani river. The absolutely rectilinear alignment of the six thermal springs, however, must mark its trace. Black banded amphibolites, dipping 65°N, outcrop within a few yards of the Sulphur spring, but show no abnormal degree of fracturing. Further east, at the "Zulu Baths", however, not only do the crystalline limestones contain fragments of the adjacent rocks, but the banded amphibolite and siliceous rocks are highly shattered.

The latter occur in widths of up to 15 feet and, in addition to fracturing, exhibit shear-banding. Taken in the field to be highly sheared vein-quartz emplaced in the fault-zone, the microscope, however, revealed the rock to be highly silicified, intensely sheared and cataclastic granulite or finegrained aplite of the type that abounds within the banded amphibolite-gneisses. One specimen was actually mostly composed of calcite, showing intensely developed, closely spaced, "feathery" glide-twinning and enclosing abundant fractured fragments of microcline, lesser amounts of oligoclase, highly undulose quartz, tremolite, shreds of muscovite, and epidote grains.

To the east of the Hlimbitwa river and in line with the main fault, there outcrop white quartzose rocks, which in the prominent Sangomani hill swell to a thickness of some 200 feet. Subsidiary lenses of lesser width flank the main body along both margins, the intervening rock being banded amphibolite-gneiss. Much of the quartz is thinly banded; under the microscope this feature was found to be due to cataclasis amounting almost to mylonitisation of the quartz. While the greater bulk of the rock appears to be sheared quartz, the felspar content of some specimens again indicated highly sheared and silicified granulite or aplite.

According to Du Toit (6, p.19 *et seq.*) post-T.M.S. faults in the Melmoth-Eshowe area, to the NE, are often marked by vein quartz and silicification.

Exposures along the tortuously twisting Lilani-Ahrens road indicate the presence of a highly disturbed fault-zone, more than 500 yards wide, along the north side of the main fault, within which the horizontal T.M.S. of the Tshane ridge has collapsed towards the latter. The banded amphibolite-gneisses are often completely shattered (Plate IX, Fig. 2) and the red aplitic granite is not only reduced to sericitic schists in some zones, but frequently so highly sheared and so decomposed by weathering that its true nature may be barely recognisable. Where overlain by weathered, reddish, argillaceous and micaceous sandstones at the base of the T.M.S., the deeply decomposed sheared granite is easily confused with these sediments.

Narrow vertical erosion gullies in completely weathered amphibolite-gneiss and aplitic granite, flanked by highly fractured material, abound in the road cuttings. A far greater number is present than could be shown on the small scale of the geological map. That they represent subsidiary faults is shown quite clearly by a narrow strip of basal T.M.S., not more than 100 yards wide, let down, with steeply upturned edges, into highly sheared, red aplitic granite and "streaky" gneiss (Geologic map and Plate IX, Fig. 1). Disturbed zones and reversals of the southerly dip within the shale band well exposed along the Ahrens road above the northern headstream of the Lilani River, indicate additional subsidiary faults. On the less steep opposite side actual displacements of basal T.M.S. demonstrate their existence more clearly. A transverse fault is indicated in continuation of the deepest gully-indentation of the Tshane ridge cliffs (Plate 1, Overlay).

The overall structural plan, as indicated by the T.M.S., is thus a *trapdoor fault*, with the horizontal T.M.S. of the Tshane ridge dipping southwards towards the main fault, the downbent strip being rent by numerous parallel subsidiary faults of lesser throw, several of which bound narrow *graben*. (Plate I, Overlay and Sections Plate X).

2. Age of Faulting

The Lilani fault-zone is obviously post-T.M.S. It was not followed westwards for any great distance, but the elevated T.M.S. scarp within the plantations on the upland plateau appears to protrude above the level of Dwyka Tillite and the Karroo dolerite to the north. It would thus appear to be post-Karroo in age. It is parallel to the great *Tugela fault*, some 30 miles farther north, which has displaced the entire lower Karroo succession by more than 1,500 feet (Du Toit, 6, p.19). The similar

Empangeni fault system further east, at first trending more or less E-W and then branching into parallelism with the coast line, displaces also the uppermost Karroo lavas (Lower Jurassic). Since the extensive faulting of the coastal area affects Lower Cretaceous sediments in Pondoland but not the Upper Cretaceous beds of Zululand, Du Toit (6) deduced it to be of post-Lower, pre-Middle Cretaceous age. Beater and Maud (10 and 11), however, consider that the main phase of faulting took place already during the Late Jurassic, with local rejuvenations up to Mid-Cretaceous times.

While Du Toit considered the Lilani fault to be the westernmost extension of his *Bombotyane fault*, bounding the Eshowe Plateau on the south with a maximum displacement of 4,000 feet (6, p.21), on the 1955 Geological Survey Map (1 :1,000,000) this fault is shown to end in the T.M.S. several miles north of Lilani. The even undisturbed northward continuation of the base of the T.M.S. above the Hlimbitwa river, coupled with the direction of downthrow, however, leads the author to support Du Toit's presentation.

That the region is sliced by numbers of E-W faults, more or less parallel to the *Tugela* and *Lilani* faults, can be seen at a glance from the easternmost buttress of the Matimatolo mountains. Immediately beyond the Igoaga stream the T.M.S. has again been dropped down by several hundred feet and a few miles beyond, at the last visible T.M.S. promontory, it has been upthrown again by a similar amount. This faulting could well be in continuation of Du Toit's *Ngoku Hill* and *Mombeni* faults between Eshowe and Amatikulu. Some of this extensive, closely spaced faulting to the south of Lilani is shown on Maud's new structural map of the coastal belt (11).

Whilst there is thus no doubt that extensive movements took place along the Lilani fault in post-Karroo times, the thickness distribution of T.M.S. below the Karroo beds suggests some movement already in pre-Karroo times. The thickness of preserved T.M.S. at the north end of the Lilani gorge, within the *trapdoor* fault-trough, appears to be considerably greater than outside the fault-zone below the basal Karroo beds.

Furthermore, it would appear that the post-T.M.S. and post-Karroo movements took place along an old pre-T.M.S. zone of weakness within the Basement Complex. Du Toit already stressed the influence of basement structure (6, p.18 *et seq.*), most of the later displacements having occurred along the E-W tectonic trend of the latter. More recently Matthews (7, p.40 *et seq.*) has emphasised that the complex post-Ntingwe thrust movements in the Tugela valley were controlled by pre-existing structures in the foundation.

The evidence in the Lilani area is as follows:

The T.M.S. on the downthrow side dips towards the main fault and upthrow side to form a *trapdoor* trough. This, together with step-faulting and the occurrence of narrow subsidiary *graben*, viz. the dropping down of extremely narrow strips of T.M.S., scarcely 100 yards wide, into basement rocks, is most rationally explained as having taken place under general conditions of tension. Yet a mass of evidence, both macro- and microscopic, indicates strong shearing movements, under general compressive stress conditions, in the basement of this very zone.

The banded amphibolite and amphibolite-gneisses and granulites show the greatest degree of divergence, from the normal rather regular E-W strike and steep dip, within and in the neighbourhood of the fault-zone. Subsidiary contortions and drag folds with axes oblique to the main trend are common. Some indicate strike-slip movements.

The intricate flow of limestone bands, their common *boudinage* as well as frequent crowding with fractured mineral grains and fragments of the adjacent rocks, is not easily explained by simple tensional faulting at shallow depth. It is also doubtful whether the intense glide-twinning of calcite could be developed on such a scale under these conditions.

Most massive competent rocks, particularly the "streaky" acid gneisses, red aplitic granite, quartz veins and zones of silicification, almost invariably show cataclastic banding, frequently amounting to mylonitisation. Only intense shear could have achieved such closely spaced and intricate deformation. Mineral granulation is widespread in these rocks. While all quartz grains in all rock types show undulose extinction, this feature is extraordinarily pronounced in the massive rocks of this tract, at times assuming, in highly granulated portions, an almost "feathery" appearance.

Finally, the intrusion of the narrow but long, persistent sheet of red aplitic granite, with its satellites, within this zone, probably during the post-Insuzi orogeny, is in itself indicative of a "line of weakness" already at this epoch.

It would thus appear that the Lilani fault is a very ancient structural zone along which movements have taken place repeatedly over a very long period of time, the latest post-Karroo movements having taken place under conditions of tension.

XII. ORIGIN OF THERMAL WATERS

The Lilani Springs, ranging in temperature from 38·2 to 41·1 °C and in salinity from 280 to 359 p.p.m., are situated at approximately 2,100 feet above sea level.

The Tugela *shushu*, with 52-53 °C and a salinity of 1,020 p.p.m., occurs at an elevation of only about 700 feet. The former are therefore some 2,000 feet below the upland plateau (Ahrens 3,996) feet, while the latter, at the bottom of the great Tugela gorge, are fully 3,100 feet below Kranskop (3,791 feet).

In his 1942 paper on the Tugela *shushu* the author drew attention to the apparent relationship between temperature and topographical depth of issue. He accordingly deduced that these springs are mainly fed from rainfall (37·7-40 inches p.a.) on the adjacent plateau regions. By far the bulk of the rain falls in summer. Taking the mean summer temperature of Greytown (19·4 °C), the nearest locality for which it is known, and assuming a geothermal gradient similar to that ascertained for comparable basement-rocks in certain other parts of South Africa, viz. 1 °C for 140-150 feet (3, p.249), the rain water falling on the upland plateau would have to percolate to a minimum depth of between 2,900 and 3,100 feet below it to issue again at the temperature of the warmest Lilani spring (±40 °C). This represents a depth of 900-1,100 feet below the bottom of the Lilani gorge. Since some subsequent cooling of the water must take place on rising again to the surface, the *actual* depth of percolation must be even greater.

The factors for localisation of the warm water are: (1) the major fault-zone, already described in detail: (2) numerous soluble limestone bands within the latter; (3) the lamprophyre dyke mentioned as heading from below the Tshane Ridge towards the closely spaced easternmost springs. This dyke apparently acts as a barrier for further "down-valley" percolation and thus causes the water to rise to the surface. This structural situation is additional evidence for the deduction that the spring waters are mainly derived from the upland plateau to the west.

The closely corresponding temperatures (38·2-41·1 °C) indicate the water of the 6 springs, spaced over a distance of only 800 yards, to rise from more or less the same depth at rather similar velocities. The only somewhat aberrant spring is the most isolated westernmost one at the "Radium Bath", whose temperature is a little, and total salinity appreciably, higher. Also its chemical composition is somewhat at variance, as already outlined.

All the chemical constituents of the waters can readily be explained as having been derived from the rocks traversed by meteoric (rain) water during percolation. Relevant features have already been discussed in Chapter VI. Additional significant points are the following. The low salinity (280-359 p.p.m.) can be explained by the high rainfall of the region, low saline content of the overlying T.M.S., and comparatively shallow depth of penetration. The low contents of chloride and sulphate, if of cyclic origin, can also be understood against the high rainfall. Some, or most, of the sulphate, however, may be due to the oxidation of sulphides in the rocks traversed. Those adjacent to the spring orifices (banded amphibolites, crystalline limestones, and silicification zones) commonly contain specks of pyrite.

Only in one case, the Sulphur spring, does reduction to sulphuretted hydrogen take place to any appreciable extent. The reason for this is unknown. Elsewhere in Southern Africa the generation of H_2S is sometimes a surface phenomenon and due to the action of sulphate-reducing bacteria on dissolved sulphates. Since opportunities for such biologic action are much more favourable at some of the non-sulphurous, more stagnant pools, e.g. the "Radium Bath" and "Zulu Men's Bath", this does not appear to be the cause of the presence of H_2S in the Sulphur spring.

The dominant *anions*, as stated, are bicarbonate and carbonate. Bond has shown that throughout the Republic of South Africa the highest average silica contents are found in alkaline, sodium carbonate-bearing groundwaters rising from rocks rich in alkalis, e.g. granites. Seldom, however, does it exceed 50 p.p.m. in ordinary, non-thermal, ground-waters (8, pp. 169-171). Appreciable fluoride contents (in excess of 1 p.p.m.), too, were found only in waters containing sodium carbonate and bicarbonate (8, pp. 169-171). This indicates its presence as sodium fluoride. The natural mineral fluorite, CaF_2, is rather resistant to weathering; but owing to the similar sizes of fluorine and hydroxyl (OH) ions, this element is a common constituent of hydroxy-silicates such as biotite and hornblende, which are major constituents of the rock types in the Lilani area.

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Department of Geology,
University of the Witwatersrand,
Johannesburg.

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DESCRIPTION OF PHOTOS

PLATE I

Air-photo, with transparent overlay, of environs of Lilani thermal springs (Air-photos reproduced under Government Printers' Copyright Authority No. 3180 of 28/6/63).

PLATE II

Fig. 1—View from Tshane ridge over upper Lilani gorge towards western plateau and Matimatolo mountains, showing vertical displacement of T.M.S. (by approx. 900-1000 feet) along main fault.

Fig. 2—Vertical banded amphibolite. Hlimbitwa River.

PLATE III

Fig. 1—Broadly banded amphibolite in process of potash felspathisation (porphyroblasts of microcline) with bodies of mottled hybrid granite (dark specks: amphibole changing to biotite). Hlimbitwa River.

Fig. 2—Contorted bodies of mottled hybrid granite within broadly banded amphibolite in process of potash felspathisation. Hlimbitwa River.

PLATE IV

Fig. 1—Contorted veins of aplite in band of amphibolite undergoing potash felspathisation on right. Hlimbitwa River.

Fig. 2—Coarse pegmatite in process of formation by potash metasomatism of amphibolite (banded type); individual porphyroblasts of microcline (bottom, centre and top) mass together with varying amounts of amphibole-quartz matrix, the former changing to biotite. Hlimbitwa River.

PLATE V

Fig. 1—Initial stage: soda-metasomatism (oligoclase-andesine) extending from fractures in massive black amphibolite to produce "replacement breccia". Hlimbitwa River.

Fig. 2—Intermediate stage: residuals of fine-grained black amphibolite in oligoclase- hornblende-epidote granodiorite-gneiss seamed with pegmatite veins and *schlieren*. Hlimbitwa River.

PLATE VI

Fig. 1—Final stage: coarse-grained biotite-hornblende-epidote granite-gneiss cut by aplites. Below Tshane ridge above Lilani River.

Fig. 2—Dyke of very fine-grained amphibolite cutting hornblende-epidote granodiorite-gneiss (cross-cutting relationship proved by marginal xenoliths of latter not shown in photo), cut in turn by aplitic apophysis extending from gneiss. Hlimbitwa River.

PLATE VII

Fig. 1—Crystalline limestone containing numerous fragments of country rock, mainly pegmatite, from enclosing banded amphibolite; rough surface of limestone due to innumerable small fragments of tremolite, quartz, felspar and hornblende. Hill above Lilani thermal springs.

Fig. 2—Abundant fragments of country rock, mainly pegmatite and aplite, in crystalline limestone within banded amphibolite. Note suggestion of residual banding on left. Hill above Lilani thermal springs.

PLATE VIII

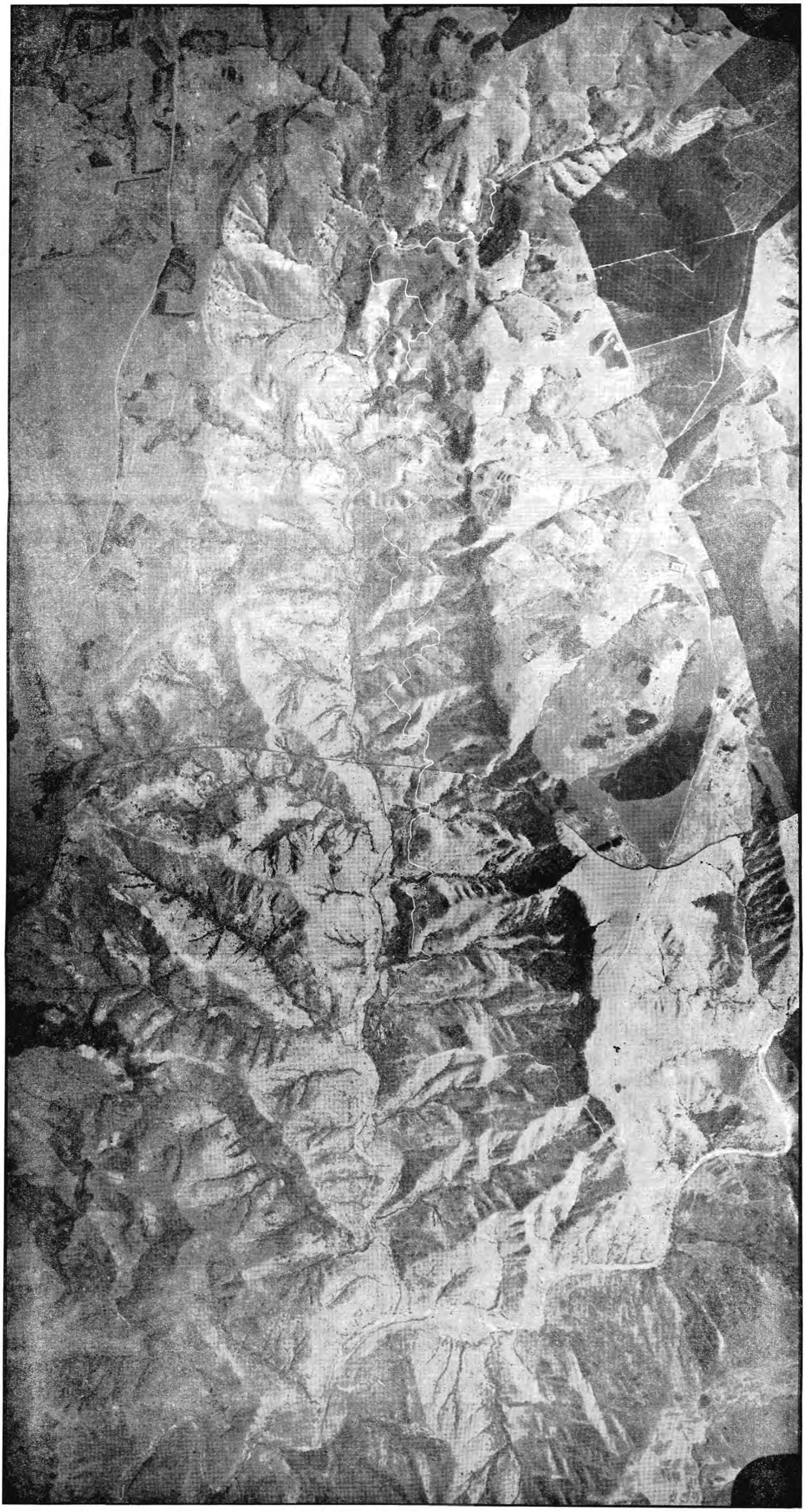
Fig. 1—Steeply dipping bedded limestone in banded amphibolite. South side of upper Lilani gorge.

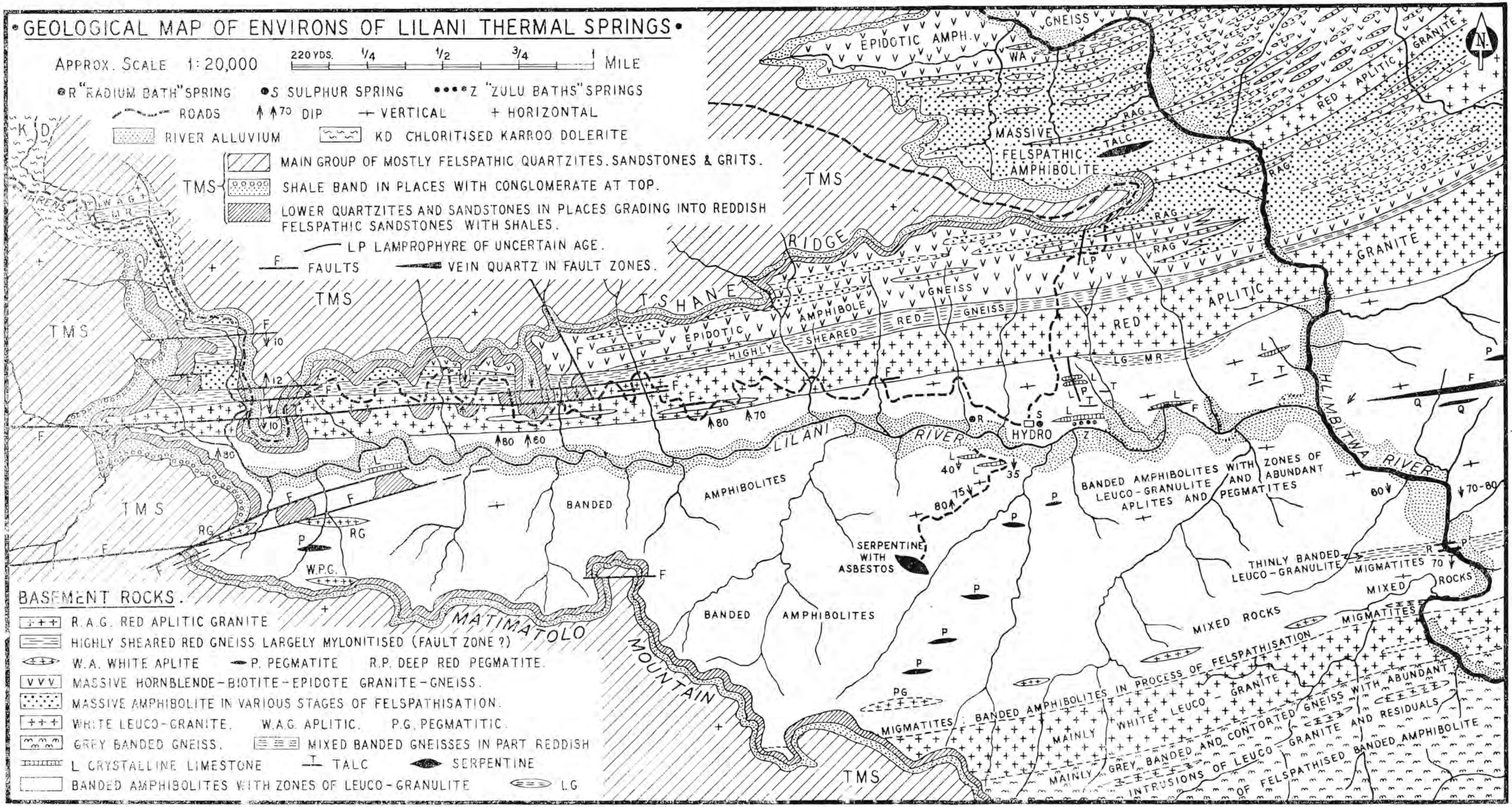
Fig. 2—T.M.S. Shale Band, with abundant sandstone layers at this locality. Road cutting above upper Lilani River.

PLATE IX

Fig. 1—Southern marginal fault of T.M.S. *graben* cut by road: steeply upturned and cleaved lower T.M.S. sandstones and quartzites (left) abutting on sheared red aplitic granite (right.)

Fig. 2—Fault in shattered steeply dipping banded amphibolite. Cutting on Lilani-Ahrens road.





GEOLOGICAL MAP OF ENVIRONS OF LILANI THERMAL SPRINGS
APPROX. SCALE 1:20,000
220 YDS. 1/4 1/2 3/4 1 MILE
R "RADIUM BATH" SPRING
S SULPHUR SPRING
Z "ZULU BATHS" SPRINGS
ROADS
70 DIP
VERTICAL
HORIZONTAL
RIVER ALLUVIUM
KD CHLORITISED KARROO DOLERITE
TMS
MAIN GROUP OF MOSTLY FELSPATHIC QUARTZITES, SANDSTONES & GRITS.
SHALE BAND IN PLACES WITH CONGLOMERATE AT TOP.
LOWER QUARTZITES AND SANDSTONES IN PLACES GRADING INTO REDDISH FELSPATHIC SANDSTONES WITH SHALES.
LP LAMPROPHYRE OF UNCERTAIN AGE.
F FAULTS
VEIN QUARTZ IN FAULT ZONES.
BASEMENT ROCKS.
R.A.G. RED APLITIC GRANITE
HIGHLY SHEARED RED GNEISS LARGELY MYLONITISED (FAULT ZONE ?)
W.A. WHITE APLITE
P. PEGMATITE
R.P. DEEP RED PEGMATITE.
MASSIVE HORNBLENDE-BIOTITE-EPIDOTE GRANITE-GNEISS.
MASSIVE AMPHIBOLITE IN VARIOUS STAGES OF FELSPATHISATION.
WHITE LEUCO-GRANITE.
W.A.G. APLITIC.
P.G. PEGMATITIC.
GREY BANDED GNEISS.
MIXED BANDED GNEISSES IN PART REDDISH
L CRYSTALLINE LIMESTONE
T TALC
SERPENTINE
BANDED AMPHIBOLITES WITH ZONES OF LEUCO-GRANULITE
LG
N.
EPIDOTIC AMPH.
GNEISS
WA
MASSIVE FELSPATHIC AMPHIBOLITE
TALC
RAG
RED APLITIC GRANITE
GRANITE
TMS
RIDGE
TSHANE
EPIDOTIC AMPHIBOLE
GNEISS
HIGHLY SHEARED RED GNEISS
RED APLITIC
LG MR
LP
HYDRO
LILANI RIVER
HLIMBITWA RIVER
BANDED AMPHIBOLITES
BANDED AMPHIBOLITES WITH ZONES OF ABUNDANT LEUCO-GRANULITE AND APLITES AND PEGMATITES
SERPENTINE WITH ASBESTOS
THINLY BANDED LEUCO-GRANULITE
MIGMATITES
MIXED ROCKS
RG
W.P.G.
PG
MATIMATOLO MOUNTAIN
MIGMATITES
BANDED AMPHIBOLITES IN PROCESS OF FELSPATHISATION
MAINLY WHITE LEUCO-GRANITE
MAINLY GREY BANDED AND CONTORTED GNEISS WITH ABUNDANT INTRUSIONS OF LEUCO-GRANITE AND RESIDUALS OF FELSPATHISED BANDED AMPHIBOLITE

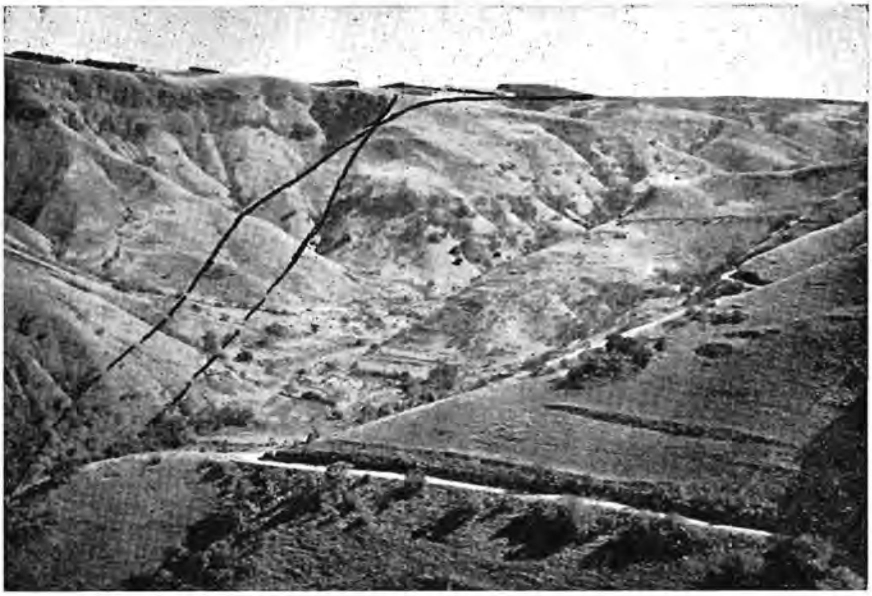


Fig. 1

Fig. 2

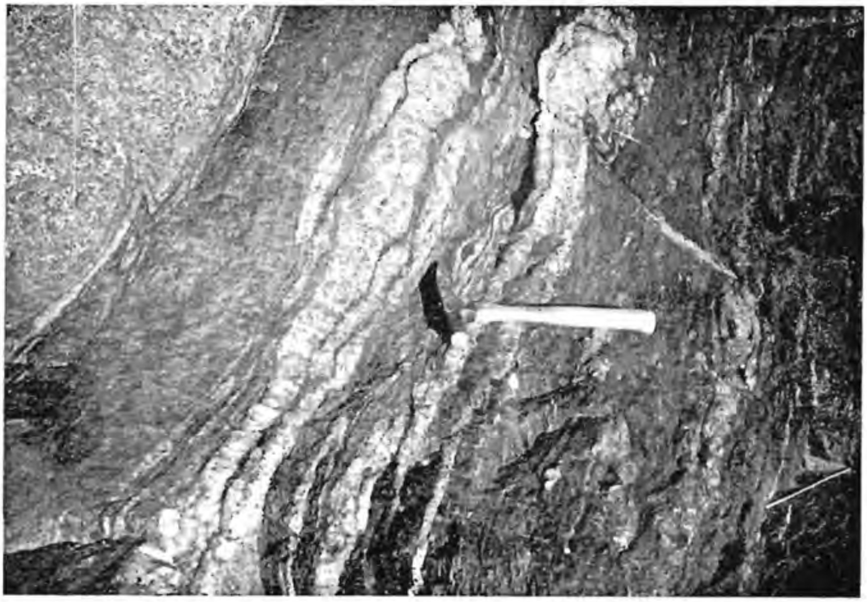


Fig. 1

Fig. 2

Fig. 1

Fig. 2

Fig. 1

Fig. 2

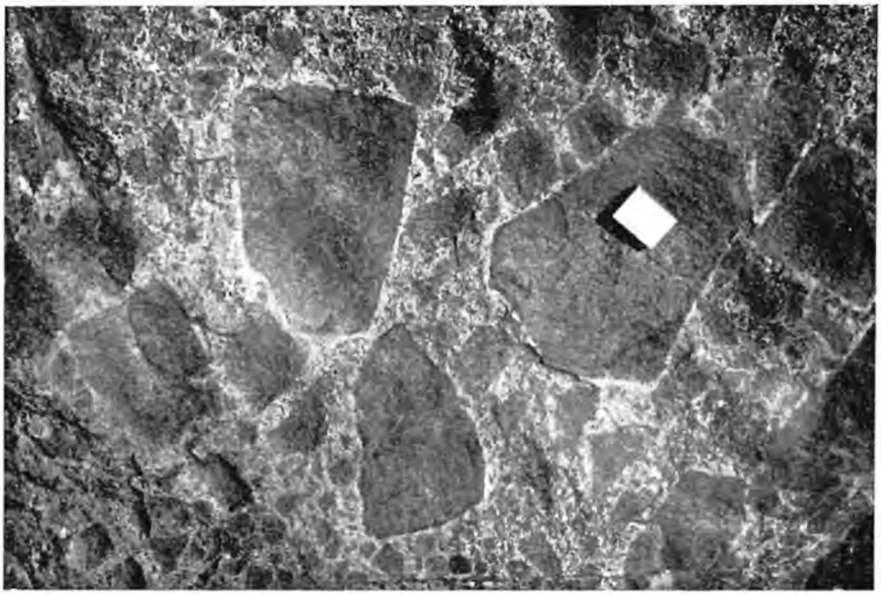


Fig. 1

Fig. 2

Fig. 1

Fig. 2

Fig. 1

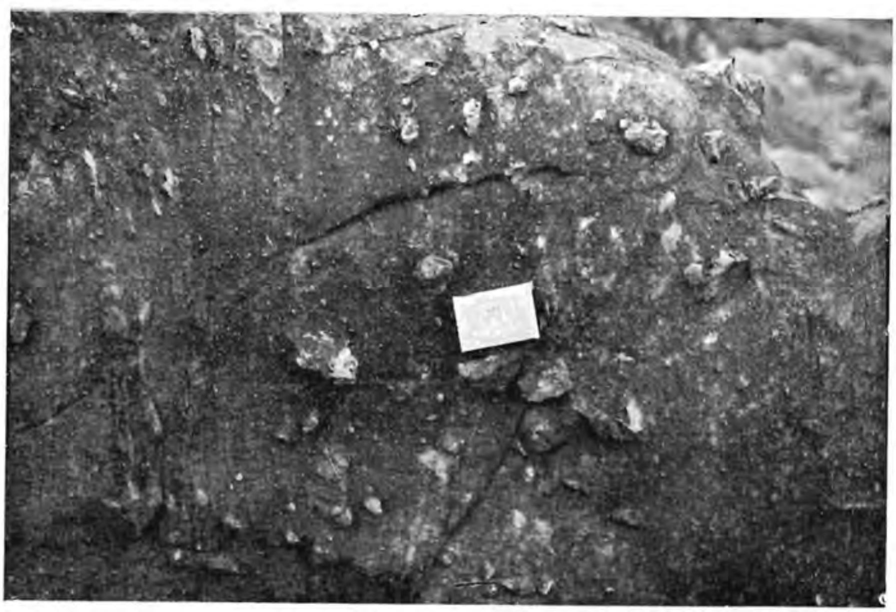
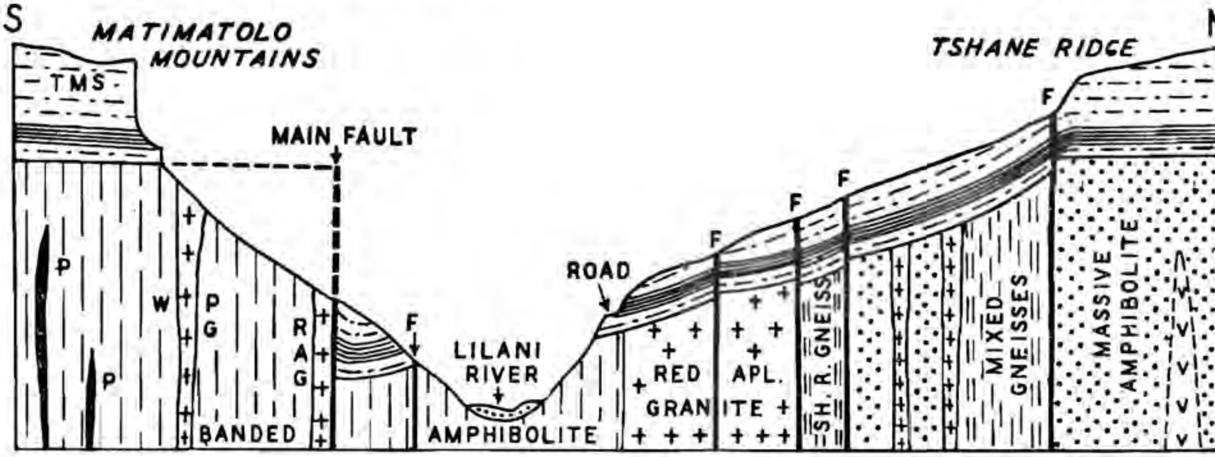


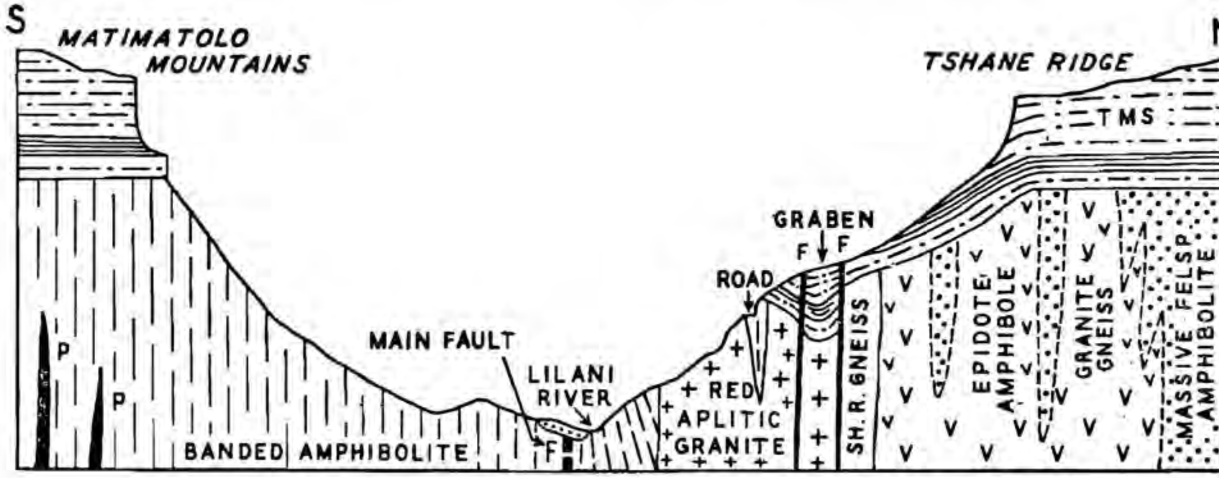
Fig. 2

Fig. 1

Fig. 2



SECTION I : ACROSS UPPERMOST LILANI GORGE.



SECTION II : ACROSS UPPER LILANI GORGE

SHOWING NARROW T.M.S. GRABEN.

VERTICAL SCALE SAME AS HORIZONTAL APPROX. 1:12,000: viz. 1 INCH = 1,000 FT.

DEPTH OF GORGE IN SECTION II APPROX. 2,000 FEET.

WITH EXCEPTION OF T.M.S. DESIGNATIONS SAME AS ON GEOLOGICAL MAP.