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THE THERMAL SPRINGS OF SWAZILAND – A REVIEW

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Abstract

The thermal springs of Swaziland and adjacent KwaZulu Natal have, over the years, attracted attention from hydrogeologists, hydrochemists and structural geologists. While some of the springs in Swaziland are well known amenities, others are less well visited and some difficult to access. There are eleven warm springs in Swaziland discharging between 1 and 10 l/s from Precambrian age rocks; all are situated at or near valley bottoms. The springs have surface discharge temperatures of between 25 and 52 ^{o}C and total dissolved solids concentrations less than 400 mg/l. In all cases the water is meteoric in origin. Geothermometry indicates that maximum temperatures up to 100 ^{o}C are achieved during circulation. If the average geothermal gradient is about 20 ^{o}C/km as recorded in a deep mine at Barberton, then this would require circulation up to a depth of several kilometres. However, it is likely that circulation bottoms at about 1 km, as pressure of overburden inhibits dilation of fractures at such depths and the excess temperature may derive from a locally enhanced geothermal gradient. The discharge water is young, with ^{14}C ages of between 4000 and 5000 years.

1. INTRODUCTION

Swaziland straddles the eastern escarpment of the Precambrian Basement plateau with Precambrian granite exposed along the base of the escarpment, east of which Karoo sediments outcrop to form the Lowveld. Typical average borehole yield in the Precambrian Basement aquifer is 1.1 l/s with over a third of boreholes drilled yielding less than 0.5 l/s (UNITED NATIONS, 1989). Prospects are better in the Karoo, particularly where it is disturbed by volcanic dykes, where borehole yields are sufficient to supply commercial irrigation schemes. Mwendera (2006) reports that modern borehole drilling is, in places, providing yields suitable for electric submersible pumps to supply rural water supply schemes. Much use is also made of the available surface water resources.

Groundwater flow systems are mostly shallow, and residence times are inferred to be in the order of tens of years. The cumulative groundwater discharge (cold springs and seepages) sustains some flow in the small streams on the plateau and the escarpment, even during extended dry seasons. Groundwater recharge is between 0.5 and 15% of average annual rainfall (PITEAU ASSSOCIATES, 1992).

The thermal springs in Swaziland (Figure 1) have been described at eight locations, Mkoba, Ezulwini, Lobamba, Mawelawela, Ngwempisi, Mpopoma (sometimes referred to as Manzane, literally ‘hot spring in Siswati), Siphofaneni and Mbondela (Spargo, 1965; Hunter, 1968, Mazor et al., 1974). In addition Madubula Thermal Spring was recorded on a 1920s mining concession map and two further springs, one at Fairview and the other at Mvuntshini, were located during geological field mapping in the late 1970s. The Ezulwini sources supply a therapeutic spa centre and the celebrated ‘Cuddle Puddle’, the springs at Lobamba are traditionally patronised by the Royal Family, while those at Siphofaneni are a tourist attraction. Other springs are more remote and have attracted little attention. There are three additional springs in South Africa just south of the Swazi/South African border.

This paper describes the thermal springs and their geological and topographical setting. It reviews the available chemical and isotopic data that have been applied as indicators of circulation temperature and likely circulation paths and discusses the tectonic setting for such circulation. The objective is to assess the springs as a hydrochemical group and to comment on the likely circulation systems.

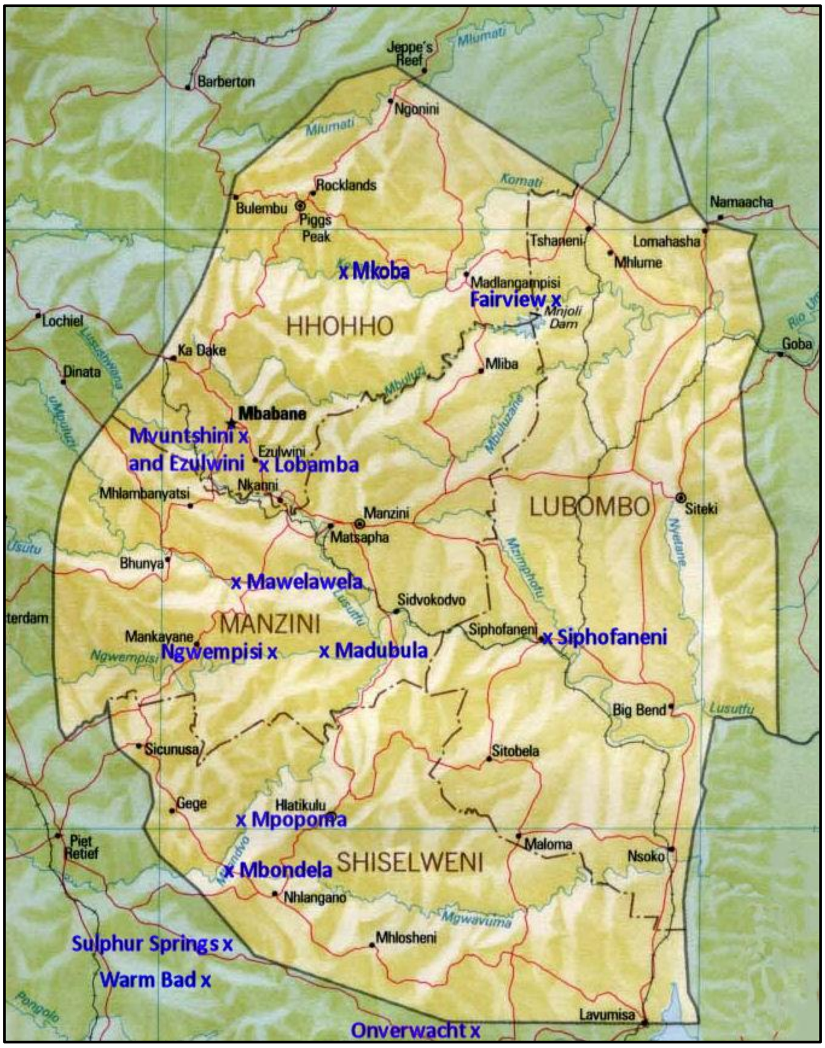

Figure 1. The Swazi thermal spring locations and adjacent Thermal sources in South Africa

2. GEO-ENVIRONMENT OF THE SWAZI SPRINGS

All the springs occur at or just above valley bottoms. All, therefore, offer the prospect of gravity driven circulation from a recharge zone at a higher elevation. They all circulate in Precambrian crystalline rock and discharge comes mainly from fracture outcrop. The last tectonic activity in the area was in Jurassic age and deep and dilated fracturing seems unlikely. Hartnady (1985), however, suggests that neotectonic activity may still be occurring and that there is a likely mantle hotspot near 30°S and 29°E. The tectonic origin of the lineaments at depth in the granitic terrain may relate to the continental plate riding over an oceanic ridge in the upper subduction zone (Kent, 1981). The major tectonic trends are north-south with a secondary north easterly trend best developed in the granodiorites.

The spring locations, discharges and discharge temperatures are summarised in Table 1 and some sites offer multiple discharge points (Robins and Bath, 1979). The spring waters range from odourless to a distinct sulphurous smell, some discharges have a white encrustation and some release gas bubbles. The springs emanate from granite, granodiorite and gneiss, some through overburden material. The discharge temperatures vary from 25 °C to 52 °C, with a mean of 41 °C, and the mean discharge is 2.5 l/s, the greatest discharge is 6 l/s at Mawelawela.

Table 1. The thermal springs of Swaziland

Spring	Location	Sources	Discharge (l/s)	Temperature (°C)	Comments
Mkoba	26° 03' S 31° 21' E	north	) 2.5	49	Discharge from N-S oriented fractures in granite. All three sources have sulphurous smell and occasional bubbles – no encrustation
		centre	)	48	
		south	1.5	52	
Mvuntshini	26° 22' S 31° 10' E	1	4.0	45	Migmatitic granite and gneiss, discharge through overburden. Faint smell of H_2S.
Ezulwini	26° 24' S 31° 11' E	upper	4.0	37	In granite gneiss. The upper source is a shallow well casing driven into a fracture containing a pump, the spring is 25 m away adjacent to a dolerite dyke
		spring	2.0	40	
		seepage	small	40	
Lobamba	26° 26' S 31° 12' E	Guest House 1	1.0	48	In weathered granodiorite. Slight sulphurous smell. Guest House sources 50 m apart and used for bathing.
		Guest House 2	2.0	47	
	26° 27' S 31° 13' E	3 (to SE)	1.5	43	
Mawelawela	26° 36' S 31° 10' E	1	6.0	35	Discharge from NW trending fracture in granite.
Ngwepisi	26° 42' S 31° 12' E	1	3.5	46	Discharges beneath large granite boulder. Strong sulphurous smell and some encrustation
Mpopoma	26° 58' S 31° 08' E	1	3.0	33	Discharge as seepages via overburden. Strong sulphurous smell and slight encrustation.
		2	1.0	33	
Mbondela	27° 03' S 31° 05' E	1	2.0	25	Issues from gneiss. Sulphurous smell, bubbles and a thin encrustation on the surface
		2	0.5	28	
Madubula	26° 42' S 31° 18' E	north bank	2.0	52	In granite. Strong sulphurous smell, rising bubbles and slight encrustation
		south bank	8.0	52	
Fairview	26° 11' S 31° 42' E	1	3.0	38	In alluvium over granodiorite into ponds
Siphofaneni	26° 42' S 31° 41' E	Men’s bath	3.0	39	In overburden over granite. Slight sulphurous smell and bubbles rising.
		Women’s bath	3.0	39	

The springs fall on two distinct lineaments (Figure 2) trending roughly north-north-east. Springs in the Temperley (western) Lineament (Temperley, 1964; Kent, 1981) are from north to south: Mkoba, and in the Ezulwinin valley Mvuntshini, Ezulwini and Lobamba, then Mawelawela, Ngwempisis, Mpopoma and Mbondela. 15 km to the south south west across the border in South Africa are Sulphur Springs and Warm Bad but this major line of warm, springs continues into South Africa as far again to the south south west.

The less well defined Eastern Line from north to south comprises Fairview, Siphofaneni and just across the border in the south south west the Onverwacht springs. The Eastern Line is parallel to the major swarm of intrusive dykes in the east of Swaziland. Madubula spring, however, is unique in that it is situated between the two spring line fracture or fault lineaments. It is nevertheless likely that its location reflects fractures and faults that have allowed deep circulation. Spargo (1965) accounts for the Mkoba spring discharge resulting from circulation in a north-south oriented fault.

The lineaments clearly offer pathways for deep groundwater circulation. Although the dominant tectonic trend is north south, there is also a subordinate, but likely deep seated, north-north-easterly trend particularly in the granodiorites.

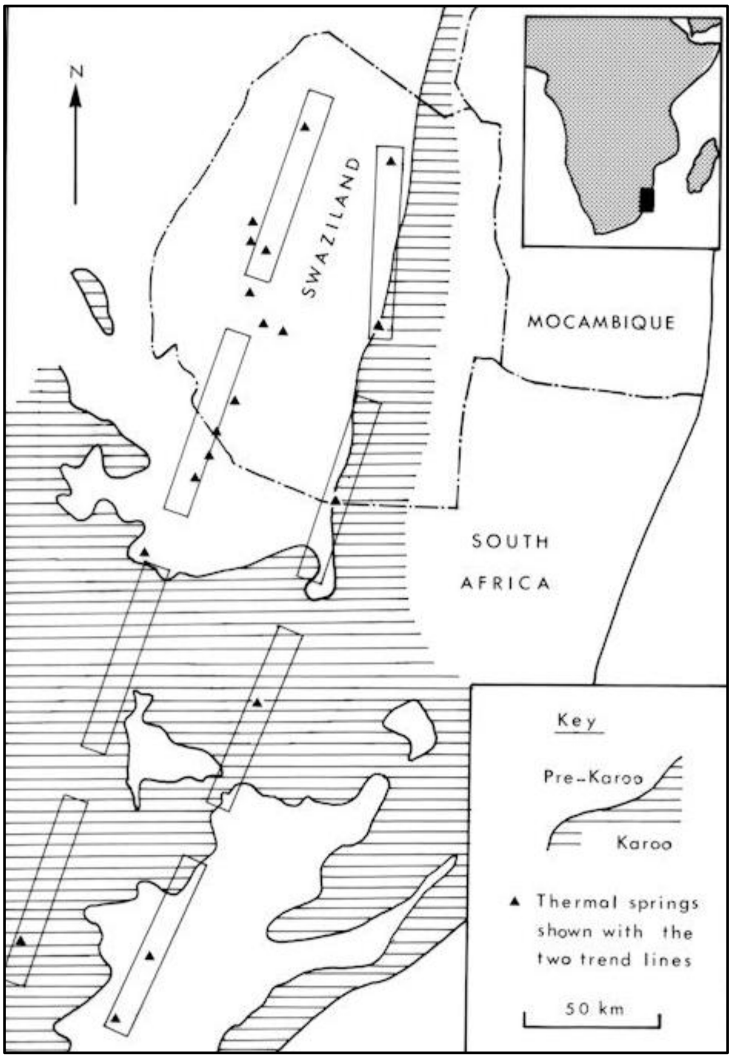

Figure 2. Thermal spring trend lines: the Eastern Line and the western Temperley Line

3. HYDROCHEMISTRY AND GEOTHERMOMETRY

Mazor et al. (1974) show, mainly on the basis of stable isotopes, that the thermal spring waters are meteoric in origin. ^{14}C age dating suggests a groundwater residence time of between 4000 and 5000 years. The spring discharges are moderately mineralised with total dissolved solids <400 mg/l (Table 2). The majority are Na-HCO_3 type groundwaters while Madabula and Fairview are Na/Cl-HCO_3 type, both also slightly more mineralised than the other springs (Figure 3). The mineralisation is primarily due to silicate hydrolysis. The thermal sources along the Temperley Line are slightly less mineralised than those on the Eastern Line and less Cl dominated, possibly reflecting a slightly more mature circulating system than springs on the Eastern Line. Local non-thermal waters tend to be less mineralised than the thermal waters and are mainly Ca-HCO_3 type but there is little evidence that mixing of shallow cold groundwaters occurs before the thermal waters emerge at the surface. The pH of the spring waters ranges between 7.3 at Ezulwini to 9.7 at Mpopoma; the average pH is 8.2.

Table 2. Major ion chemistry, measured discharge temperatures and inferred base level temperatures of the thermal waters (mg/l)

Spring	**Measured temp. (^oC)**	**pH**	**Na**	K	**Ca**	**HCO_3**	**SO_4**	**Cl**	**F**	**SiO_2**	**Chalcedony temp. (^oC)**
Temperley Line Mkoba	52	9.3	37	1.8	1	99	8	14	7.2	68.4	88
Mvuntshini	45	8.8	37	1.4	3	69	4	7	7.2	53.5	76
Ezulwini	40	8.4	26	1.3	4	55	3	5	4.9	44.9	68
Lobamba	48	9.0	44	1.4	3	77	5	19	8.1	59.9	82
Mawelawela	35	8.4	41	1.4	3	95	4	9	5.4	42.8	66
Ngwempisi	46	8.2	34	1.3	5	69	4	5	6.0	40.6	64
Madubula	52	9.0	68	2.1	3	75	12	37	14.5	65.2	86
Mpopoma	33	9.4	70	1.5	2	96	12	24	12.5	64.2	85
Mbondela	27	-	40	2.2	3	77	7	9	6.0	46.0	69
Sulphur Springs	28	9.0	38	1.9	3	93	5	8	5.4	49.2	72
Warm Bad	31	9.9	75	1.9	1	132	9	15	11.0	75.5	94
Eastern Line											
Fairview	38	9.2	106	2.9	2	99	17	55	21.0	25.7	45
Siphofaneni	39	8.1	140	5.1	9	113	19	120	18.0	55.6	78
Onverwacht	26	9.6	139	4.2	1	210	13	67	27.9	84.2	99

The saturation indices with respect to calcite are close to or slightly less than zero. The Ca^{2+} and HCO_3^- levels are likely controlled by calcite equilibrium at temperatures approaching those of the surface discharges, assuming carbonate is available on the fracture walls. Saturation indices with respect to fluorite are also close to zero which is normal for granitic terrain. Chalcedony geothermometers (Amorsson, 1975) indicate base temperatures of between 60 and 100 ^oC.

Spring temperature is notably consistent and indicative of a stable circulation environment. Spargo (1965) recorded temperatures of 49, 53 and 53 ^oC at Mkoba whereas Robins and Bath (1979) recorded the same springs at temperatures of 49, 48 and 52 ^oC. Variation in the middle spring temperature results from its discharge through alluvium and likely mixing with river water, whereas the north and south springs emerge directly from bedrock.

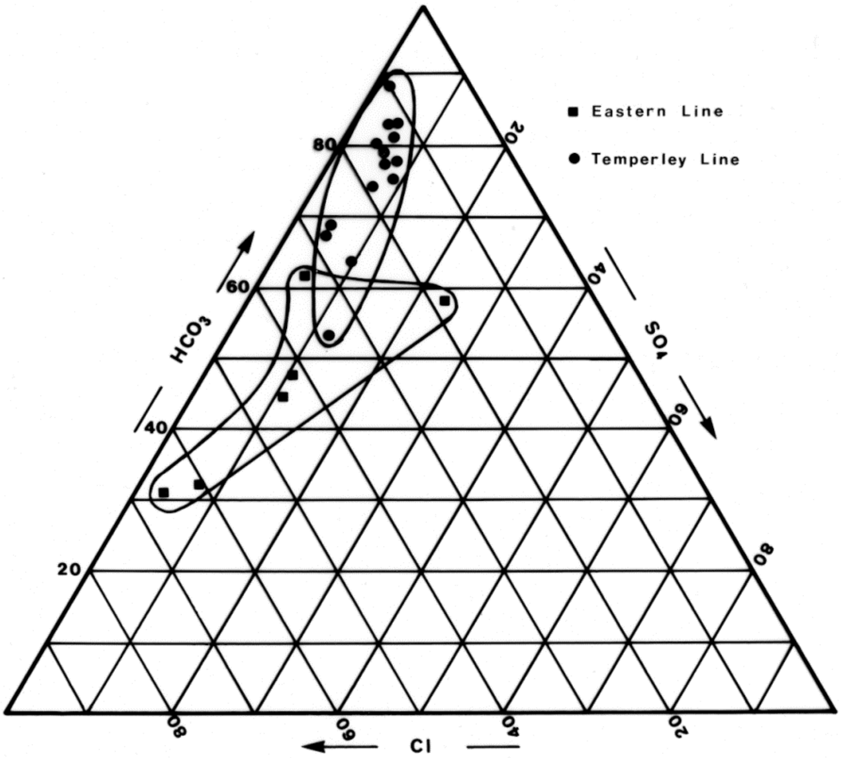

Figure 3. Thermal spring discharge major iron chemistry for springs in the Eastern trend line and in the Western or Temperley trend line

Spring discharge is variable. The Siphofaneni spring, for example, had changed from a recorded discharge of 1.9 l/s in the late 1960s (Hunter, 1968) to 6 l/s in the late 1970s (Robins and Bath, 1979) to only 0.6 l/s in the late 1980s (Dakin et al., 1988), the latter change possibly reflecting the onset of dryer conditions leading up to the drought of the early 1990s. Similar variation has been recorded at Mkoba, Lobamba and Mawelawela although the Ezulwini discharges have been remarkably constant.

Dissolved gases in the discharge from one of the springs suggest oxygen and carbon dioxide have been depleted by oxidation and carbonation processes during circulation (Mazor et al., 1974). Noble gases and stable isotopes show the waters to have been kept in closed circuit conditions and their concentrations suggest palaeotemperatures at the time of infiltration of between 21 and 31 ^{o}C, similar to contemporary summer rainy season temperatures.

4. GROUNDWATER CIRCULATION

Deep groundwater circulation results from gravity drainage from a high elevation recharge zone to discharge at valley bottom. Once flow is established convection provides additional energy. That all the spring sources occur at valley bottoms suggests association with structural lines of weakness, some in line with mapped features such as faults and fracture zones, others less obvious.

The geothermal gradient is about 20 ^{o}C per km. To achieve the observed circulation temperatures the spring waters need to penetrate to at least 1000 m depth, less if the geothermal gradient is enhanced within the thermal lineaments alluded to by Hartnady (1985). Chalcedony geothermometry, however, indicates that maximum temperatures up to 100 ^{o}C are achieved during circulation. If the average geothermal gradient is only about 20 ^{o}C/km, as recorded in a deep mine at Barberton, then this would require circulation up to a depth of several kilometres. It is, nevertheless, likely that circulation bottoms at about 1 km, as pressure of overburden inhibits dilation of fractures at such depths and the excess temperature may derive from a locally enhanced geothermal gradient caused by the fractures. The discharge water is young, with ^{14}C ages of between 4000 and 5000 years. The flow velocity needed for groundwater to flow through a system of interconnected dilated fractures to a depth of 1500 m and back in 5000 years is 0.6 m/yr.

5. CONCLUSIONS

The thermal springs of Swaziland and the adjacent springs in South Africa are a consistently weakly mineralised group of deep circulating groundwaters. The groundwaters are $NaHCO_3$ and $Na/Cl-HCO_3$ types. They fall within two distinct lineaments and there is some evidence that the Eastern Line may be less mature than the western Temperley Line.

Assuming that the recharge element of the systems takes place at higher elevation than the discharge zones, a gravity driven flow system enhanced by convection allows continued circulation of groundwater. Circulation is likely to a depth of about 1 km although geothermometry suggests deeper circulation would be necessary, or a locally enhanced geothermal gradient, as base circulation temperatures are <100 ^{o}C. The circulation period is about 5000 years.

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