Review of BRGM Hydrogeological
Survey of the Transvaal
Supergroup dolomite in the
Kanye Basin, Botswana

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Contents

A Review of the Hydrogeological Survey of the Transvaal Supergroup dolomite in the Kanye area

1. Introduction

The BRGM study is an unusually detailed piece of scientific research based upon geological, tectonic and structural analysis to yield drill sites from which an understanding of groundwater occurrence in the area might develop. The report (Section 8.7) is remarkably frank in drawing attention to the uncommon nature of such detailed research and to the present difficulty of interpretation of results.

The investigation centres around the development of a conceptual geological model postulating the most favourable conditions for intense fracturing, since these might contain groundwater of greatest economic significance. Three types of structural setting are proposed (Section 8.6) as the most favourable zones for intense fracturing associated with various major NE-SW trending fractures, joint and fault patterns.

Interpretation of air photographs revealed a dense pattern of lineaments presented in a fracture map (enclosure 3) from which 15 geophysical and 10 drill site locations were selected to assess the three types of structural setting. Having established this strategy our understanding of the results obtained suggests that the three types of structural setting were not important zones of open fracturing. Indeed, because of the nature of the results, the BRGM report is unable to reach any proven conclusions regarding which elements of the geological, tectonic or structural model are of greatest fracture significance for groundwater occurrence.

This should not detract from the scientific detail nor the potential value of the investigation in developing a better understanding of the general hydrogeological nature of fractural dolomite aquifers in Botswana. Indeed from a scientific viewpoint it is disappointing to see this study in what has proven to be such a poor aquifer. However, the results must be considered disappointing with regard to the help they give in assessing the distribution and availability of groundwater in the Kanye dolomite. Nevertheless our understanding from the BRGM report is that this was not the purpose of the research.

Since the practical need at this time is to assess the potential of the Kanye dolomite as a source of supply in the Gaborones area, our examination of the data presented in the BRGM report must be to that end. A full reworking of the information in a conventional water resources assessment was not required of us; in fact we assume this to be the subject of a follow up study by BRGM. Instead we have used the new information and understanding to provide a preliminary quantitative assessment of the potential of the dolomites as a major groundwater source of supply.

We have examined the BRGM data and made use of what is believed to be understood of other similar aquifers in eastern Botswana to arrive at resource estimates.

?. Geology

2.1 Outline Geology

The Kanye Dolomite Series occupies an irregularly shaped basin some 300 km^2 in area and forms part of the more extensive Proterozoic Transvaal Supergroup.

The surrounding formations vary in age and type and the area has been subject to intense tectonic activity, which largely determines the present shape of the basin. Many of the geological contacts with the surrounding formations, particularly in the southwest, are related to intrusions or faulted contacts with other sedimentary formations:

- in the north the dolomites are overlain by uncomfortable arenaceous deposits of the Waterberg Supergroup
- older Ventersdorp Supergroup shales with volcanics form the eastern boundary
- the post-Transvaal Mmathele granite forms the southern boundary
- the western edge of the basin comprises the Upper Transvaal Supergroup shales and the Segwagwa post-Waterberg intrusion

Hydraulic connection with these varying rock types may occur predominantly through fractures. Outside the dolomite such fractures appear to be free of manganese infill.

The Kanye dolomites have been sub-divided and re-mapped by BRGM on a litho-stratographic basis related to the abundance of chert. The greatest development of dolomite occurs in the northern part of the basin where the total thickness is about 1200m. Five lithostratigraphical units are recognised largely on the basis of alternations of siliceous chert within a massive, dark grey dolomite. The sequence is capped by a chert breccia of rather uncertain origin and distribution which is responsible for the more rugged and hilly topography in the north. The sequence comprises:

100m	Chert breccia
50m	Uppermost chert-free dolomite
200m	Upper chert-rich dolomite
400m	Central chert-free dolomite
350m	Lower chert-rich dolomite
200m	Basal chert-free dolomite

Deep erosion has affected the area. This peneplanation has removed the younger parts of the dolomite sequence in the south. The higher more cherty sequence is resistant to erosion forming hills in the eastern central and northern part of the basin.

Dolerite sills affect the chert-rich formations, perhaps associated with preferential intrusion along bedding planes. They are absent from the southern part of the area due to the deeper level of erosion. Here the dolomite has been deeply weathered forming areas of low relief.

Alluvial deposits are poorly developed reflecting the lack of surface water drainage channels. Calcrete occurs preferentially over a wide area of the southern part of the basin.

2.2 Hydrogeological Implications

BRGM record no evidence for the existence of deep karst in the Kanye dolomite; this is the feature of the Ramotswa and Pitsanyane areas providing major storage and large production yields. However, a shallow karst exists at Kanye but it is discontinuous and above the water table over the northern region. It is perhaps more extensive and better developed in the south and we would agree with the BRGM observation that it probably represents an ancient karst since solution openings appear filled with various weathering products and carbonate deposits.

The fresh dolomite bedrock beneath the karst is characterised also by infilling of once open joint and fissure systems. Manganese associated with quartz is reported and BRGM comment that a most surprising feature is the almost complete filling of open voids despite some degree of more recent reactivation of the fractures. This is attributed to the lack of an active surface water drainage system and hence of the percolation necessary to re-open manganese filled fracture systems (or karst).

The BRGM report sought correlations between structures, origins and geology in order to guide future exploration for groundwater to the most productive sites. Few helpful relationships are recorded.

* relations between local fracture pattern and karst could be identified only in some boreholes

* shallow karst is obviously not restricted to zones with exceptionally dense fracture patterns

  depth of karst development is greatest in chert-rich dolomites

* karst cannot be identified on the ground nor from air photographs

* no preferential tectonic lineament trend is associated with manganese infilling

* no distinction could be found between faults and fractures when comparing degree of infilling

* manganese infilling has affected all lithostratigraphical positions within the dolomites

From this it may be concluded that the nature, extent and occurrence of open fractures, or of productive karst, is essentially still unknown. Also we would agree with BRGM that the hydrogeological potential of these dolomites is much lower than was expected before their exploration began.

Despite providing a picture of a complex and unattractive aquifer system, the BRGM study does give a detailed structural and geological basis for further groundwater investigations. There exists, however, scope for a degree of more conventional hydrogeological analysis which can provide some indication of the potential size and distribution of any groundwater resource within the area.

3. Physiography and Drainage Areas

The physiographic setting of the dolomite outcrop is unusually complicated but divides broadly into two important regions defined by BRGM as active and fossil river drainage zones (Fig.1).

The active drainage system lies to the northeast of an unobtrusive but significant north-south catchment divide crossing the outcrop from the Ditshilo Hills in the north to Gamarotswana in the south.

3.1 Eastern drainage system

The active drainage system arises from the high relief of the extreme north of the dolomite outcrop in the Ditshilo and Dinaka Hills. There are three sub-catchments. The largest may be described as the Taupone basin and comprises the headwaters of the Moreane river covering about $62km^2$ of dolomite. In the extreme north-east of the outcrop is a second area of dolomite ($22km^2$) drained by the Nneneke river. This drainage area contains the Kanye wellfield and will be referred to hereafter as the Kanye basin. To the north west of this basin some $5km^2$ of dolomite lies within the headwaters of the northerly draining Metsemotlhaba catchment. This surface water divide along the northern margin of the Kanye basin separates a strong and active northward drainage system developed upon Waterberg Quartzites from the dolomites. In the context of the BRGM report this physiographic feature has significance since groundwater leakage from the quartzites is postulated. Groundwater flow in the opposite direction to topographic and surface flow must therefore be inferred.

3.2 Western catchment

BRGM report no other active rivers over the remaining larger area of dolomite to the west and south of the Ditshilo-Gamarotswana catchment divide. Here the land surface of the dolomite outcrop slopes gently and relatively uniformly to the south west. In the north of this zone stronger relief is present on the western flank of the Ditshilo Hills, around the Masoke ring and at Mamadungwa hill. Published maps show no evidence of stream channels. BRGM explain this contrast in relief and drainage through changes in rock type within the dolomite sequence and the development of calcareous and ferruginous crust forming a "buried landscape".

BRGM report identification of an important fossil river system of impressive size from aerial photographic interpretation in this western area. It runs from north to south for a distance of about 20km along the middle western edge of the dolomite basin approximately following the present topography. At Maelo the fossil river is shown to swing south-westwards following a gentle depression crossing the most south-western outcrop of the dolomite. BRGM consider the present state of this to be of "rather recent origin" with the fossil river comprising a tributary of a major sand river valley, the Mosilebe, some 10km to the south of the dolomite basin.

3.3 Drainage pattern in relation to resources potential

Our interpretation of this physiographic information suggests that there are significant implications for groundwater availability in this western region by comparison with the eastern draining Taupone and Kanye basins. We would agree with BRGM that in the western region any surface water flow following heavy rain is likely to be restricted to very local runoff covering only short distances before collection in local surface depressions. Groundwater recharge would be diffuse, evaporation losses high, and percolation to any karst or geological structure limited.

We consider the recharge potential in the Taupone and Kanye basins to be appreciably better. The more rugged topography of the headwaters in the Dinaka and Ditshilo hills, the occurrence of active stream channels in the lower reaches of the basins, and the BRGM report of more extensive developments of water courses within the dolomites than depicted on published maps indicate coherent streamflow during major rainfall events. The opportunity for major recharge of any karst or geological structure is greatly enhanced under such conditions.

We conclude from this evidence that the groundwater potential of the eastern catchment area of the Kanye dolomite is significantly better than elsewhere.

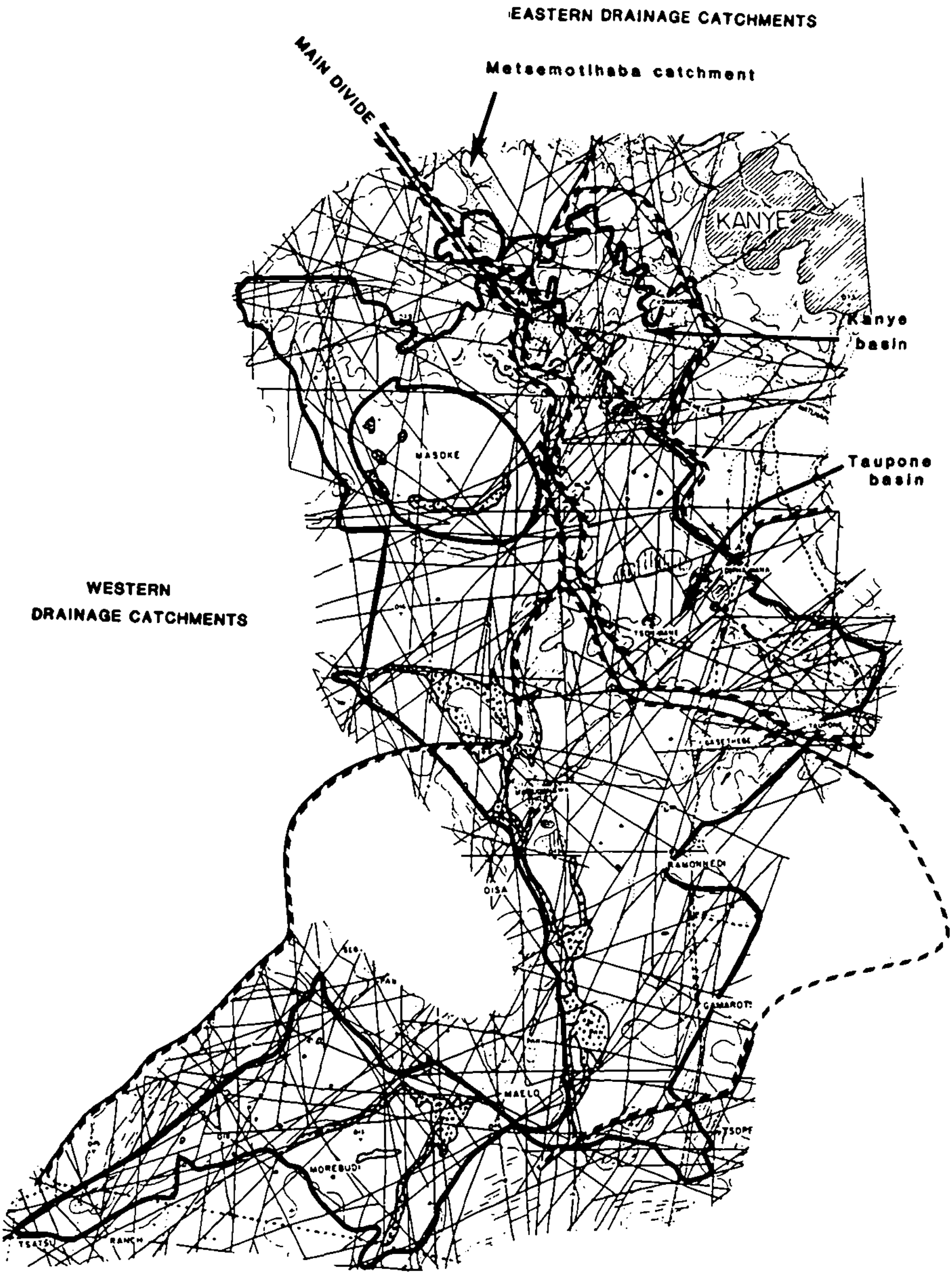
4. Estimates of Groundwater Recharge

Groundwater studies elsewhere in eastern Botswana have indicated recharge rates of between 4 and 7 percent of mean annual rainfall (MAR). From the description of the geology and physiography of the Kanye dolomites it is not unreasonable to propose an upper maximum recharge to the dolomites of 5 percent MAR. Meteorological data presented by BRGM shows a mean rainfall (1924-1983) at Kanye of 515.7mm and a median of 489.6mm. Maximum recharge of about 25mm per year can therefore be expected.

On the basis of topography from published maps of the area according to the drainage basins shown in Figure 1, estimates of recharge are given in Table 1. We show a gross maximum recharge on the basis of 25mm recharge per year. In view of our comments on the characteristics of physiography and of drainage we would suggest this maximum recharge would apply only to the more favourable conditions in the eastern part of the basin.

BRGM made comparisons with dolomites in South Africa where a recharge rate of 2.5 percent was derived. Given the low relief of the western catchments and the extensive development of calcrete together with indications of a lower rainfall across the dolomite outcrop away from Kanye, estimates of recharge to the western catchments of perhaps 12.5mm (2.5% MAR at Kanye) are indicated.

For planning purposes we suggest that the long-term direct recharge from rainfall to the dolomite outcrop amounts to only 4.7 million cubic metres per year (Mm^3/yr). The predicted direct recharge to the Kanye basin (0.6 Mm^3/yr) slightly exceeds the present wellfield abstraction averaging 0.5 Mm^3/yr.



Figure

Catchment areas

TABLE 1

Estimates of Recharge

	Drainage Area (km^2)	Maximum[1] Recharge (Mm^3/yr)	Reduced[2] Recharge (Mm^3/yr)	Estimated long-term groundwater recharge (Mm^3/yr)
Eastern Catchments				
Kanye basin	22	0.6		0.6
Taupone basin	62	1.6		1.6
Western Catchments				
North	80	(1.5)	0.75	0.75
Central	52	(1.3)	0.65	0.65
Southern	40	(1.1)	0.55	0.55
Southwest	43	(1.1)	0.55	0.55
	299			4.7

1 Maximum recharge 25 mm/yr

2 Reduced recharge 12.5 mm/yr

Potentially on the basis of these predictions the Taupone basin represents the most attractive area for groundwater within the dolomite outcrop.

5. Piezometric Evidence

BRGM present a preliminary water level contour map (Enclosure No.6). This is based on data from 45 wells and boreholes mainly in the southern part of the outcrop and attention is rightly drawn in the report to uncertainties regarding the accuracy of the interpretation. Nevertheless it is one of the major indications for occurrence and movement of groundwater within the dolomites. Our general experience of sparse groundwater data suggests that, providing a coherent and connected groundwater body exists, then even the most preliminary piezometric map provides important resource and exploration information.

The most noticable feature of the piezometry is a prominent and persistent groundwater ridge running north-south from the Ditshilo hills to Maelo. This is shown in Figure 2, based largely on the BRGM interpretation, but amended slightly from our examination of the published data.

BRGM propose that the piezometric ridge suggests a flow of groundwater from the northern Waterberg sandstones into the dolomite, draining thence through "privileged" fault and fractures toward other sedimentary formations of the Ventersdorp, especially east of the dolomite. No groundwater loss is expected towards the southern basement complex but some flow to the southwest is anticipated despite the particularly sparse water level information in that area.

A major conclusion from the study influencing future exploration strategies concerns proposals to investigate faults separating the dolomite from Ventersdorp rocks to intercept groundwater originating from the Waterberg sandstones and flowing through the dolomites. Here we would make various comments concerning the data, their interpretation and the implications for future exploration.

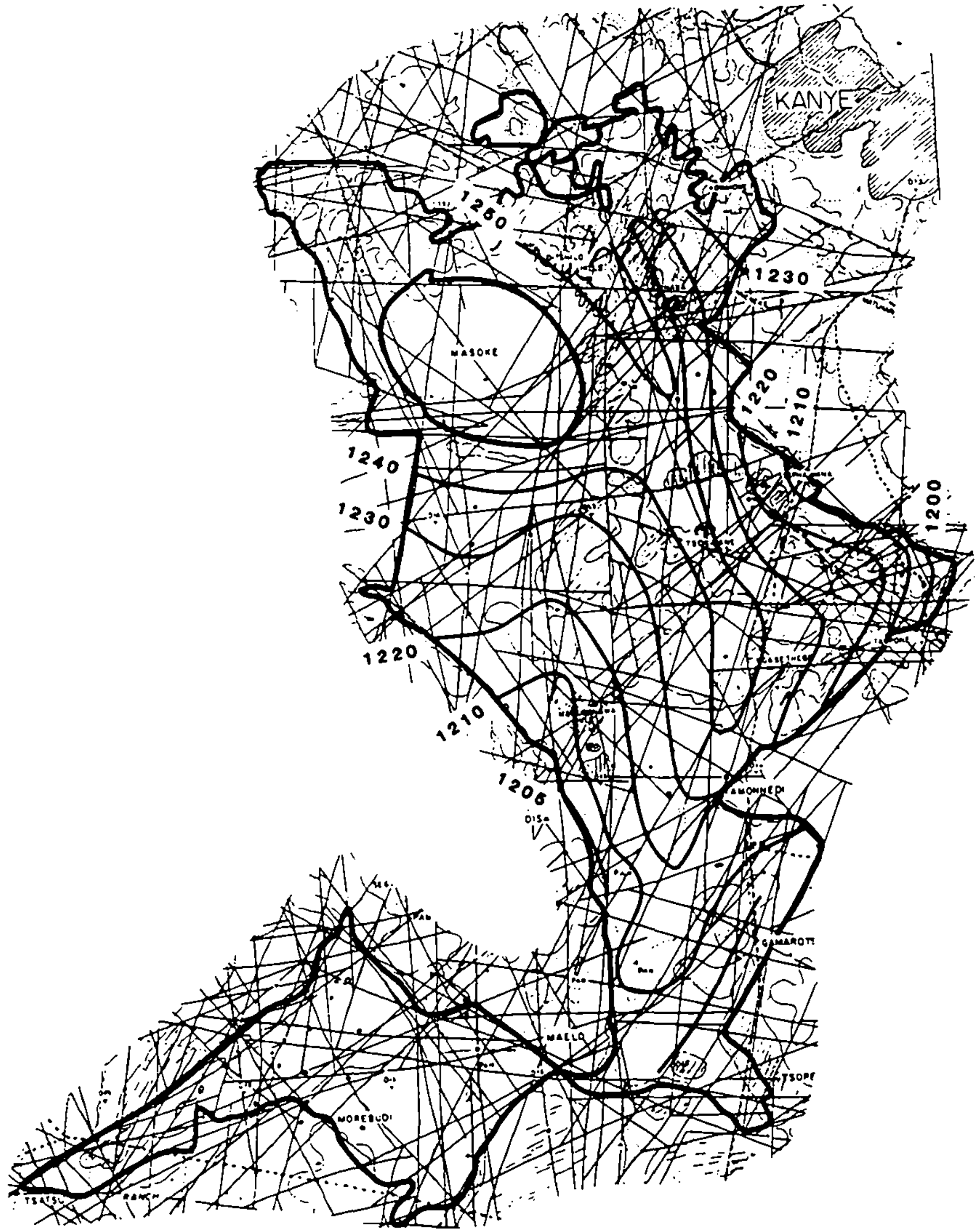


Figure 2

Water table elevation (mOD)

* Evidence for underground recharge of the dolomites from the Waterberg sandstones is based largely on the piezometric information supported by some chemical data. Given the importance attached to this in proposals for further work we are surprised that no direct evidence is given for groundwater in the sandstones.

* Proposals are made to recover this groundwater as it drains out of the dolomite. Since we would agree with BRGM that the sandstone probably comprise an aquifer with better storage and recharge characteristics (page 192), we are surprised that no proposals are made to exploit the sandstones directly.

  If the persistent groundwater ridge is formed by flow of sandstone groundwater through the dolomite, then a zone of high transmissibility must be inferred. The extent of the feature appears such that leakage of groundwater into any northeast trending fractures is at best difficult and restricted. This seems to contradict BRGM interpretations.

* BRGM discard the origin of the groundwater axis from direct recharge within the dolomite outcrop. We note that the mound is centered upon a NNW-SSE fault from Ditshilo Hill to south of Tsokwana which follows the drainage axis of the Taupane basin. Despite the general imprecision imposed by the scattered water level observations, recharge along this drainage axis should not be discounted. Our observations on the nature of the drainage pattern and estimates of recharge indicate the Taupone basin as the largest potential renewable resource.

* We would also draw attention to the major surface water catchment divide which lies close to the groundwater axis defined by the piezometric data. Normal movement of dolomite groundwater toward the northeast and southwest following topographic gradients seems an equally likely explanation of the piezometry. This would discount a Waterberg sandstone origin for groundwater in dolomites but still allow for direct recharge on the outcrop.

We would strongly recommend that any further exploration is directed toward confirming the position and the origin of the apparent groundwater ridge. At this stage it seems central to understanding the hydrogeology of the Kanye dolomite. Further drilling to explore the faulted drainage axis of the Taupane basin as a possible preferred zone for groundwater abstraction should be combined with regional exploration to locate the true position of the groundwater ridge relative to the topographic divide.

Concepts of recharge and aquifer transmissivity may also be interrogated from the piezometric data. BRGM pumping tests yield transmissivity values for fractured dolomite of between $1m^2/d$ and $44m^2/d$ with a mean of $10m^2/d$. These are similar to values produced in the non-karstic dolomite country rock at Ramotswa. For a regional transmissivity of $10m^2/d$ the groundwater flow on either side of the groundwater ridge is calculated at 0.74 Mm^3/year, 0.5 Mm^3/year to the east and 0.24 Mm^3/year to the west. Some 40 percent of the inferred groundwater flow is predicted moving eastwards north of Tsokwane. Here again the relative importance of the Taupone basin is indicated.

However, this approach does indicate an inconsistency within the overall semi-quantitative picture. The inferred groundwater flow and the long-term recharge must be equal. Here we are in fact comparing a flow of 0.74 Mm^3/year with a recharge estimated at 4.7 Mm^3/year. A regional transmissivity of about $40m^2$/d or a much reduced recharge is implied.

Whilst we can be confident that direct recharge is unlikely to exceed 4.7 Mm^3/year we are less certain about an upper limit for regional transmissivity. $40m^2$/d is not out of the question but it would suggest that some greater degree of open fracturing or preferred movement of groundwater, perhaps through a shallow karst, has failed to be detected. Generally however these flow and recharge considerations confirm the broad BRGM contention that the dolomites comprise an aquifer of local rather than regional significance. There remains, however, the question of the volume of groundwater stored within the aquifer.

6. Estimates of Groundwater Storage

From details of the drilling and test pumping results combined with the broad descriptions of the occurrence of groundwater relative to the geology of the area, a conceptual model of the Kanye dolomite has been compiled from the BRGM report. The main features of the aquifer used to estimate the volume of groundwater held in storage comprise:

* a fractured bedrock extending to a maximum depth of 100m below the regional water table
* beneath high ground in the north where water levels are deeper, a saturated bedrock depth of 50m
* a shallow water bearing karst in the western and southwestern outcrop areas only
* a shallow water bearing karst only in low lying exposures of dolomite with chert
* a saturated karst thickness of 15m as indicated by BRGM exploration drilling
* an area of weathered bedrock confined to the Taupone basin with an average saturated thickness of 25m
* storativity of the shallow karst (and weathered bedrock) based upon pumping test values of 4 percent

* storativity of the fractured bedrock 0.3 percent from pumping tests
* storativity values are similar to those adopted for Ramotswa and Pitsanyane dolomites; recoverable groundwater 20 percent from bedrock, 50 percent from karst and weathered bedrock.

From these broad characteristics estimates suggest a recoverable storage totalling about 24 Mm^3 throughout the whole outcrop (Table 2). The Taupone basin is again indicated as the most attractive prospect, largely due to resources within the weathered bedrock area. The recoverable storage in the Kanye wellfield area is of the same order as the existing abstractions and the estimated recharge. Elsewhere the conceptual model predicts a small groundwater resource over relatively large areas. Shallow karst in the south and southwestern outcrops total only 5.7 Mm^3. Generally groundwater recovery from storage of 0.3-0.5 Mm^3/km^2 is postulated for shallow karst and the lower Taupone basin. Elsewhere bedrock yields of 0.03-0.06 Mm^3/km^2, an order of magnitude less, are proposed.

Further Studies

Within the context of a regional groundwater strategy it is useful to draw comparisons between the Kanye area and other dolomite aquifers in Eastern Botswana. The main attraction at Ramotswa and Pitsanyane arises from the limited development of deep karst. This provides an opportunity for siting large production wells, albeit with some difficulty. The deep karst also enhances the hydrogeological importance in providing relatively large storages, and, through an open fracture system, important connections into secondary and minor storages within the rock matrix. Furthermore, at these locations the deep karst is in association with active stream systems providing large and instantaneous recharge following major rainfall events. Whilst opinions may differ concerning the extent of the groundwater resource, there is little disagreement concerning the hydrogeological significance of such deep karst.

TABLE 2

Estimates of Aquifer Storage

	Extent of waterbearing shallow karst (km^2)	Extent of fractured bedrock (km^2)	Saturated thickness (m)	Stora-tivity (%)	Total Storage (Mm^3)	Percent Recovery	Recoverable Storage (Mm^3)
Eastern Catchments							
Kanye basin			50	0.3	2.6	20	0.5
Taupone basin	12		25	4.0	12.0	50	6.0
		20	50	0.3	3.0	20	0.6
		30	100	0.3	9.0	20	1.8
					26.6		8.9
Western Catchments							
North		60	50	0.3	9.0	20	1.8
Central		52	100	0.3	15.6	20	3.1
South		30	100	0.3	9.0	20	1.8
	10		15	4.0	6.0	50	3.0
		10	85	0.3	2.5	20	0.5
					42.1		10.2
Southwest			15	4.0	5.4	50	2.7
		9	85	0.3	2.3	20	0.5
		34	100	0.3	10.2	20	2.0
	31	262			17.9		5.2
				TOTAL	86.6		24.3

The failure to detect similar deep karst in the Kanye dolomite is the most significant and disappointing feature of the exploration so far. The possibility of deep karst, particularly beneath the ancient drainage system in the southern part of the Kanye dolomite is proposed by BRGM by analogy with Ramotswa. We would agree this is a possible target for further scientific exploration but all of the evidence from the present study would suggest that even if deep karst exists it can be expected to be blocked by manganese, silica and calcite. Furthermore, and in contrast to Ramotswa and Pitsanyane, there is no active surface water system in this area of the Kanye dolomite. We must conclude therefore that this is at best a very poor prospect as a potential major source of groundwater.

With regard to the shallow karst identified by BRGM in the Kanye dolomite we can find little evidence to suppose this would comprise a major aquifer. It is described as either filled with manganese or collapsed. Furthermore it appears to be discontinuous and unable to be located except by drilling. Over much of the area the water table is below the karst, whilst in the south, where groundwater has been located within it, the saturated thickness is small (15m). There are no active stream channels to promote recharge and a calcrete capping is likely to hinder even local percolation. Here again is a poor groundwater prospect.

The BRGM proposals for further exploration of these features is aimed at completing a scientific study to understand the hydrogeology of the area. We do not interpret the proposals as any indication of a major groundwater resource and would agree entirely with the BRGM view that the resources with the dolomite will be of local rather than regional significance.

The BRGM strategy to explore the faulted marginal contracts of the dolomite is logical. The evidence seems to suggest these may be less affected, or even free, of manganese infilling. However, we would favour exploration mainly along the northeastern margin of the basin, largely on the basis of active stream channels as potential sources of recharge to such features.

We would particularly support further work in the Taupone basin. Despite relatively unsuccessful drilling our evaluation suggests this to be the best prospect for an additional local source of supply. Here we would agree that further work to establish the position and nature of the groundwater mound is most desirable. The BRGM strategy depends largely upon the concept of groundwater from Waterberg sandstones moving through the dolomite to marginal faults draining into the Ventersdorp. No direct evidence is presented in the BRGM report for groundwater in these sandstones and we have suggested two alternative explanations for the piezometry which are not dependent upon an underflow from the sandstones.

We believe a prime target for exploration must be the NNW trending fault along the drainage axis of the Taupone basin which appears to coincide with the axis of the groundwater mound. If this juxtaposition can be confirmed together with groundwater from the sandstones then a preferred flow pathway of high transmissivity must be inferred.

Finally we would return to a point made earlier and relating to the concept of the dolomite acting as a conduit for Waterberg sandstone groundwater moving toward the Ventersdorp of the eastern margin. If this is the case then exploration within the sandstones and recovery of groundwater directly from them ought to be considered as a local exploration strategy.