Brief explanation of the Kanye 1:250,000 geological map

There is an E-W bedrock exposure-belt across the southern part of the Sheet where conventional geological mapping by the Botswana Geological Survey Department has been published as two geological maps. These are the 1:125,000 geological map of the Jwaneng Area (Sheet 2424D; Tombale, 1986; Cullen, 1958), and the 1:25,000 geological map of the Molopo Farms Project Area that includes the geology of Sheet 2424C (Gould & Rathbone, 1988). The geology of these southern areas shown on the present map is relatively detailed as it incorporates the results of the conventional mapping by the Botswana Geological Survey Department with an interpretation of the high-resolution airborne magnetic data. By contrast, the geology of the northern half of the sheet is only shown at Group level. However, major faults (including the Dikgomodikae Lineament) and dykes are shown as these are clearly defined by the magnetic data.

The logs of about 209 water boreholes, as well as the logs of about 50 exploration boreholes (mainly into the Molopo Farms Complex or for kimberlites) were used in compiling the geology map. The water boreholes include a tightly spaced cluster in the Jwaneng Wellfield in 2424B1. Otherwise most water boreholes are concentrated in the southern, populated part of the Sheet.

Lobatse Group including the Kanye Felsite

The oldest rocks shown on the map are siliceous lavas, including feldspar-quartz porphyries, quartz porphyries and flow-banded rhyolites of the Lobatse Group that are exposed in the Jwaneng area (Tombale, 1986). Here they underlie Transvaal Supergroup strata and are intruded by the Gaborone Granite. The various phases of the Gaborone Granite as well as of the surrounding extrusive volcanic rocks of the Lobatse Group have all been precisely dated at about 2780Ma (Key & Ayres, 2000).

The Kanye Felsite comprises black to purple, fragmental rocks with minor feldspar phenocrysts. They have a strong magnetic signature that defines their arcuate, strongly faulted outcrop around the southern margin of the Gaborone Granite.

Gaborone Granite

The western extremity of the Gaborone Granite extends into the eastern part of the Sheet to the east of Jwaneng. It is essentially unexposed and the majority of boreholes drilled into its outcrop area intersected dolerite to indicate that the granite is strongly cut by mafic sheets and dykes. The granite outcrop has a distinct magnetic pattern of closely spaced intersecting lineaments trending E-W, WNW-ESE, NE-SW and ENE-WSW. Dolerite dykes control the ENE lineaments, as shown on the 1:125,000 geological map of the Kanye area (Aldiss &

others, 1990). Other lineaments probably relate to master joints and/or faults. Tombale (1986) records an exposure of coarse-grained granite (probably the Thamaga Granite phase) at Tshono Pan, and also notes that fine-grained purple granite (probably Ntlhantlhe Granite phase) was found in a well at Pitseng.

Transvaal Supergroup (mostly from Tombale, 1986)

A complete sequence of Transvaal Supergroup strata is exposed in the south-eastern part of the Sheet unconformably overlying felsic rocks of the Gaborone Granite and Lobatse Group. These rocks extend westwards beneath the Kalahari cover where it is generally only possible to subdivide the sequence at the Group level from borehole information. However, relatively magnetic ferruginous quartzites near the base of the Segwagwa Group locally define dome and basin fold patterns on the airborne magnetic maps. The Transvaal Supergroup outcrop coincides with the core of an E-W ridge across the centre of the Kanye Sheet with relatively thin or no Kalahari cover. Waterberg strata unconformably overlie the Transvaal Supergroup strata to the north and south.

The basal Black Reef Quartzite is thin (about 10m thick) but persistent and comprises grey conglomerate overlain by pure quartzites. These grade upwards into sandstones and shales, transitional into the ferruginous (and locally manganiferous) shales at the base of the overlying Ramonnedi Formation of the Taupone Group. These in turn grade into dolomites that become increasingly siliceous upwards, culminating in bedded cherts, banded iron formations and chert breccias of the Masoke and Kgwakgwe formations. Stromatolites are preserved in the dolomites. The total thickness of the Taupone Group is about 400m.

The overlying Segwagwa Group is about 1200m thick and mostly comprises clastic sedimentary rocks. A basal 430m thick Ditlhojana Formation is composed of pyritic and micaceous shales grading up into ferruginous quartzites. Yellowish-green to reddish-brown laminated argillites form the base of the overlying Tlaameng Formation whose top is marked by a discontinuous chert-clast conglomerate. Andesitic volcanics of the Tsatsu Formation are an important regional marker horizon. They are not well exposed but their outcrop has a characteristic calcrete cover. Unfortunately the lavas are not magnetic and cannot be traced beneath the Kalahari from airborne magnetic data. The amygdaloidal lavas have a total thickness of about 260m. Interbedded shales and quartzites capped by a pure quartzite of the Mogapinyana Formation overlie the lavas. About 130m of black and white laminated cherts and bluish-green shales of the Gatsepane Formation mark the top of the Segwagwa Group.

Kgare Hill (24º 54’ 51”E 24º 16’ 37”S) and Kgare Pan (24º 56’ 50”E 24º 16’ 02”S), previously interpreted as felsite and silicified Ecca sandstones by Green (1966), are underlain by fine-grained, cross-bedded sandstones and cross-bedded quartzites respectively. These rocks define a NW-trending syncline and they are now interpreted as part of the Segwagwa Group.

Molopo Farms Complex

The easternmost parts of the c.2044±24Ma (Kruger, 1989) Molopo Farms Complex underlie the SW part of the Kanye Sheet. A N-S belt of basal ultramafic rocks through Tubane defines the eastern margin of this intrusive complex. It is dissected by the NE-trending Dikgomodikae Lineament (Chatupa, 1995) that is partly infilled by serpentinised lenses of the Molopo Farms Complex. Gould & others (1987) provide a detailed account of the whole complex, updated in Chatupa (1995) to include the results of mineral exploration undertaken throughout the late 1980s and early 1990s (Reichhardt, 1994; von Gruenewaldt & others, 1989).

The basal ultramafic cumulate rocks form part of the 'Ultrabasic Series' of Gould & others (1987), and are referred to as the Lower Molopo Farms Complex in the map legend. They comprise variably serpentinised, cyclically layered orthopyroxene cumulates (pyroxenites and harzburgites) separated by central olivine-rich cumulates (peridotites) with minor norites and gabbros. Gould & others (1987) record a maximum thickness of 1850m for the whole unit where it has been intersected by a series of boreholes on their Tubane Grid.

The overlying Upper Molopo Farms Complex ('Layered Basic Series' of Gould & others, 1987) is shown in two formats on the accompanying map, (1) as a series of discontinuous lenticular bodies that mimic the outline of the whole complex, and (2) as composite units referred to as 'A network of Upper Molopo Farms Complex intrusive sheets intruding Upper Transvaal Supergroup strata'. These second units form the cores of the Complex's northern and southern lobes and comprise a network of interconnecting mafic sheets, that are too irregular and too small to show separately, infiltrating through the host Transvaal Supergroup strata. They include intrusions equivalent to the 'Minor Intrusive Suite' of Gould & others (1987).

The main lithologies of the relatively homogeneous Upper Molopo Farms Complex are clinopyroxene-norites (orthopyroxene-plagioclase cumulates), with orthopyroxene-gabbros, quartz-bearing gabbro-norites, melanorites and feldspathic orthopyroxenites and less common dolerites and diorites. Pegmatitic phases of the main lithologies are common. Gould & others (1987) record a minimum thickness of 1700m for this unit where it is developed as a coherent sheet on the eastern edge of the Complex. Individual sheets within the composite unit vary in thickness up to several hundred metres.

More isotope geochronology is required on all major lithologies in order to ascertain whether any units may are related to the ~1927Ma tholeiitic magmatism recorded by Hanson & others (2004) throughout the Kaapvaal Craton (see later).

Petrological, mineral and petrochemical evidence suggest that the Molopo Farms Complex crystallized from at least two chemically distinct parental liquids with two stages of emplacement (e.g. Reichhardt, 1994). Magma that crystallised to form the Lower Molopo Farms Complex was initially emplaced as moderately to steeply dipping coherent sheets into gently dipping Transvaal Supergroup strata that had already been folded into E-W dome and basin structures with wavelengths of about 4km. Magma accessed the upper crust along the subvertical NE- trending Dikgomodikae Lineament and spread laterally into the surrounding Transvaal strata. It is likely that ultramafic sheets were emplaced at a high crustal level (<3km depth). This because an attenuated Transvaal Supergroup sequence was present in southern Botswana relative to a fuller succession in the main Transvaal basin to the east that hosts the contemporaneous Bushveld Igneous Complex (Beukes, 1990). This lack of a thick hanging wall sequence is thought to be significant for the emplacement of the succeeding mafic sheets.

The ultramafic sheet thermally altered its wallrock (as noted in footwall recrystallized quartzites at 24º 01' 43" E 25º 20' 29" S) and also created a complex fracture system in its hanging wallrocks. Differentiation within the ultramafic sheet produced basal harzburgites overlain by pyroxenites (bronzites) and possibly immediately overlying mafic sheets (previous studies of Gould & others, 1987; Von Gruenewaldt & others, 1989; Reichhardt, 1994). However, other basic sheets and dykes originated from new magma source(s) injected along lines of weakness created by the initial emplacement of the ultramafic sheet. These ‘newer basics’ of the Upper Molopo Farms Complex form a series of laterally impersistant sheets and interconnected feeders that give a distinctive ‘spider’s web’ pattern on the high-resolution airborne magnetic maps. Some mixing of the old and new magma took place as noted in earlier studies and the mixing zone has been the focus of most private sector mineral exploration since the work of Gould & others (1987). Exploration has been based on a Bushveld-type mineralization model (PGEs in cumulate rocks that crystallised from mixed liquids at their basal interface with older magmatic rocks). However, the zone of mixing is clearly not as uniformly developed in the Molopo Farms Complex as it is in the Bushveld Complex and exploration based on looking for a ‘new’ Bushveld type of PGE mineralization is probably not valid.

It is proposed that cooling of the main ultramafic sheet led to gravitational collapse to produce the major ‘basin’ north of the Dikgomodikae Lineament with a c40km E-W diameter and smaller ‘basins’ south of the Lineament. The basic sheets of the Upper Molopo Farms Complex mimic the shapes of the enclosing ‘basins’. The laterally discontinuous nature of mineralization in basic sheets noted by previous exploration (notably by Goldfields) can be attributed to the laterally discontinuous nature of the host rocks.

Dolerite, diorite, syenite and granite, possibly coeval with the Molopo Farms Complex

Discrete areas with noisy magnetic signatures east of the Molopo Farms Complex are interpreted as outcrop areas of syenitic-dioritic intrusions based on logs of borehole from these areas. The largest of these intrusions with an E-W diameter of about 20km is located SW of Jwaneng Mine as a ring structure cored by dolerite. The smallest intrusions with diameters of less than 2km are taken from Tombale (1986).

A small oval shaped magnetic anomaly occurs at 24º 17'S along the eastern margin of the Sheet that is magnetically similar to the East and West Kubung complexes within the outcrop of the Gaborone Granite further to the east described by Aldiss & others (1989). These two eastern complexes are mainly composed of syenite and diorite. The diorites have yielded an Rb-Sr errorchron age of about 2932Ma (Barton in Aldiss & others, 1989).

Drilling has confirmed that the circular body with a diameter of about 5km east of Keng shown by Gould & Rathbone (1988) as a 'Low density body, age and nature uncertain' is granite.

Waterberg Group

Red to purple ferruginous quartzites and siltstones of the Waterberg Group (Crockett & Jones, 1975) are relatively well exposed in a southern half graben, but extremely poorly exposed in the northern part of the Sheet where they are mostly concealed beneath Karoo and Kalahari sediments. Characteristic features of the Waterberg outcrop are large areas with noisy magnetic signatures outlined by sharply defined edge anomalies. Borehole information indicates that mafic sheets within the Waterberg strata cause this characteristic magnetic pattern that is used to define the whole Waterberg outcrop pattern throughout the Kanye Sheet. Jones (1966) notes that intra-Waterberg dolerite sheets in SE Botswana have an undulating morphology, may locally form sheet swarms and commonly have dyke-like apophyses at their margins (possibly to explain the strong edge magnetic anomalies).

Post-Waterberg and pre-Karoo mafic intrusions

Mafic sheets are a characteristic feature of the Waterberg outcrop on the Kanye Sheet to from part of a major Paleoproterozoic intraplate magmatic event of the Kaapvaal Craton, dated by Hanson & others (2004) at between about 1930Ma and 1870Ma, and specifically at 1927Ma for the Moshaneng Dolerite exposed near Kanye. The mafic sheets range from gabbronorite with quartz, through gabbro/dolerite, quartz-gabbro, quartz diorite, quartz monzodiorite and quartz monzonite to melagranodiorite (Gould & others, 1987). Chemically they are all classed as continental tholeiites (Hanson & others, 2004).

Karoo Supergroup –Ecca and Beaufort Groups

Karoo strata are confined to the northern part of the Sheet. Ecca Group strata are found on the southern (upthrown) side of the NE-trending Dikgomodikae Lineament, whereas Ecca and Beaufort Group strata are preserved on the northern side of this regional fault zone. Beaufort Group strata are mostly found on the northern downthrown side of another NE-trending fault some 14km NW of the Dikgomodikae Lineament. The Beaufort-Ecca contact has an overall E-W trend with local offsets controlled by faulting. The rocks lie within the Kweneng area of the 'Southern Belt Central Kalahari Sub-Basin' of Smith (1984), found south of the Zoetfontein Fault. The outcrop pattern suggests that the Karoo strata have gentle northerly dips.

Borehole logs show that the Ecca Group typically comprises a sequence of 'coal measures' of interbanded pale grey to white sandstones, conglomerates, variably carbonaceous, dark grey shales and siltstones and coal seams. (of the Kweneng Formation of Smith, 1984). Green (1966) notes that the E-W ridge (through the south-centre of the Sheet) with little or no Kalahari cover formed a topographical high during Karoo times to mark the southern edge of the Karoo Basin in what is now central Botswana. He noted that coal seams within the Ecca disappear southwards towards the basin margin where arenaceous sediments are dominant. A feature of the Ecca Group appears to be thick sandstone beds, possibly up to about 150m in thickness based on water borehole logs. However, Smith (1984) more accurately records much thinner sandstone beds within a total Ecca Group thickness in the Kweneng area of up to about several hundred metres.

The overlying Beaufort Group (Kwetla Formation) comprises pale grey fine-grained strata that weather to shades of yellow, pink and purplish-browns. Mudstones, shales and siltstones are assigned to the Beaufort Group although in many boreholes it is not possible to separate Ecca from Beaufort lithologies. The maximum thickness of Beaufort Group strata is about 150m.

Late or post-Karoo mafic sheets and dykes

Several WNW-trending dolerite dykes are clearly defined as linear, magnetic anomalies. The longest dyke can be traced for over 100km right across the southern part of the Sheet and continues towards the WNW right across the Mabutsane Sheet The large dykes are disrupted by faults and characteristically splay and split at intervals of about 20km along strike. Mafic sheets are present within the Karoo and were intersected in a number of boreholes. Most of the sheets appear to be less than 20m in thickness although two boreholes are shown as intersecting over 100m of dolerite.

Kimberlites

More than 15 kimberlites have been discovered in the Jwaneng field in the southern half of the Sheet, including the massively economic 2424DK2 pipe that is presently being mined. Unusually for Botswana, at least some of the kimberlites appear to be Permian in age (post-Ecca, pre-Beaufort) based on a radiometric age of 235Ma for 2424DK2 (Kinny & others (1986) quoted in Carney & others, 1994). Others are post-Karoo and ~175Ma in age.

The airborne magnetic data shows that there appears to be a strong tectonic control on the field as a whole as well as on individual pipes. Thus the kimberlite field is aligned parallel to, and immediately south (upthrow side) of the NE-trending Dikgomodikae Lineament, which has clearly influenced kimberlite emplacement. The closely spaced pipes at Jwaneng have a similar NE-trend. Other pipes occur on faults trending NE-SW or ENE-WSW. One pipe (2424DK1) occurs on a NW-SE fault and another pipe (21424DK3) is found at the intersection of this fault with a NE-trending fault.

Kalahari Beds

There is an E-W area up to 20km in width through the southern part of the Sheet eastwards from Moleleme Hill, with bedrock exposure in the east (Tombale, 1986) and progressively thicker Kalahari cover in the west (Gould & Rathbone, 1988). Elsewhere there is up to about 100m of stratified sand, sandstone, clay, gravel, calcrete and silcrete overlying bedrock. Kalahari isopachs are shown on the accompanying map to indicate relatively thin Kalahari cover in the NE, as well as in the SE (across the Jwaneng Sheet; Tombale, 1986).

Economic

Coal: Coal seams up to about 15m in thickness are present in the Ecca Group succession although past exploration programmes have failed to locate economic deposits.

Diamonds: 8.9 million tons of kimberlite was mined at Jwaneng in 2003 that yielded 12.8 million carats of diamonds.

Groundwater: The water requirements of Jwaneng Mine are supplied from a northern well field into Ecca sandstones. Other aquifers include fractured pre-Karoo rocks including Waterberg Group sandstones and Transvaal Supergroup lithologies. Many water boreholes appear to be sited on or next to dolerite dykes. Unconsolidated Kalahari sediments are another potential aquifer.

Industrial Minerals: There is an **a**ggregate quarry into Waterberg strata at Jwaneng and an abandoned aggregate quarry at Kgare Hill. Other isolated hills in the southern part of the Sheet could also provide a local source of road stone. Calcrete has been used in road construction from local borrow pits close to the main roads.

Precious and base metals: Gould & others (1987) note that sulphide mineralization consisting of intergrown pyrrhotite, chalcopyrite and pyrite occurs at several horizons in the lowest 300m of the Lower Molopo Farms Complex. The sulphides are disseminated and never exceed 5% of the rock. They record maximum values of 2000ppm Cu and 4000ppm Ni. The sulphide-bearing horizons contain up to 0.95ppm precious metals. Otherwise Gould & others (1987) failed to find any other signs of potentially economic mineralization. Subsequent exploration has been similarly unsuccessful in locating economic amounts of PGEs, gold or base metals (Chatupa, 1995). Intensive exploration in the eastern part of the Complex since the work of Gould & others (in the first half of the 1980s) by several exploration companies has indicated that any mineralization is discontinuous over very short distances to mimic the discontinuous nature of the host rocks.

The Transvaal Supergroup is prospective for gold and base metals and possibly for skarn-type deposits where dolomites are intruded by major intrusions such as the Molopo Farms Complex or the numerous syenitic-dioritic intrusions around Jwaneng.

References

Carney, JN, Aldiss, DT & Lock, NP. 1994. The Geology of Botswana. Bulletin, Geological Survey of Botswana, 37, 113p.

Chatupa, JC. 1995. Molopo Farms Complex, Botswana – an update on the geology and Ni-Cu-PGE mineralization. Unpublished Report, Geological Survey of Botswana, JCC9/95, 23p.

Crockett, RN & Jones, MT. 1975. Some aspects of the geology of the Waterberg System in eastern Botswana. Transactions, Geological Society of South Africa, 78, 1-10.

Cullen, DJ. 1958. The geology of the Dikgomo di Kae area. Geological Survey of Bechuanaland Protectorate, Records for 1956, 5-11.

Gould, D & Rathbone, PA. 1988. 1:250,000 Geological Map of the Molopo Farms. Geological Survey of Botswana.

Gould, D, Rathbone, PA & Kimbell, GS. 1987. The geology of the Molopo Farms Complex, southern Botswana. Bulletin, Geological Survey of Botswana, 23, 178p.

Green, D. 1966. The Karoo System in Bechuanaland. Bulletin, Geological Survey Department, Government of Bechuanaland, 2, 74p.

Hanson, RE, Gose, WA, Crowley, JL, Ramezani, J, Bowring, SA, Bullen, DS, Hall, RP, Pancake, J & Mukwakwami, J. 2004. Paleoproterozoic intraplate magmatism and basin development on the Kaapvaal Craton. Age, paleomagnetism and geochemistry of ~1.93 to~1.87Ga post-Waterberg dolerites. South African Journal of Geology, 107, 233-254.

Jones, MT. 1966. Geology of the Mochudi and Marico River area (an explanation of quarter degree sheets 2426A&B). Unpublished report, Geological Survey of Botswana, MTJ/37/66, 29p.

Key, RM & Ayres, N. 2000. The 1998 edition of the National Geological Map of Botswana. Journal of African Earth Sciences, 30, 427-451.

Kinny, PD, Williams, IS, Compston, W & Bristow, JD. 1986. Archaean xenocrysts from the Jwaneng kimberlite pipe, Botswana. Fourth International Kimberlite Conference. Geological Society of Australia, Abstract Series, 16, 267-269.

Kruger, FJ. 1989. The geochronology and Sr-isotope geochemistry of the Molopo Farms Complex, Bushveld Magmatic Province: a preliminary report. Unpublished report, Geological Survey Department, Botswana.

Reichhardt F.J. 1994. The Molopo Farms Complex, Botswana: History, Stratigraphy, Petrography, Petrochemistry and Ni-Cu-PGE Mineralization. Exploration & Mining Geology, 3, 263-284.

Smith, RA. 1984. The lithostratigraphy of the Karoo Supergroup in Botswana. Bulletin, Geological Survey of Botswana, 26, 239p.

Tombale, AR. 1986. 1:125,000 geological map of the Jwaneng area. Geological Survey Department, Botswana.

Von Gruenewaldt GL, Behr SH and Wilhelm HJ. 1989. Some preliminary petrological investigations of the Molopo Farms Complex, Botswana, and its Ni-Cu sulphide mineralization. In: MD Prendergast & MJ Jones (eds.), Magmatic Sulphides-The Zimbabwe Volume, Institution of Mining and Metallurgy, London, England, 95-105

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