POST-IMPACT DOLERITE DYKES IN THE ~145 Ma MOROKWENG CRATER, SOUTH AFRICA: IMPACT RELATED? S. Misra[1], M. A. G. Andreoli[2,3], [1]School of Geological Sciences, University of KwaZulu-Natal, Durban-4000, South Africa (misras@ukzn.ac.za), [2] School of Geosciences, University of Witwatersrand, Johannesburg-2050, South Africa; [3]NECSA, P.O. Box 582, Pretoria 0001, South Africa (marco@necsa.co.za).

Introduction: The Morokweng crater, situated in the North-West province of South Africa (Fig. 1), was formed on a target of Archaean crystalline basement (granite and greenstones) and its volcano-sedimentary Proterozoic to Phanerozoic Cover by the impact of a LL-6 chondrite at ~145±2 Ma [1-5]. The actual diameter of the crater, mostly buried under < 70 Ma Kalahari Group continental sediments, sand and calcrete, is still debatable [6, 7]. Our recent observations of combined geophysical and Landsat 7 imagery confirm that the original diameter of the crater (before significant erosion prior to the deposition of the Kalahari Group [8]) ranged between a minimum of ~160 km and a maximum of ~220 ± 20 km [9, 10].

A close examination of the gravity and low to medium resolution airborne magnetic data reveal the presence of several radial faults within the Morokweng crater that subdivide the structure into four distinct sectors (Eastern, Western, Northern and Southern) exposing different stratigraphic levels [10]. The most important radial fault extends in a SSE direction up to a distance of ~200 km from the crater centre and is occupied in its more distal section by the ~100 km long Paddakoor dolerite dyke. In our present study we study the geochemistry of this dyke to evaluate its relationship with the impact. A number of other dykes cutting the central melt sheet (within Ring 1 in Fig. 1) could not be sampled due to extensive Kalahari cover.

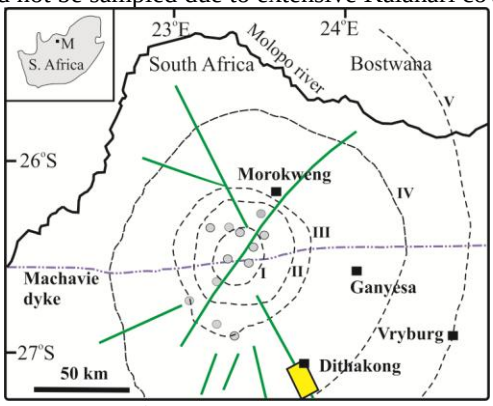

Fig. 1. Sketch map of Morokweng impact structure based on geophysical interpretation [10, 11]. Major structural features include: concentric ring-like structures (I to V), faults (solid lines) and a major E-W dyke (Machavie dyke: dot-dash line), grey circles are boreholes used to study the Morokweng crater [10]. Yellow box indicates present study area.

Sampling and analytical techniques: Five samples of fresh dolerite dyke were collected from outcrops between Reivilo (1 sample) and Dithakong (4 samples), small towns to the southwest of Vryburg (Fig. 1). The major oxides and selected trace elements were analysed at the XRF laboratory (PANalytical), School of Geological Sciences, University of KwaZulu-Natal, Durban, South Africa. We used International rock standards BHVO-1 during analyses of major oxides, and BHVO-1; 2 and BCR-2 for trace elements (V, Cr, Sr, Zr, Ba, Ni, Cu and Zn). Our precision and accuracy of analyses of major oxides and trace elements were better than ±2% and ±12% respectively.

Petrography: Under microscope, the samples of dolerites were found to include both medium and fine grained types. In the former, the laths of plagioclase create ophitic to sub-ophitic texture with anhedral ortho-, and clinopyroxenes and subhedral equant opaques (Fig. 2a). In cases (LMS 20), minor biotite and partly serpentinized olivine are also present. The fine grained variety (LMS 22) is porphyritic with prismatic phenocrysts of clinopyroxene and uralitized orthopyroxene within a fine grained matrix of laths of plagioclase, two pyroxenes and opaques showing interstitial texture (Fig. 2b).

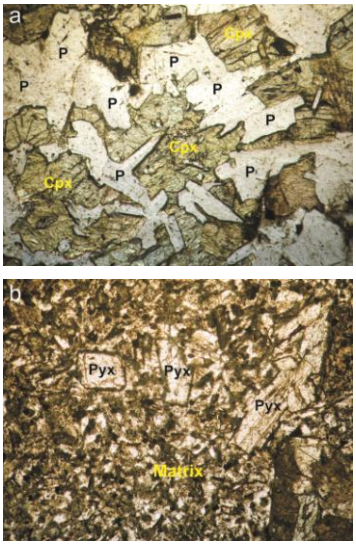

Fig. 2. Photomicrograph of (a) medium grained dolerite dyke showing ophitic to sub-ophitic texture, (b) fine grained mafic dyke showing phenocrysts of pyroxenes within matrix, abbreviations: P- plagioclase, Cpx- clinopyroxene, Pyx- phenocrysts of plagioclase, Matrix- fine grained mafic matrix consisting of laths of plagioclase with interstitial clinopyroxene and opaques, length of photographs-2 mm.

Geochemistry: The average major oxide and selected trace element compositions of Morokweng mafic dykes (Table 1) show that these dykes generally have high SiO_2 (~51 to 59 wt. %) and well within the range

of basaltic andesite to andesite fields [12]. The rocks show wide variations in magnesium number {Mg#-mole MgO/ (mole MgO+ mole FeO^T)}: between 0.47 and 0.68, and in (Na_2O+K_2O): between 2.42 and 5.26. The rocks are characterized by high CIPW normative quartz that varies in a wide range between ~6 and 22 wt%, and orthoclase between ~1.8 and 14 wt%. The normative an/(ab+an) ratio is also low to moderate and shows significant variation between 0.34 and 0.53.

Table 1. Average chemical (on anhydrous basis) and CIPW normative compositions of Morokweng dyke (n=5) from west of Vryburg.

	Average	Normative minerals	Average. proportions
SiO_2 (wt%)	55.65 (4.15)	Quartz (q)	12.87 (6.08)
TiO_2	0.90 (0.25)	Anorthite (an)	19.72 (5.38)
Al_2O_3	12.66 (0.42)	Diopside (di)	11.44 (6.97)
Fe_2O_3	10.73 (2.07)	Sphene (sp)	1.41 (0.97)
MnO	0.17 (0.03)	Hyperthene (hy)	15.31 (7.45)
MgO	8.24 (2.32)	Albite (ab)	19.82 (4.05)
CaO	7.50 (2.42)	Orthoclase (or)	7.55 (5.62)
Na_2O	2.33 (0.48)	Apatite (ap)	0.32 (0.07)
K_2O	1.28 (0.95)	Ilmenite (il)	0.30 (0.18)
P_2O_5	0.14 (0.03)	Hematite (hm)	10.77 (2.07)
	99.60		99.51
LOI	3.22 (2.99)		
V (ppm)	241 (92)		
Cr	479 (232)		
Sr	193 (90)		
Zr	103 (23)		
Ba	310 (135)		
Ni	220 (82)		
Cu	141 (41)		
Zn	104 (30)		

The rocks also contain relatively high incompatible trace elements Sr (110-310 ppm), Zr (88-133 ppm), and Ba (~190- 460 ppm) that are ~2, ~1.4 and ~50 times higher over the average N-MORB [13], along with compatible trace elements Cr (~140-770 ppm) and Ni (~110-305 ppm), which are ~1.8 times higher over average Indian Ocean MORB [14]. However, the average proportion of V in the Morokweng dyke is similar to that of average Indian Ocean MORB. The proportions of average Cu and Zn in the Indian Ocean MORB [14] and upper continental crust [15] are almost similar (~90 ppm), and the average Morokweng dyke has ~1.6 higher Cu over these most abundant terrestrial rock end members.

Discussion: The emplacement of the Machavie (Fig. 1) and Paddakoor dolerite dykes along fractures that are radial to, or at the very centre of the Morokweng impact crater defines them as post-impact and <145 ±2 Ma in age. As such they are significantly younger than and unrelated to the ~ 180 Ma Karoo magmatic cycle in southern Africa. Indeed, the dykes we sampled are distinct from Karoo dykes [16, 17] by their higher SiO_2 and normative quartz (Table 1), which seems to be unusual for any mantle derived mafic dykes.

The Paddakoor dykes samples also contain high normative orthoclase and albite, which together with relatively high SiO_2, Zr and Ba might indicate mixing of sialic crustal components within its parent magma. As crustal contamination cannot increase Cr and Ni proportions in dykes, we propose that the geochemically anomalous signature of these basaltic melts requires the mixing-in of an additional, highly magnesian component such as a LL-chondrite [5] or an Archaean greenstone. A few genetic models could be proposed for these dykes, taking into consideration their medium to fine grain size (Fig. 2) indicative of rapid chilling, and their post-Jurassic, pre-Kalahari (i.e. late Cretaceous) age. Accordingly, the dykes could represent mantle derived tholeiitic melts unrelated to the impact event, yet contaminated by upper continental crust and greenstones while rising though impact-related faults and breccia. A different, testable hypothesis only applies the model above to the dolerite from a quarry 85 km SW of Vryburg (Fig. 1), the most distant from the centre of the impact. Indeed, its composition (LMS 1D- SiO_2: 51.3 wt%; Al_2O_3: 12.8%, $Fe_2O_3^T$: 14.3%; MgO: 6.5 %; CaO: 10%, Na_2O: 2.3%, K_2O: 1.0%, Ni: 110 ppm, Cr: 143 ppm) best compares to a common basalt. By contrast, the samples collected closest to the centre, near Dithakong (see Fig. 1) display the more unusual compositions (LMS28- SiO_2: 59.3 wt%; Al_2O_3: 12.6 %, $Fe_2O_3^T$: 9.5%; MgO: 10.0%; CaO: 4.4%, Na_2O: 2.1%, K_2O: 0.3%, Ni: 307 ppm, Cr: 540 ppm). As such, the dykes could represent impact melts (granite + sediments + greenstones +/- impactor) injected from the now eroded, overlying melt sheet. Further studies on various hypotheses are under progress.

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