Ages of detrital zircon grains from Neoproterozoic siliciclastic rocks in the Shakawe area: implications for the evolution of Proterozoic crust in northern Botswana

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Abstract — The Precambrian rocks of northern Botswana comprise poorly exposed igneous complexes, high-grade metamorphic rocks, as well as sedimentary sequences including mainly siliciclastic and carbonate rocks. New U—Pb SHRIMP data are presented for detrital zircons from siliciclastic rocks collected from the Shakawe area in northern Botswana. These data show three main age groups at *c.* 1020 Ma, 1090 Ma, and 2050 Ma which support contentions for local provenance of the sediments. They also fix the maximum age of the deposition of these siliciclastic rocks at 1020 Ma. The results support field evidence suggesting that the siliciclastic rocks exposed in the Shakawe zone are part of the Ghanzi—Chobe Supergroup.

Introduction

The Neoproterozoic Ghanzi—Chobe Supergroup of Botswana (Figure 1) is a lateral equivalent of the Damara Supergroup of Namibia and the Katangan Supergroup of Congo and Zambia. Sedimentary sequences of the Ghanzi—Chobe Supergroup start with a major basal conglomerate, unconformably overlying older units, such as Kibaran-age bimodal volcanic rocks termed the Kgwebe volcanic sequence (Kampunzu et *al.*, 1998 and references therein). Previous U—Pb zircon dating of the Kgwebe rhyolites yielded an age of 1106 ± 2 Ma (Schwartz *et at.*, 1996) which was taken as the maximum age of the Ghanzi—Chobe Supergroup. However, in Congo, the Katangan Supergroup basal units contain detrital minerals from *c.* 880 Ma granites (Armstrong *et* at., 1999). The basement rocks in the Katangan basin are well exposed and therefore have been extensively documented (Cahen *et at.*, 1984). In contrast, Precambrian rocks are poorly exposed within the Kalahari Desert and therefore the age of crustal terranes in northwest Botswana is still poorly documented. Clastic sedimentary rocks and related detrital zircons can provide powerful information on source regions *(e.g.* Compston and Pidgeon, 1986; Machado *et at.*, 1996). The aim of this paper is therefore to present new SHRIMP U—Pb ages of detrital zircon grains from siliciclastic rocks from northern Botswana and to consider the implications for Proterozoic crustal evolution in the region.

Geological setting and rock description

The Neoproterozoic Ghanzi—Chobe Supergroup includes three terranes from south to north (Figure 1): Ghanzi, Rooibok, and Xaudum (Carney *et* at., 1994; Key and Ayers, 1998). These terranes are tectonically bounded and their lithostratigraphic relationships are still under investigation. Older basement complexes in northern Botswana include: (1) Mesoproterozoic Kibaran-age granitoids (Kampunzu *et at.*, 1999) and a bimodal volcanic sequence termed the Kgwebe metavolcanic rocks (Kampunzu *et* at., 1998). Small bodies and dykes of Mesoproterozoic granitoids have been discovered at the southwest margin of the Zimbabwe Craton in eastem Botswana (Van de Wel *et* at., 1998), but their link with the Kibaran-age rocks reported here is not known. (2) Palaeoproterozoic rocks with U—Pb zircon ages of c. 2.05 Ga. These rocks are granitoids and rhyolites in the Okwa valley, western Botswana (Ramokate *et* at., 2000), granitoids in the Qangwa area, northern Botswana (Hanson *et al.*, 1998a), and granulite-facies rocks including kizingitic garnet—sillimanite gneiss in the Gweta region, northeast Botswana (Mapeo, R.B.M., Armstrong, R.A. and Kampunzu, A.B., unpublished data).

The clastic sedimentary rock sample selected for U—Pb SHRIMP zircon investigation, IPP-97/1, was collected from a pit dug for water in the Shakawe area (Figure 1; GPS co-ordinates *18°23’50’*S, 21°17’25.6”E). Rocks recovered from various pits in the area represent supracrustal siliciclastic sequences of immature sedimentary rocks (mainly conglomeratic sandstones and arkosic sandstones) associated with more mature sedimentary rocks (grey sandstones, siltstones, and shales). Cross bedding has been observed in several samples. None of the rocks show evidence of metamorphism, which suggests that these siliciclastic rocks could be part of the Ghanzi—Chobe Supergroup. A strong tectonic fabric (mylonitic foliation and related lineation) has been observed in some samples from burrow pits and open wells, but we were not able to document the geometry and the geographic extent of this fabric due to absence of outcrops.

The sample IPP-97/1 selected for dating is an immature coarse arkosic sandstone. The rock is medium to coarse grained in texture with layering defined by graded bedding. It contains angular fragments of monocrystalline and polycrystalline quartz (lithic fragments), subhedral feldspar (mainly plagioclase), haematite, zircon, titanite, and epidote grains. Epidote is formed from the breakdown of feldspars and is localized along fractures. The rock is highly fractured with a well-defined proto-mylonitic fabric, with secondary micas developed along the shear bands. The occurrence of abundant subhedral feldspar grains along with angular quartz implies relatively short sedimentary transport distances. Therefore, we infer that the age of detrital zircons in this sample should

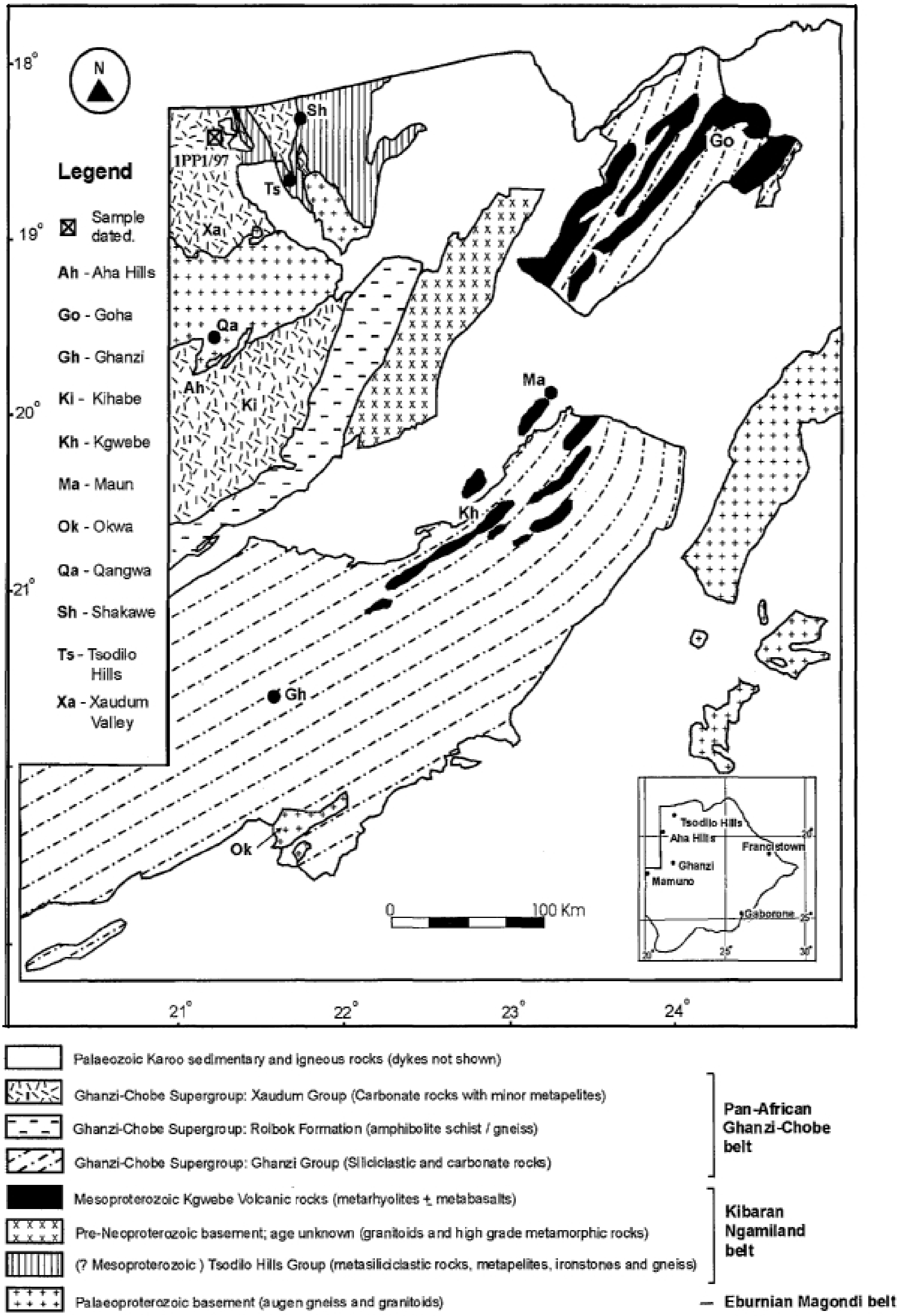

Figure 1 Geological map of northern Botswana, modified from Camey *et al.* (1994) and Key and Ayers (1998).

mainly constrain the age of the local crustal source of these clastic sedimentary rocks.

Analytical techniques

The sample was crushed and the zircons separated using standard heavy liquid and Frantz isodynamic separation techniques in a clean laboratory. The final concentrate was hand-picked under a binocular microscope and the zircon grains were mounted in epoxy together with the zircon standard AS3 (Duluth Complex gabbroic anorthosite; Paces and Miller,

1989) and the standard SL13 of the Research School of Earth Sciences, Australian National University. The grains were then sectioned approximately in half, polished and photographed. Cathodoluminescence imaging on a scanning electron microscope was carried out prior to the analyses to aid in the selection of the best target areas for the analyses. The SHRIMP data have been reduced in a manner similar to that described by Williams and Claesson (1987) and Compston *et al.* (1992). U/Pb in the unknowns were normalized to a ^{206}Pb*/^{238}U value of 0.1859 (equivalent to an age of 1099.1 Ma) for AS3. The U and Th concentrations were determined relative to those measured in the SL 13 standard. Ages were calculated using the radiogenic ^{207}Pb/^{206}Pb ratios, with the correction for common Pb made using the measured ^{204}Pb and the appropriate common Pb composition, assuming the model of Cumming and Richards *(1975).* Uncertainties in the isotopic ratios and ages in the data table (and in the error boxes for the plotted data) are reported at the 1σ level, but unless otherwise stated in the text, the final weighted mean ages are reported as *95%* confidence limits, with all statistical analyses and calculations done using the Isoplot/Ex software (Ludwig, 1998).

Results

The sample yielded abundant zircon grains which are generally light pink in colour and of variable shape and form. Few grains have sharp crystal faces preserved. More commonly, zircon grains have slightly rounded terminations but with quite well-preserved crystal forms and angular shape (Figure 2). Many of the mounted angular grains are fragments of originally larger crystals. The form and shape of the zircon grains support a short sedimentary transport distance of the grains and provenance from a source area close to the basin, as inferred above on the basis of the angular shape of quartz crystals and the preservation of a large amount of subhedral feldspar. There are no metamorphic multifaceted grains in the population of zircons. Cathodoluminescence imaging shows that most of the zircons have very well-developed compositional zoning, consistent with an igneous origin. Cores of inherited zircon are also common. A second discrete population of zircons were found during analysis (see below), these being impossible to detect petrographically as they also have good igneous zoning, similar to the zircons of the first group (Figure 2).

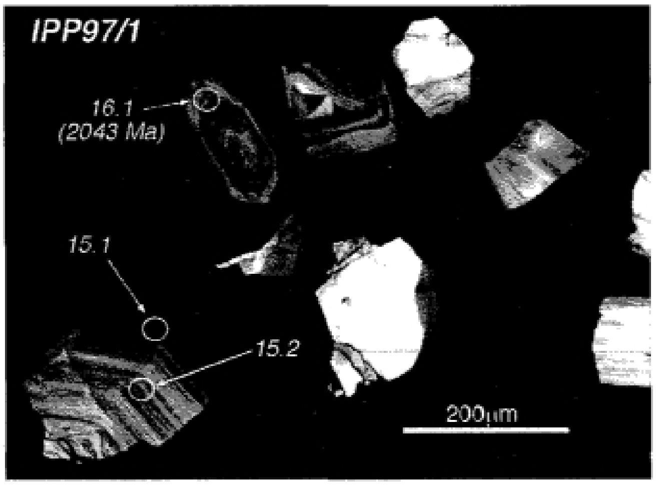

Figure 2 Cathodoluminescence images of a selection of zircons from sample IPP-97t1. The numbers refer to the analysis as recorded in Table 1. Note the typical magmatic zoning preserved in grains 15 and 16. Analysis 15.1 yields a Mesoproterozoic age whereas analysis 16.1 gives a Palaeoproterozoic age.

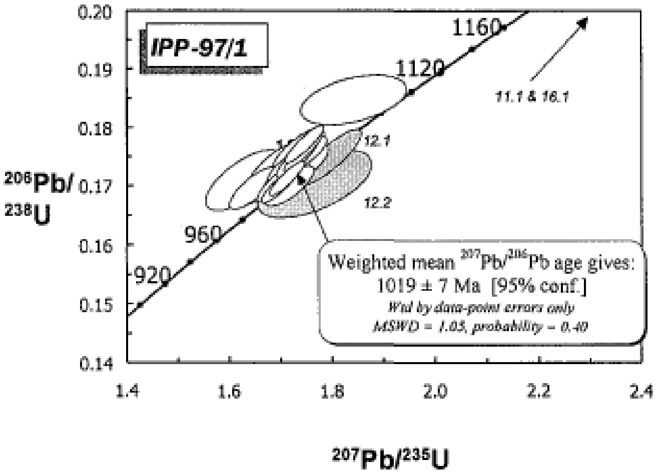

Figure 3 U—Pb concordia plot of SHRIMP analyses for sample IPP-97/I. The analyses of the Palaeoproterozoic detrital zircons plot off-scale on this diagram. These analyses, as well as the two analyses from grain 12 (12.1 and 12.2), were excluded from the age calculation. The concordia is calibrated in Ma.

Twenty-five analyses were done on sixteen different grains to get a comprehensive picture of the zircon geochronology. The sample was analysed on SHRIMP II and all results are reported in Table 1 and are plotted on a standard Wetherill U—Pb concordia diagram in Figure 3.

The zircons show a large range in U and Th concentrations and isotopic compositions, but statistical analysis of the data permits the identification of sub-populations within the sediment. The majority of the analyses plot on concordia with ^{207}Pb/^{206}Pb ages falling into a narrow range between 936 ±44 Ma and 1056 ±23 Ma (1σ errors). These can be combined as a group with a statistically robust weighted mean ^{207}Pb/^{206}Pb age of 1019 ±7 Ma (N 21; MSWD = 1.05; Prob. = 0.40). Whether or not there are two or more sub-populations within this group of analyses is impossible to determine from this data set, as there are no obvious physical or geochemical criteria for identifying such sub-populations. In calculating a maximum age of sedimentation for this rock, there are two possibilities, namely the maximum age of the sediment is given by the youngest zircon analysed (936 ±88 Ma; 2σ), or, if all the zircons do indeed come from a single population, then the maximum age is given by the weighted mean ^{207}Pb/^{206}Pb age of 1019 ±7 Ma (2σ). In the discussion of the maximum age of sedimentation we use this weighted mean, rather than the age of a single analysis which is an unreliable constraint.

A number of analyses fall outside this age group. The two analyses on grain 12 represent a second source of detrital zircons which are slightly older than the main group but are still of Mesoproterozoic age. The weighted mean ^{207}Pb/^{206}Pb age for repeat analyses on this grain gives 1088 ±44 Ma (2σ uncertainties). Analyses 11.1 and 16.1 clearly show that there is a third, Palaeoproterozoic population of detrital zircons

Table 1 Summary of SHRIMP U–Th–Pb zircon results for sample IPP-97/1

Grain	U	Th		Pb*	^{204}Pb/	f206	Radiogenic Ratios						Ages (in Ma)						
spot	(ppm)	(ppm)	Th/U	(ppm)	^{206}Pb	%	^{206}Pb/^{238}U	±	^{207}Pb/^{235}U	±	^{207}Pb/^{206}Pb	±	^{206}Pb/^{238}U	±	^{207}Pb/^{235}U	±	^{207}Pb/^{206}Pb	±	Conc. %
1.2	1090	389	0.36	193	0.00005	0.08	0.1740	0.0028	1.761	0.030	0.0734	0.0003	1034	15	1031	11	1025	9	101
1.3	804	456	0.57	145	0.00004	0.07	0.1687	0.0019	1.714	0.024	0.0737	0.0005	1005	11	1014	9	1033	13	97
2.2	97	81	0.84	19	0.00009	0.15	0.1702	0.0022	1.718	0.038	0.0732	0.0012	1013	12	1015	14	1019	34	99
3.2	120	154	1.29	28	0.00033	0.586	0.1840	0.0029	1.864	0.070	0.0735	0.0024	1089	16	1069	25	1028	67	106
3.3	188	210	1.12	40	0.00005	0.09	0.1745	0.0020	1.767	0.029	0.0734	0.0008	1037	11	1033	11	1025	21	101
4.1	107	154	1.44	24	0.00020	0.335	0.1723	0.0024	1.735	0.046	0.0730	0.0015	1025	13	1021	17	1015	43	101
5.1	185	147	0.80	36	0.00014	0.257	0.1750	0.0026	1.751	0.033	0.0726	0.0007	1040	14	1028	12	1002	21	104
6.1	90	84	0.94	18	0.00007	0.119	0.1724	0.0028	1.748	0.043	0.0736	0.0013	1025	15	1026	16	1029	35	100
7.1	298	264	0.89	60	0.00007	0.116	0.1736	0.0022	1.750	0.027	0.0731	0.0005	1032	12	1027	10	1017	15	102
7.2	267	223	0.83	51	0.00008	0.13	0.1683	0.0024	1.663	0.032	0.0716	0.0008	1003	13	994	12	976	22	103
8.1	335	231	0.69	65	0.00005	0.093	0.1761	0.0022	1.766	0.026	0.0727	0.0004	1046	12	1033	9	1006	12	104
8.2	237	147	0.62	43	0.00007	0.12	0.1686	0.0024	1.671	0.033	0.0719	0.0008	1004	13	998	13	983	24	102
9.1	632	602	0.95	130	0.00003	0.054	0.1746	0.0022	1.763	0.025	0.0732	0.0004	1037	12	1032	9	1020	10	102
9.2	300	468	1.56	69	0.00002	0.03	0.1712	0.0024	1.725	0.029	0.0731	0.0006	1019	13	1018	11	1017	16	100
10.1	271	288	1.06	57	0.00005	0.088	0.1739	0.0033	1.744	0.038	0.0728	0.0006	1033	18	1025	14	1007	17	103
10.2	296	292	0.99	59	0.00001	0.02	0.1687	0.0023	1.736	0.033	0.0746	0.0008	1005	13	1022	12	1058	23	95
11.1	201	134	0.67	86	0.00004	0.074	0.3771	0.0047	6.595	0.089	0.1269	0.0005	2063	22	2059	12	2055	7	100
12.1	89	95	1.07	19	0.00001	0.017	0.1740	0.0032	1.815	0.041	0.0757	0.0008	1034	18	1051	15	1086	23	95
12.2	82	96	1.18	17	0.00048	0.81	0.1693	0.0039	1.784	0.076	0.0764	0.0025	1008	22	1040	28	1106	67	91
13.1	284	154	0.54	52	0.00015	0.25	0.1722	0.0027	1.709	0.037	0.0719	0.0009	1024	15	1012	14	984	26	104
14.1	285	243	0.85	56	0.00009	0.16	0.1723	0.0022	1.737	0.030	0.0731	0.0007	1025	12	1022	11	1018	21	101
14.2	486	241	0.50	87	0.00001	0.02	0.1700	0.0020	1.731	0.023	0.0738	0.0004	1012	11	1020	9	1037	12	98
15.1	609	451	0.74	115	0.00004	0.07	0.1694	0.0022	1.712	0.028	0.0733	0.0006	1009	12	1013	10	1023	16	99
15.2	166	153	0.92	33	0.00020	0.34	0.1698	0.0035	1.645	0.052	0.0703	0.0015	1011	19	987	20	936	44	108
16.1	220	108	0.49	90	0.00000	0.01	0.3754	0.0052	6.520	0.098	0.1260	0.0006	2055	24	2049	13	2043	8	101

Notes: (1) Uncertainties given at the 1σ level. (2) f206 % denotes the percentage of ^{206}Pb that is common Pb. (3) Correction for common Pb made using the measured ^{204}Pb. (4) For % Conc., 100% denotes a concordant analysis giving $^{207}Pb/^{206}Pb$ ages of 2055 ±14 Ma and 2043 ±16 Ma respectively (2σ).

Geological implications

This study was conducted on a sample of immature, coarse arkosic sandstone composed of angular quartz and abundant subhedral feldspar grains. These features presumably indicate a short sedimentary transport distance of the grains. This is supported by the form and shape of detrital zircon grains extracted from sample IPP-97/1, and consequently provenance from a source area close to the basin is inferred for these siliciclastic rocks and the studied detrital zircons. Therefore, the U—Pb zircon ages presented in this paper could constrain the age of the main zircon-bearing lithologies in the local crustal source area of these clastic sedimentary rocks. The detrital zircons include three major populations, one of Palaeoproterozoic age at *c.* 2.05 Ga and two of Mesoproterozoic age at *c.* 1.09 Ga and 1.02 Ga. Assuming that these ages represent the whole spectrum of zircon-bearing lithologies in the provenance area of the sediments, these data indicate the presence of Palaeoproterozoic and Mesoproterozoic basement complexes in that region. The basement complex exposed in northern Botswana is known to include rocks with U—Pb zircon ages fitting into these two groups and this provides support for the contention that the sediments were sourced locally. The dominant source of detrital zircons in these siliciclastic rocks comprises rocks with ages between 1.1 and 1.0 Ga. Igneous rocks emplaced during this time range are part of the late Kibaran igneous event which represents a major crust-forming period in sub-equatorial Africa (e.g. Thomas and Eglington, 1990; Cornell *et al.,* 1996; Hanson *et al.,* l998b; Kampunzu *et al.,* 1998; 1999; Wareham *et al.,* 1998). The absence within the zircon populations of Mesoproterozoic zircon within the age range 1.4 – 1.25 Ga (early-Kibaran-age event) is important to stress. Granitoids with zircon ages in this range are known in central and southern Africa, namely in the Choma—Kalomo block in southwest Zambia (Hanson et *al.,* 1988), in the Katangan province in southeast Congo (Cahen et *al.,* 1984), and in the Rehoboth area in Namibia (Hoal *et* al., 1989; Ziegler and Stoessel, 1993; Hoal and Heaman, 1995). The absence of Archaean zircon grains is also noteworthy. Either early Kibaran and Archaean rocks do not exist in northwest Botswana or they were not exposed to erosion during the deposition of the siliciclastic rocks located in the Shakawe area.

U—Pb detrital zircon studies around the world have shown that the youngest detrital zircon in clastic sedimentary rocks provides an older limit to deposition of the sedimentary sequence in the basin *(e.g.* Armstrong et *al.,* 1990; Krogh and Keppie, 1990). The youngest zircons analysed have an age of *c.* 1020 Ma, taken to provide the maximum age of deposition for the sedimentary sequence exposed in the Shakawe zone. Therefore, the deposition of these rocks happened after *c.* 1020 Ma and before 530 Ma, which is the age of the last deformation event within the Ghanzi—Chobe belt (Ramokate et *al,* 2000). This time range indicates that the siliciclastic rocks in the Shakawe zone are part of the Neoproterozoic Ghanzi—Chobe Supergroup sequence. This age range is broadly similar to that for deposition of sedimentary rocks in the Katangan belt. Therefore, our data support the correlation between the adjacent Neoproterozoic Ghanzi—Chobe and Katangan basins (Kampunzu and Cailteux, 1999), and provide a good basis for a regional correlation of Neoproterozoic basins in central and southwestern Africa.

Conclusions

This study on detrital zircon grains of an arkosic sandstone from the Shakawe zone shows that: (1) the maximum age of deposition of the sediments studied is *c.* 1020 Ma, whereas the minimum age is set by the last deformation event in the region at *c.* 530 Ma. These data imply that the siliciclastic rocks in the Shakawe zone are part of the Ghanzi—Chobe Supergroup; (2) the age spectrum of the detrital zircons enable the identification of two major crustal units as the source of the sedimentary rocks. A Palaeoproterozoic crustal component with U—Pb zircon age of *c.* 2.05 Ga and a late-Kibaran age component with U—Pb zircon age between *c.* 1.1 – 1.0 Ga. These results are consistent with a local origin for the sediments because the pre-Neoproterozoic basement exposed in northern Botswana includes Palaeoproterozoic and late Mesoproterozoic rock assemblages. The absence of both early Kibaran (1.4 – 1.25 Ga) and Archaean detrital zircons is taken to suggest the absence of (exposed) rocks of these ages in northern Botswana during the deposition of the Neoproterozoic siliciclastic rocks in the Shakawe zone.

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