Evolution of the Namaqua-Natal Belt, southern Africa – A geochronological and isotope geochemical review

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Abstract

Juvenile crust formation within the Namaqua-Natal Belt occurred during two principal periods at ∼1.4 and ∼2.2 Ga with little evidence for significant contributions from older crustal sources. Palaeoproterozoic lavas and associated calc-alkaline granitoids are preserved in the Richtersveld sub-province and, to a much lesser extent, in the Bushmanland sub-province. Development of crust within the Aggeneys and Okiep terranes of the Bushmanland sub-province during the Mesoproterozoic involved significant reworking of pre-existing Palaeoproterozoic lithosphere, whereas the Garies terrane (Bushmanland sub-province) and the Gordonia and Natal sub-provinces show little or no reworking of older protoliths.

Deformation of Archaean components is evident near the south-western margin of the Kaapvaal Craton but there is no evidence for a significant Eburnean (∼1.8 Ga) orogeny in the Kheis sub-province. Rather, the 'Kheisian' fabric is now dated as younger than ∼1.3 Ga, and is thus an early phase of the Mesoproterozoic evolution of the Namaqua-Natal Belt. Graben formation with associated extrusion of lavas and deposition of sediments of the Koras Group occurred relatively early in the history of the Belt, predating most of the intrusive granitoid activity evident in other sub-provinces.

Early, juvenile, dominantly mafic to intermediate Mesoproterozoic igneous units formed at ∼1.2–1.3 Ga in the Gordonia and Natal sub-provinces. Two major periods of granitoid intrusion occurred at ∼1.15 and ∼1.03–1.08 Ga and were both of regional extent. The Little Namaqualand Suite intruded at ∼1.15 Ga in the Bushmanland sub-province, as did various individual plutons in the Gordonia and Natal sub-provinces. Spektakel, Keimoes and Oribi Gorge Suite granitoids, often megacrystic in character, were emplaced at ∼1.03–∼1.08 Ga. These latter granitoid suites each span several structural terranes, indicating that accretion of these domains was essentially complete by ∼1.03 Ga. Igneous activity as part of the Namaqua-Natal orogenesis was concluded by ∼1.0 Ga throughout the belt. Subsequent ∼0.85–0.75 Ga magmatism, evident only in the west, reflects the start of a new cycle which ultimately produced the Damara and Gariep belts.

The dominant, penetrative regional fabric was produced prior to peak metamorphism at ∼1.02–1.04 Ga. Limited geochronological evidence also records an earlier phase of high-grade metamorphism at ∼1.16 Ga in both the western and eastern sectors of the Belt. Transcurrent shearing is dated at ∼1.06–1.03 Ga in the Natal sub-province. Equivalent shearing, although not directly dated, also occurred in the west as a result of indentor tectonics produced by collision with the Kaapvaal Craton. Subsequent exhumation and cooling of the rocks of the Namaqua-Natal Belt resulted in temperatures as low as ∼350 °C by ∼0.95 Ga. Except in the Gariep Belt and its foreland in the west, there is little evidence for subsequent, Pan-African overprinting or activity within the Namaqua-Natal Belt.

The age of the supracrustal gneisses remains contentious. Early, ∼2 Ga metavolcanics and metasediments in the Richtersveld sub-province are presumably also present in parts of the Bushmanland sub-province because granitoids of that age occur in both sub-provinces. The Koeris amphibolites from the Bushmanland Group have provided a ∼1.65 Ga Sm–Nd date, whereas supracrustal gneisses in the Garies terrane (Bushmanland sub-province), Gordonia sub-province and Natal sub-province have provided ∼1.2 to ∼1.3 Ga dates. It therefore seems likely that supracrustal lithologies were deposited during at least three intervals as the Namaqua-Natal Belt developed.
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1. Introduction

Minerals preserving evidence for Mesoproterozoic metamorphic activity in South Africa were first recognised in the 1950s, and their regional significance was documented by Nicolaysen and Burger (1965) when they reported ∼1000 Ma radiometric dates from high-grade gneisses and granitoids in Namaqualand and Natal. Despite the wide separation of these two areas with intervening Phanerozoic cover (Fig. 1), Nicolaysen and Burger (1965) proposed the existence of a single Namaqua-Natal metamorphic belt. Subsequent regional geophysical studies (De Beer and Meyer, 1984) and geochronological investigations of lithologies intersected in deep boreholes which penetrated the Phanerozoic cover (Eglington and Armstrong, 2003, and references there-in) have proven the existence of a contiguous belt along the southern margin of the Kaapvaal Craton (Fig. 1).

Whilst the northern margin of the Namaqua-Natal Belt is reasonably well-defined by geological, geophysical and geochronological studies, the southern boundary is still subject to debate. The deep crustal Beattie geophysical anomaly and associated Southern Cape Conductive Belt have been interpreted as marking the southern limit of the belt (De Beer and Meyer, 1984; Pitts et al., 1992; Eglington et al., 1993) but other, similar, geophysical anomalies occur south of the Beattie Anomaly, prompting alternative viewpoints that the Belt extends further south (Du Plessis and Thomas, 1991). Geochronological data from some plutons of the Cape Granite Suite, situated well south of the Beattie Anomaly, indicate that these granitoids contain inherited zircons up to about 2 Ga in age [unpublished data from National Physical Research Laboratory (NPRL), CSIR (previously Council for Scientific and Industrial Research)], possibly supporting the latter view.

Easterly extensions of the Namaqua-Natal Belt occur offshore on the Agulhas Plateau (Allen and Tucholke, 1981), in the Falkland Islands (Thomas et al., 2000), Western Dronning Maud Land, Antarctica (Groenewald et al., 1991) and the Mozambique Belt (Grantham et al., 2003). To the west, the Namaqua-Natal Belt has been traced across southern Namibia, in the Awasib Mountain Land, and lithologies of similar age also occur along the southern margins of the Damara Belt (Becker et al., 2006), in Botswana (Singletary
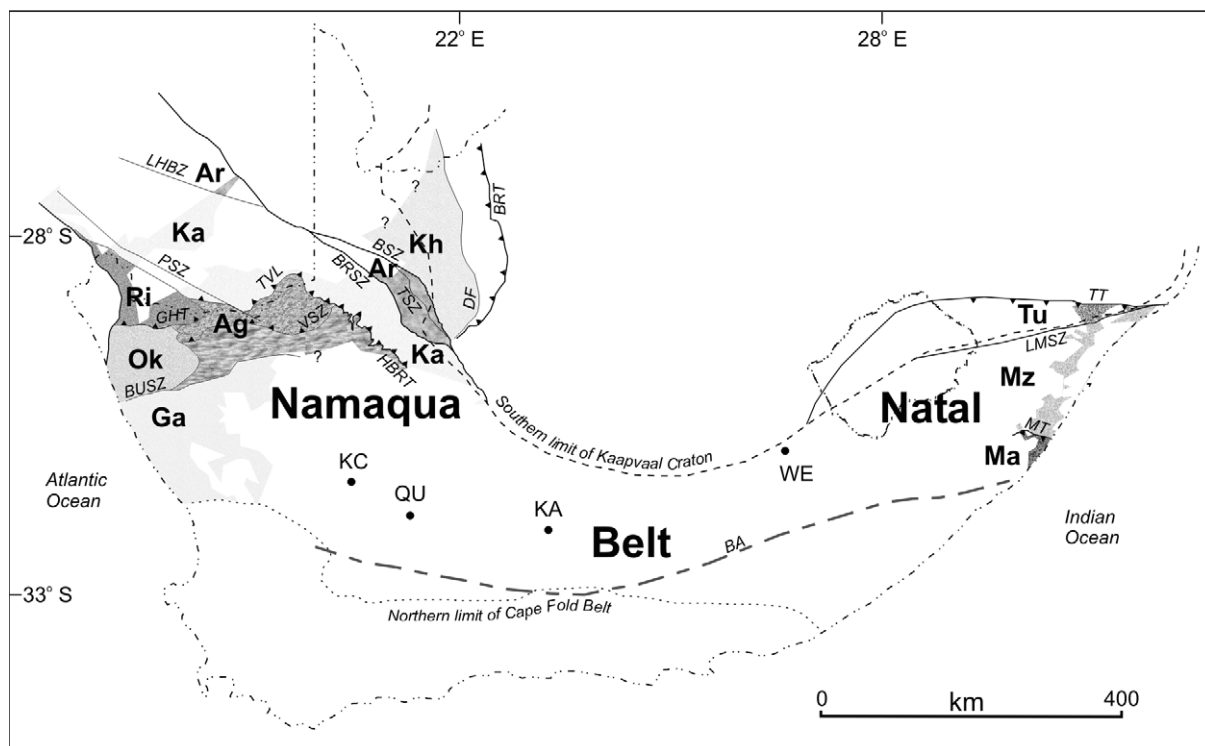

Fig. 1. Regional extent of the Namaqua-Natal Belt (various patterns) relative to the Archaean Kaapvaal Craton and the Phanerozoic Cape Fold Belt. Principal deep borehole intersections are also indicated (KC, QU, KA and WE), as are the sub-provinces and terranes comprising the Belt. Ri – Richtersveld sub-province; Bushmanland sub-province: Ag – Aggeneys terrane, Ga – Garies terrane, Ok – Okiep terrane; Gordonia sub-province: Ar – Areachap terrane, Ka – Kakamas terrane; Kh – Kheis sub-province; Natal sub-province: Ma – Margate terrane, Mz – Mzumbe terrane, Tu – Tugela terrane. Thrusts, faults and shear zones: BA – Beattie anomaly, BRSZ – Bovenrugzeer shear zone, BRT – Blackridge thrust, BSZ – Brakbosch shear zone, BUSZ – Buffels River shear zone, DF – Dabep fault, GHT – Groothoek thrust, HBRT – Hartbees River thrust, LHBZ – Lord Hill Boundary Zone, LMSZ – Lilani-Matigulu shear zone, MT – Melville thrust, PSZ – Pofadder shear zone, TSZ – Trooilapspan shear zone, TT – Tugela thrust, TVL – Tantalite Valley line, VSZ – Vogelstruislaagte shear zone.

et al., 2003) and in southern Zambia (Hanson et al., 1988). Regional compilations and comparisons of Mesoproterozoic belts of southern and central Africa have traditionally referred to these belts as "Kibaran" (Thomas et al., 1994) but more recent work has demonstrated that igneous and metamorphic activity within the Kibaran Belt itself is older than the typical ~1.0–1.2 Ga ages of the Namaqua-Natal Belt (Tack et al., 2002). Fig. 2 illustrates the geochronological emplacement history for igneous lithologies from the principal Mesoproterozoic belts of Africa and Antarctica relative to those of the Namaqua-Natal Belt.
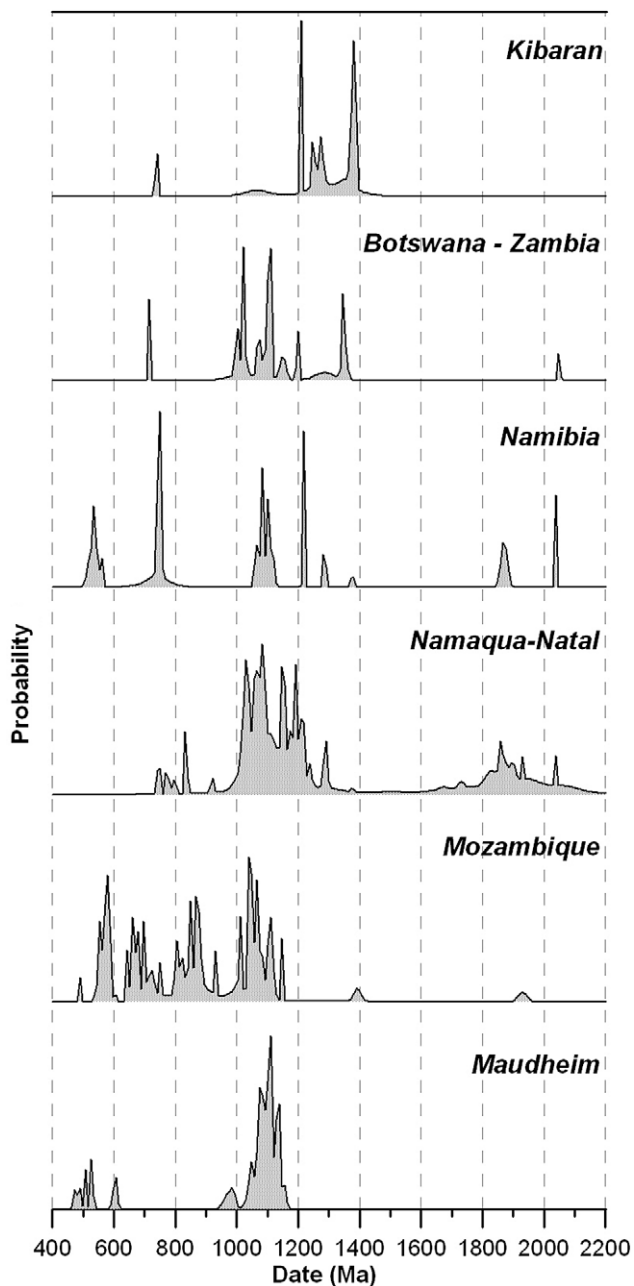

Fig. 2. Probability distribution of emplacement dates (see text for definition) from the Namaqua-Natal Belt relative to dates from potential correlatives in Namibia, Botswana, central Africa and Antarctica for the period from 2200 Ma to 400 Ma.

Various geological, geophysical and geochronological studies have identified several tectonically distinct domains within the Namaqua-Natal Belt, exhibiting dates ranging from Archaean to Neoproterozoic. Most, however, record activity from the mid-Palaeoproterozoic to Mesoproterozoic. For the purposes of the present summary, the structural classifications of Hartnady et al. (1985) and Thomas et al. (1994) have been adopted for the western (Namaqua) portion of the Namaqua-Natal Belt whereas that of Thomas (1994) is followed for the eastern (Natal) exposures. Major features and boundaries of the terranes and sub-provinces are summarised in Table 1 and illustrated in Fig. 1. It should be noted, however, that the structural subdivision of the western (Namaqua) sector of the Namaqua-Natal Belt is far from unequivocal, as is evident from comparison of the subdivisions published by Joubert (1986), Hartnady et al. (1985), and Thomas et al. (1994).

2. Data coverage

Data for this review were taken from a web version of the DateView geochronology database (Eglington, 2004), which also contains references to original sources of the information. Records within this database, classified as representing igneous emplacement, high temperature metamorphism (>500 °C) or cooling (<500 °C), have been used to produce summary graphs, generally presented as probability density functions. These probability density functions emphasise periods with either more precise or more frequent activity (see Eglington and Armstrong, 2004 for an illustration of the methodology). Most emplacement dates are based on modern U–Pb zircon dating because comparative studies of different isotope systems within the Belt have demonstrated that Rb–Sr, Sm–Nd and Pb–Pb whole-rock dates frequently reflect later disturbance (Eglington and Armstrong, 2004). Whole-rock dates are used only where no U–Pb zircon or monazite dates are available or where whole-rock dates have been demonstrated as equivalent to U–Pb dates. Dating of high-temperature metamorphism is generally based on U–Pb zircon and monazite or Ar–Ar hornblende analyses, whereas lower temperature (cooling) dates are derived from Rb–Sr, Ar–Ar and K–Ar dating of minerals such as micas or fission track dating of titanite. DateView currently contains >23,000 records, of which 750 are relevant to the Namaqua-Natal Belt and a further 940 to the other Mesoproterozoic belts with which comparisons are drawn.

Fig. 3 illustrates the variable coverage of geochronological data for the various sub-provinces comprising the Namaqua-Natal Belt. The Bushmanland and Natal sub-provinces have been most studied, particularly using modern zircon U–Pb techniques, hence the greater number of emplacement and metamorphic dates reported. Zircon-based investigations within the Gordonia and Kheis sub-provinces are notably limited and modern U–Pb dating of lithologies in the Richtersveld sub-province is also not available.

Table 1
Summary of tectonic subdivisions applied in the current compilation

Sub-province	Terrane	Major geological features
Richtersveld		
	Not subdivided	Calc-alkaline lavas and granitoids. Thrust southwards over the Aggeneys terrane along the Groothoek thrust. Boundary with Kakamas terrane is mostly obscured by late shearing along the Pofadder lineament
Bushmanland		
	Aggeneys	Para- and orthogneisses, metavolcanics, granites. Significant stratiform mineralisation. Several phases of deformation, including early S-vergent recumbent folds and thrusts and late NW dextral shear zones. Boundary with the Kakamas terrane is defined by the Hartbees River thrust
	Okiep	Para- and orthogneisses, voluminous granites and charnockites. Significant Cu mineralisation associated with 'steep' structures. Several phases of deformation, including early S-vergent recumbent folds and thrusts and late NW dextral shear zones. Boundary with the Garies terrane occurs at the Buffels River shear zone. Poorly defined boundary with the Aggeneys terrane
	Garies	Para- and orthogneisses, voluminous granites and charnockites. Several phases of deformation. Southern boundary not known
Gordonia		
	Kakamas	High-grade supracrustal gneisses, charnockites and granites. Early SW-vergent thrusts and late NW, dextral shear zones. Boundary with the Areachap terrane is defined by the Bovenrugzeer shear zone
	Areachap	Transitional zone between high-grade gneisses of the Kakamas terrane and low-grade metasediments and metavolcanics of the Kheis sub-province. NE-vergent folding and thrusts, late NW, dextral shearing. Boundary with the Kheis sub-province is defined by the Brakbosch and Trooilapspan shear zones and faults
Kheis		
	Not subdivided	Thin-skinned fold and thrust belt. Quartzite, phyllite and metabasalt. Eastern limit of the Kheis sub-province is the Dabep fault
Natal		
	Tugela	Dominantly mafic to intermediate supracrustal gneisses and mafic metavolcanics. Some granitoids. N-vergent folding and thrusting of multiple thrust sheets onto the Kaapvaal Craton. Southern contact with the Mzumbe terrane is the Lilani-Matigulu shear zone, which also marks the southern edge of the Kaapvaal Craton
	Mzumbe	Voluminous granitoids, various supracrustal gneisses. Early N-vergent folds, late NE sinistral shearing. Boundary with the Margate terrane is the Melville thrust
	Margate	Voluminous granitoids and charnockites, various supracrustal gneisses and granulites. Early N-vergent folds, late NE sinistral shearing. Southern boundary not known

Subdivisions and features generally follow Hartnady et al. (1985), but with more recent nomenclature of Thomas et al. (1994).

Fig. 4 illustrates the number of Rb–Sr and Sm–Nd records stored in DateView. Rb–Sr records include isochron regressions, mineral model ages and initial $^{87}Sr/^{86}Sr$ data (in cases where isochron results are not available) for individual units. Sm–Nd records include isochron regressions where available, but mostly comprise model initial (and epsilon) values averaged for individual units. As with the geochronological information (Fig. 3), disparate coverage of lithologies in the different sub-provinces of the Namaqua-Natal Belt is evident.

3. Comparative geochronology

The Richtersveld sub-province straddles the boundary between South Africa and Namibia and comprises a suite of supracrustal sedimentary and volcanic lithologies which formed at ~2 Ga and were intruded by the Vioolsdrif granitoids during the period ~2 to ~1.75 Ga (Reid et al., 1987b). Rocks within this domain range from very low metamorphic grade in the core of the Vioolsdrif batholith to amphibolite grade at the margins (Joubert, 1986; Thomas et al., 1994). Geochronological data for the domain

are principally concentrated in the late Palaeoproterozoic and Neoproterozoic. Unfortunately, no modern U–Pb zircon data have been published for the various Palaeoproterozoic rocks of this area, and evidence for the two-stage intrusion of the granitoids is based on the concordance of multiple whole-rock isotope systems and limited older bulk-population U–Pb zircon dating (Reid, 1982; Kröner et al., 1983). No geochronological evidence exists for intrusive activity within the Richtersveld sub-province coeval with the Mesoproterozoic activity elsewhere in the Namaqua-Natal Belt (Fig. 5), but outcrops of Aroams Gneiss, dated at ~1.15 Ga in the Bushmanland sub-province (Armstrong et al., 1988; Pettersson et al., 2004), have been reported from within the southern Richtersveld sub-province (Moore et al., 1990). Igneous activity resumed at ~0.85 Ga with the intrusion of the Richtersveld Igneous Complex in what is considered to be the start of a new, post-Namaquan orogenic cycle (Frimmel et al., 2001). Supracrustal sediments and volcanics overlying the Palaeoproterozoic lithologies preserve extrusion ages of ~0.75–0.85 Ga, despite regional Pan-African (~0.5 Ga) overprinting in and adjacent to the Gariep and Damara
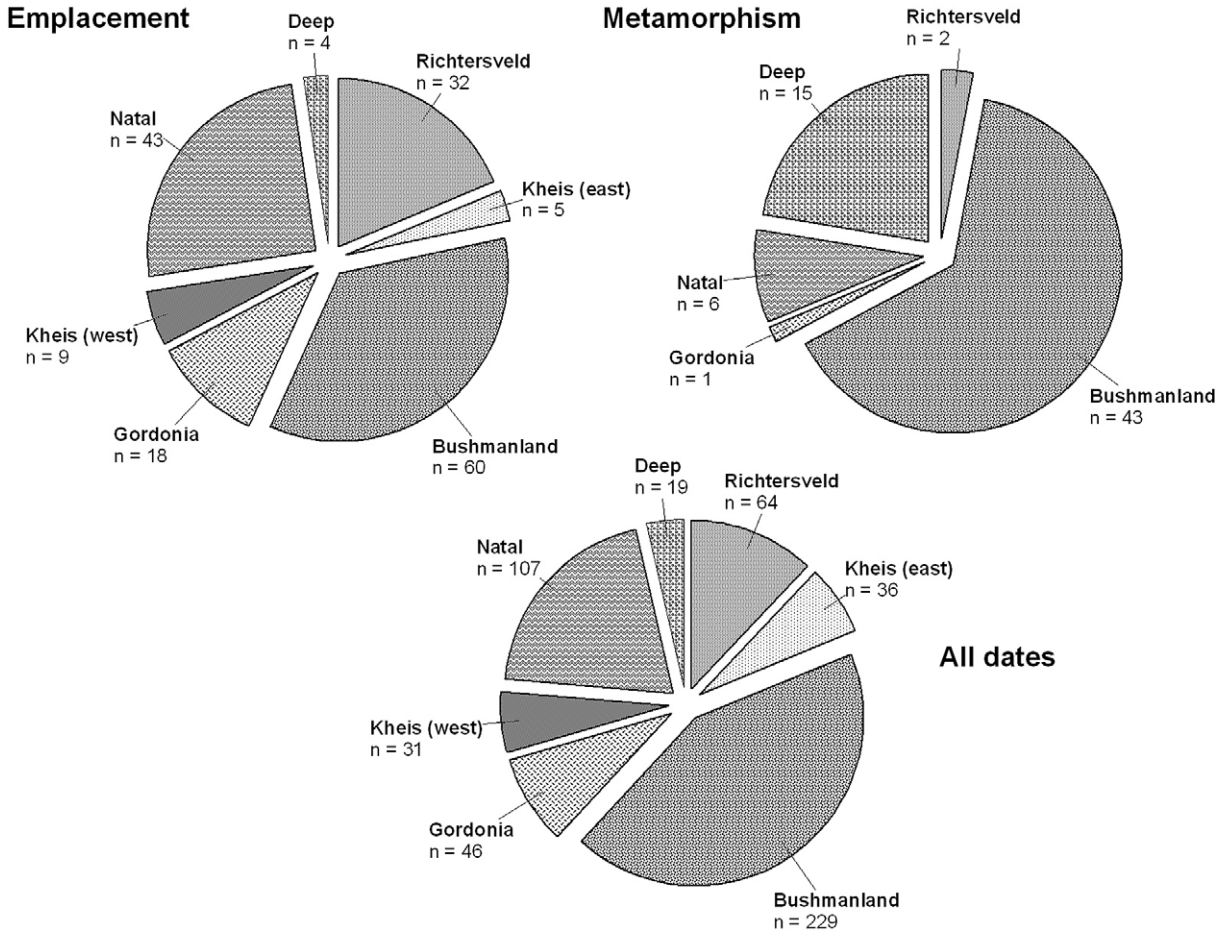
Fig. 3. Pie charts illustrating the number of radiometric dates available for sub-provinces comprising the Namaqua-Natal Belt. The number of dates is based on records deemed acceptable and stored in DateView. Where several model ^{207}Pb/^{206}Pb zircon dates have been published for a unit and the original data are available (principally for old NPRL, CSIR data), the original data have been regressed to determine the intercept age and this age stored in the database. 'Deep' refers to deep crustal and lithospheric xenoliths collected from younger kimberlites.
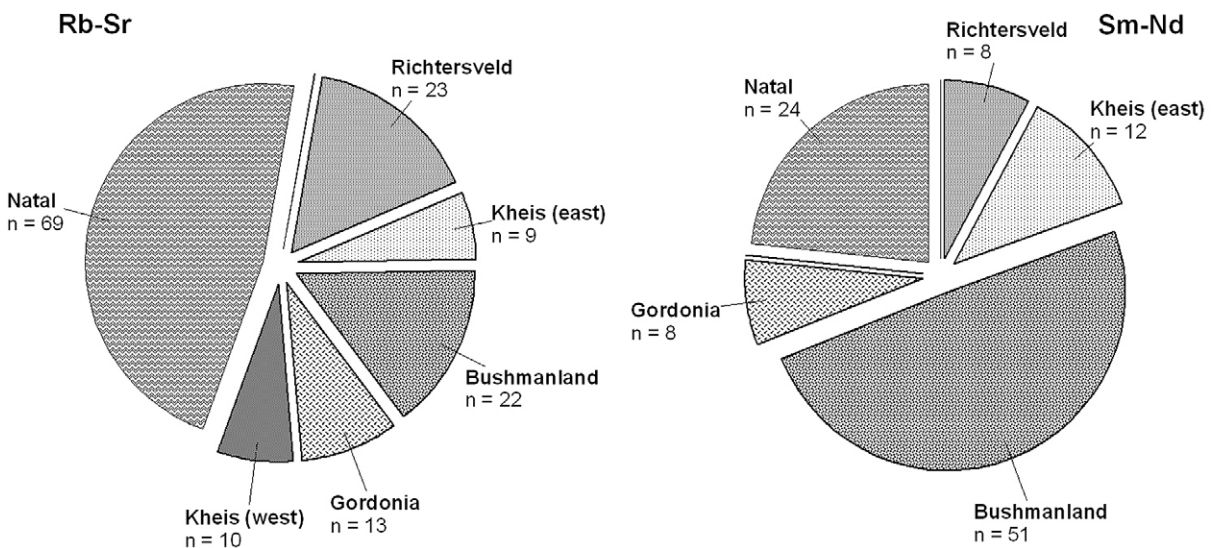

Fig. 4. Pie charts illustrating the number of Rb–Sr and Sm–Nd records available for sub-provinces comprising the Namaqua-Natal Belt, as stored in DateView.

Belts (Frimmel and Frank, 1997). Similar, ~0.75 Ga magmatism has also been recorded further north in Namibia (Hoffman et al., 1996; De Kock et al., 2000).

The Bushmanland sub-province preserves some evidence for ~1.8–2 Ga magmatic activity but is dominated by magmatism at ~1.3 to ~1.0 Ga (Fig. 5) (Barton, 1983; Reid et al., 1997a; Robb et al., 1999; Clifford et al., 2004). Many of the younger intrusions dated exhibit inheritance of ~1.8 to ~2 Ga zircons, whilst late Palaeoproterozoic ages of emplacement have been noted for Koeris Formation amphibolites (Sm–Nd whole-rock, Reid et al., 1997a) and for the Brandewynsbank (SHRIMP U–Pb zircon, Robb et al., 1999) and Steinkopf gneisses, Gladkop Suite (imprecise Pb–Pb and Rb–Sr whole-rock, Barton, 1983). The Achab granitoid-gneiss, previously considered to be Palaeoproterozoic in age (Pb–Pb whole-rock, Watkeys, 1986; discordant SHRIMP zircon, Armstrong et al., 1988), has recently provided zircon ion microprobe dates of 1.16–1.19 Ga (Bailie and Reid, 2000; Pettersson et al., 2004).

No geochronological evidence for Palaeoproterozoic crust is evident in the data available from the Kakamas terrane (Barton and Burger, 1983), but several older dates have been recorded from the Aggeneys and Okiep terranes (Barton, 1983; Reid et al., 1987a, 1997a; Robb et al., 1999; Clifford et al., 2004; and recalculated CSIR data). Schmitz and Bowring (2000, 2003) have used the distinction between the Kakamas (Gordonia) and Aggeneys and Okiep (Bushmanland) geochronology to distinguish between these terranes and sub-provinces below younger cover immediately south-east of the exposed Namaqua basement rocks. Eglington and Armstrong (2003) also utilised regional geophysical patterns and isotope characteristics in their investigation of basement intersected in deep boreholes which penetrated Phanerozoic cover successions. They concluded that the sub-Phanerozoic basement, at least as far east as the Weltevrede borehole (Fig. 1), is a continuation of the Bushmanland sub-province. The Garies terrane, situated in the south-west of the Belt, preserves only very limited evidence of Palaeoproterozoic crust in detrital zircons from the supracrustal Dabidas Formation [Council for Geoscience (CGS) and Research School of Earth Sciences, Australian National University (RSES), unpubl. data].

Data for the Gordonia sub-province are limited (Fig. 3), comprising whole-rock and bulk-population, U–Pb zircon dates (Barton and Burger, 1983) and zircon evaporation results (Cornell et al., 1990a) from surface exposures, and
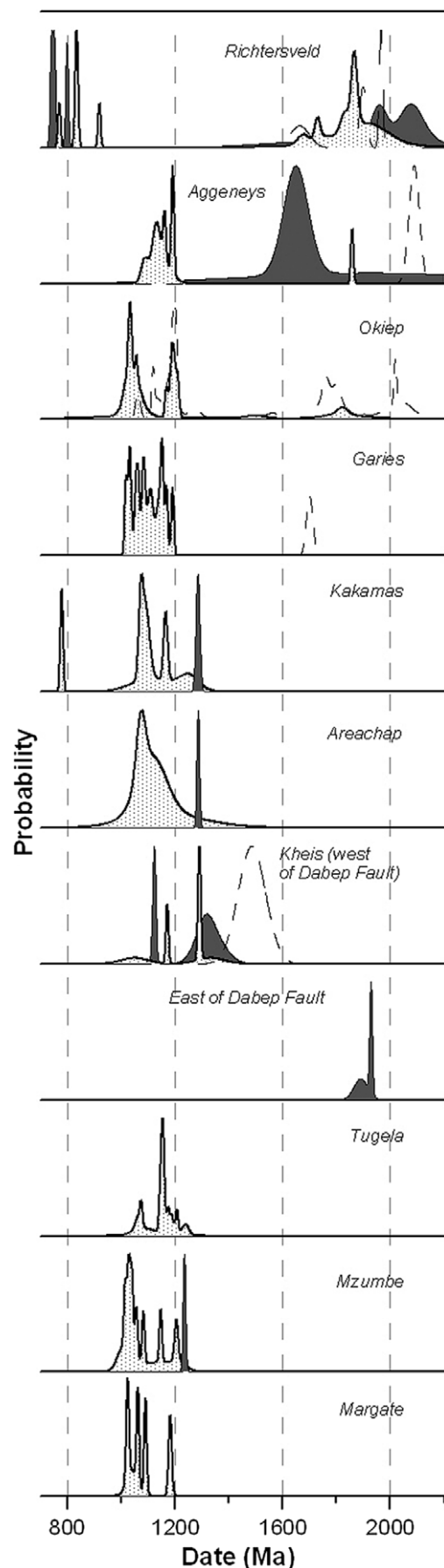

Fig. 5. Probability distribution of emplacement and inheritance dates from terranes of the Namaqua-Natal Belt for the period from 2200 Ma to 700 Ma, illustrating the principally bimodal distribution of apparent formation of crust in the Belt. Early (~1.9–1.7 Ga) and later (~1.3–1.0 Ga) periods of activity are evident, as is younger (~0.8 Ga) activity prior to the Pan-African Damara and Gariep orogenies. Pale stippled field illustrates intrusion dates, dark pattern represents extrusion dates and dashed curves represent inherited components.
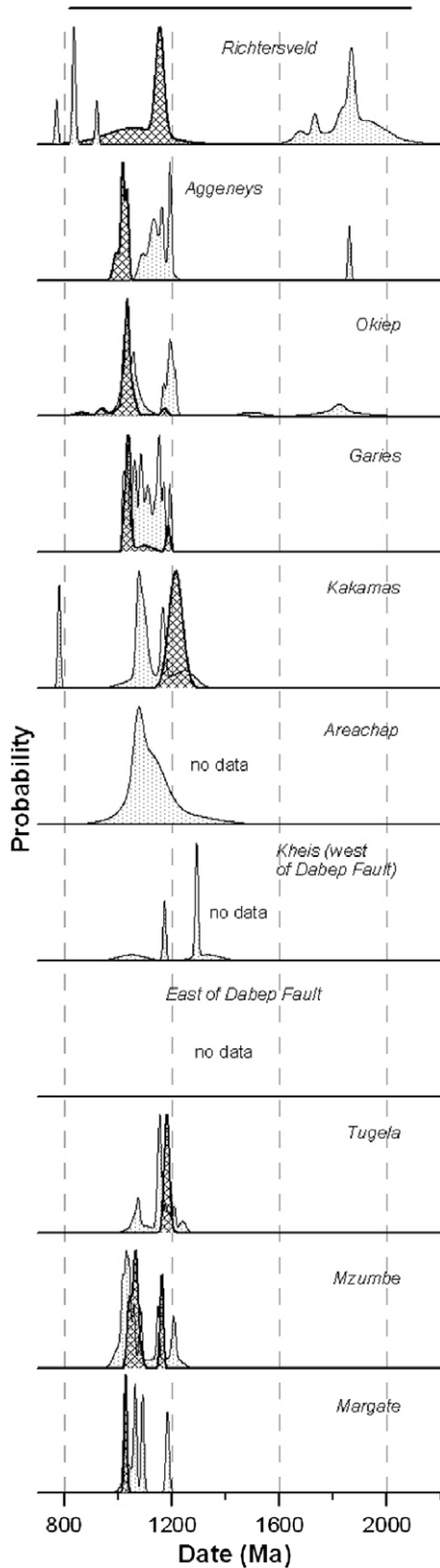
Fig. 6. Probability distribution of dates reported as reflecting metamorphism (cross-hatch pattern) in terranes of the Namaqua-Natal Belt for the period from 2200 Ma to 700 Ma relative to emplacement ages. Dates shown exclude all isotope systems and minerals which are considered to reflect cooling (e.g. mica Rb–Sr, Ar–Ar and K–Ar results). Most of the dates shown are based on U–Pb dating of rims on zircons.
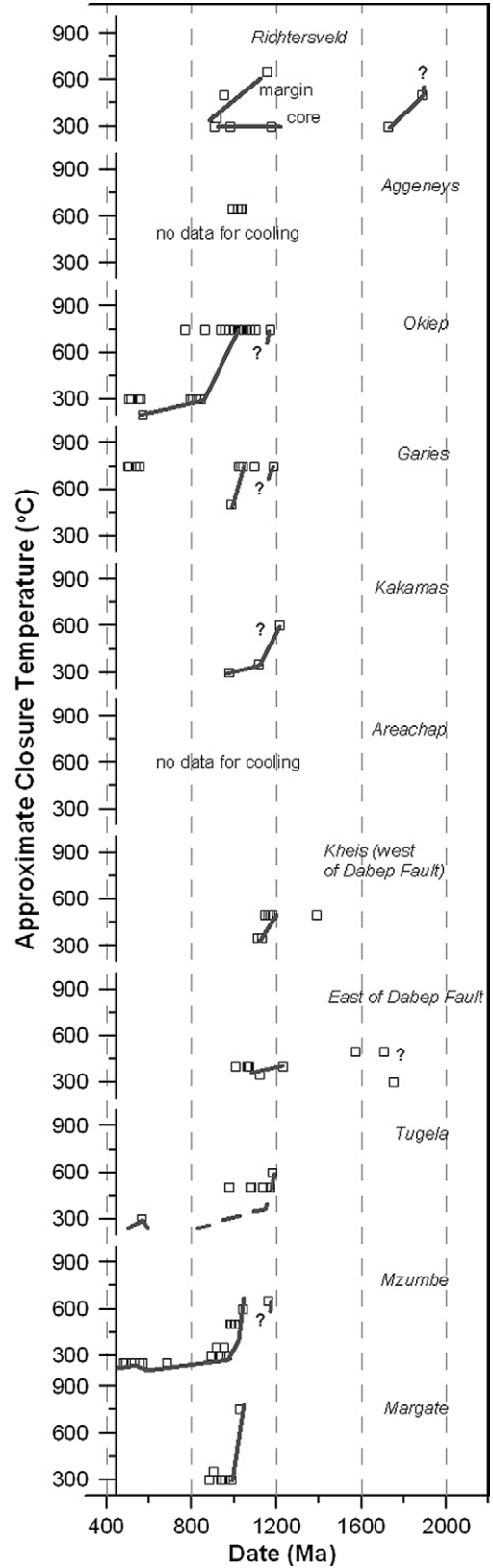
Fig. 7. Possible cooling paths as constrained by radiometric data from terranes and sub-provinces comprising the Namaqua-Natal Belt for the period from 2200 Ma to 450 Ma. Squares represent dates and associated average closure temperatures for the mineral and isotope system analysed. Uncertainties in both dates and closure temperature are ignored for the sake of clarity.

single-grain, U–Pb zircon analyses of deep crustal and lithospheric xenoliths entrained in Mesozoic kimberlites (Schmitz and Bowring, 2000, 2003). The data from this sub-province also exhibit a bimodal distribution of ages during the Mesoproterozoic (Fig. 5). No geochronological evidence for pre-existing Palaeoproterozoic or older crust has yet been reported from the Gordonia sub-province.

The Kheis sub-province is, in part, a western continuation of the Archaean Kaapvaal Craton with younger, Palaeo- and Meso-Proterozoic units, which have been affected by the Namaqua-Natal tectogenesis (Hartnady et al., 1985; Moen, 1999). Archaean units, which have been dated from the south-western margin of the Kaapvaal Craton, include the Marydale volcanics (Barton et al., 1986) and the Draghoender and Skalkseput granitoids (McCourt et al., 2000a). The Archaean units are overlain by various supracrustal successions, the youngest for which geochronological data are available being basalt of the Hartley Formation, which has a $^{207}Pb/^{206}Pb$ zircon evaporation age of 1928 ± 4 Ma (Cornell et al., 1998; confirmed by unpubl. SHRIMP analyses cited in Eglington and Armstrong, 2004). Detrital zircons, with a minimum ~2.0 Ga age, have been recorded from sandstone of the Fuller Formation, upper Olifantshoek Supergroup (CGS and RSES, unpubl. data), providing additional evidence for the late Palaeoproterozoic age of the Olifantshoek Supergroup.

Various publications have called on Eburnian (~2 Ga) orogenesis within the Kheis sub-province to explain structural, fluid flow or geological features of the area and of the south-western parts of the Kaapvaal Craton (Stowe, 1986; Duane and Kruger, 1991; Thomas et al., 1994; Cornell et al., 1998) but the *geochronological* evidence for major orogenesis is sparse to non-existent. Nicolaysen and Burger (1965) reported a 1708 Ma (no uncertainties given) Rb–Sr muscovite model date for Kaaien schist from Blaauwputs, Marydale and Burger and Coertze (1974) reported a minimum Ar–Ar date of >1780 Ma (no uncertainties or decay constants given) for lava of the Kaiing Formation. The latter date was subsequently linked to mafic schist of the Groblershoop Formation, Brulpan Group (Schlegel, 1988). Subsequent interpretations of the Kheisian tectonism as being late Palaeoproterozoic all appear to be based on these data. Cornell et al. (1998) provided a zircon U–Pb date of 1928 ± 4 Ma for Hartley Formation basalt which, from structural evidence, must predate deformation associated with the 'Kheis orogeny'. They also reported a 1750 ± 60 Ma Rb–Sr biotite – whole-rock date from the Mamatlun dolerite dyke, which does not carry a Kheisian fabric. The significance of this date is not certain as the Rb–Sr isotope system in dykes is notorious for providing inaccurate or spurious intrusion ages. Humphreys and Cornell (1989) described high-grade metamorphism near Prieska and the Kheis domain has become entrenched in the literature as a *major* late Palaeoproterozoic orogenic belt which has had a significant impact on the interior of the Kaapvaal Craton (e.g. Duane and Kruger, 1991; Thomas et al., 1994). The domain has been further linked to

~2 Ga granitoids in the Okwa fragment of Botswana (Ramokate et al., 2000) and to the Magondi Belt of north-west Zimbabwe (Stowe, 1989). Dating of the ~1.98 Ga Hurungwe granite, which post-dates granulite-grade metamorphism in the Magondi Belt, shows that this metamorphism occurred prior to extrusion of the Hartley Formation basalts of the Olifantshoek Supergroup, hence correlation of the Olifantshoek and Magondi successions is not appropriate (McCourt et al., 2000b). Similarly, correlation of the Kheis sub-province with ~2 Ga lithologies from Botswana (Singletary et al., 2003, and references therein) is not supported because these rocks are also older than the Hartley Formation.

Moen (1999) has shown that previous interpretations, which placed the boundary between the Kheis domain and the Kaapvaal Craton at the Blackridge thrust within the Olifantshoek Supergroup, are incorrect and that the eastern limit of the Kheis domain is actually the Dabep fault, which is situated west of the Blackridge thrust (Fig. 1). Moen's (1999) review of the lithostratigraphy and structure of the Kheis sub-province concluded that most of the structural elements in the domain could well have formed during the early stages of the Namaqua-Natal orogenesis. Indeed, Moen noted that the intrusive Kalkwerf gneiss, which contains a fabric interpreted as 'Kheisian', provides imprecise bulk-population, zircon U–Pb dates of ~1250 to ~1400 Ma. This gneiss has subsequently been dated on SHRIMP and provides what is interpreted as a formation age of ~1293 Ma (unpublished U–Pb SHRIMP zircon date cited in Eglington and Armstrong, 2004). The 'Kheisian' fabric is thus an early phase of the Mesoproterozoic evolution of the Namaqua-Natal Belt, and not Palaeoproterozoic in age. The oldest dates in the Kheis sub-province (west of the Dabep fault) for closure of isotope systems in micas are about 1.4 Ga (Eglington and Armstrong, 1999). Older, up to ~1.8 Ga, dates occur east and south of the Dabep fault. Several of the diagrams in the present paper (Figs. 5–8), which illustrate the geochronological development of the Namaqua-Natal Belt, thus distinguish between the Kheis sub-province *sensu stricto* (west of the Dabep fault) and the area east of the fault.

Tinker et al. (2002) described seismic evidence for eastwards-directed thrusting subsequent to extrusion of the Hartley Formation basalts and before deposition of the Volop Group, both sub-units within the Olifantshoek Supergroup. This deformation must have occurred between ~1.9 and ~1.7 Ga. Altermann and Halbich (1991) provided a comprehensive review of tectonic features of the south-western Kaapvaal craton, including the area east of the Dabep fault. Evidence for thrusting during deposition of the Olifantshoek Supergroup was identified in surface exposures, the most notable thrust being the Blackridge thrust which, prior to the investigation by Moen (1999), was considered the eastern limit of the Kheis sub-province. This syn-Olifantshoek Supergroup tectonism should no longer be correlated with the Kheis sub-province and
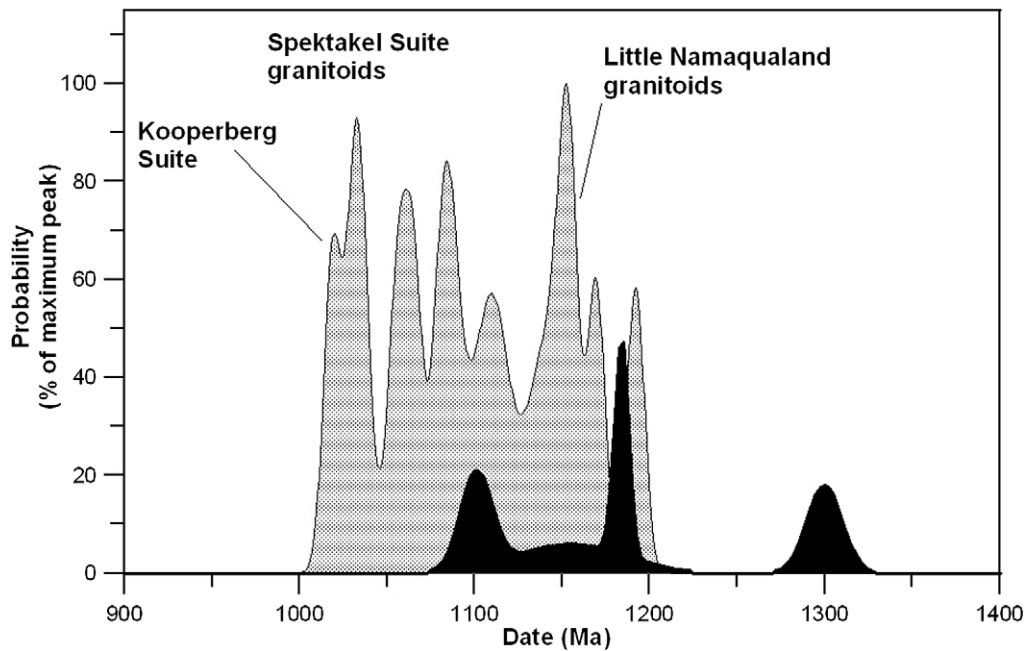
Fig. 8. Probability distribution of reported dates for metasediments from the Garies terrane, Bushmanland sub-province relative to dates for intrusive activity. Detrital zircon dates shown in black and igneous dates stippled.

remains poorly constrained with respect to geographic extent and precise age. Whilst not part of the development of the Namaqua-Natal Belt, the topic of the present paper, it is worth re-iterating that no geochronological evidence exists for *major* orogenesis associated with this syn-Olifant-shoek Supergroup tectonism. The few mica dates from this region do not necessarily reflect metamorphism since the micas could equally be detrital. A detailed structural, petrographic and isotope investigation is required to better understand this period of low-grade tectonic activity. Geological models need to acknowledge that there is no evidence for a major Palaeoproterozoic 'Kheis orogeny' and interpret the late Palaeoproterozoic evolution of the Kaapvaal Craton accordingly.

Early igneous activity within the Kheis sub-province, during the Namaqua-Natal orogenesis, has been recorded from a series of volcanic units (Wilgenhoutsdrif, Koras) (Barton and Burger, 1983; Gutzmer et al., 2000) and from the Kalkwerf gneiss (see above). Initial Mesoproterozoic magmatism occurred at ∼1.3 Ga, broadly coeval with igneous activity in the Areachap and Kakamas terranes, Gordonia sub-province (Cornell et al., 1990a; Evans et al., 2000) and in the Awasib Mountain Land of Namibia (Hoal and Heaman, 1995). Equivalent magmatism has not been identified in the Natal and Bushmanland sub-provinces. Mesoproterozoic model $^{Nd}T_{DM}$ dates for some intrusions from the Prieska area (Cornell et al., 1986) indicate that this domain, south-east of the Dabep fault, was also affected by magmatism during Namaqua-Natal orogenesis.

Koras magmatism has generally been considered to have occurred late in the development of the Namaqua-Natal Belt, possibly as a consequence of transcurrent shearing (Thomas et al., 1994), but the geochronological evidence now shows that this is not the case. The Koras succession comprises undeformed lavas and sediments which overlie older, deformed lithologies, and are preserved in graben structures within the Kheis sub-province (Botha et al., 1979; Thomas et al., 1994; Moen, 1999). U–Pb zircon dating indicates that lavas within the succession were extruded between ∼1.18 Ga (Botha et al., 1979; Gutzmer et al., 2000) and 1.12 Ga (Moen and Armstrong, unpubl. data). Whilst these are the youngest emplacement dates recorded from the Kheis sub-province, they are some 100–200 million years older than the final stages of orogenesis and igneous intrusion within the Namaqua-Natal Belt (Fig. 5). Granitoid intrusions, which are considered part of the Keimoes Suite, have also been mapped within the Kheis sub-province (Moen, 1999). Dating of these granites in the adjacent Gordonia sub-province indicates that the Suite intruded at ∼1.08 Ga (Barton and Burger, 1983; CSIR data, recalc.).

Emplacement dates for units from the Natal (eastern) sector of the Namaqua-Natal Belt are exclusively ∼1.25 to ∼1.03 Ga (Fig. 5) and no Palaeoproterozoic dates have been recorded (summarised in McCourt et al., 2006). As with several domains within the Namaqua-Natal Belt, there is a clear bimodality in the Mesoproterozoic ages recorded from the Natal sub-province (Fig. 5).

The distribution of emplacement dates during the ∼1.2–1.0 Ga period is distinctly bimodal, a feature that is evident throughout the Namaqua-Natal Belt although it is most strongly developed in the Okiep and Garies terranes. More intense periods of igneous activity occurred at ∼1190 ± 30 Ma and ∼1040 ± 30 Ma (Fig. 5). Robb et al. (1999) suggested that these two periods be termed the "Kibaran" and "Namaquan" episodes, respectively.

Unfortunately, the age of the period termed "Kibaran" does not coincide with that of the principal activity within the Kibaran Belt of central Africa (Tack et al., 2002) (Fig. 2), hence the terms O'okiepian (1210–1180 Ma) and Klondikean (1040–1020 Ma), suggested by Clifford et al. (2004), are preferred.

Formation of juvenile crust occurred at ~1.29 to ~1.2 Ga in the Gordonia and Natal sub-provinces (Harmer and Burger, 1981; Barton and Burger, 1983; Thomas and Eglington, 1990; Cornell et al., 1990a; Thomas et al., 1999). Intrusion of a suite of granitoids occurred throughout the Belt at ~1.15 Ga: the Little Namaqualand Suite (Robb et al., 1999; Clifford et al., 2004) and the Aroams Gneiss (Armstrong et al., 1988; Pettersson et al., 2004) in the Bushmanland sub-province, the Kakamas Suid granitoid in the Gordonia sub-province (Barton and Burger, 1983) and the Mzimlilo Granite and Bulls Run complex in Natal (Eglington et al., unpubl. data). Coeval, ~1.15 Ga igneous activity is also common in the Tugela terrane of the Natal sub-province (McCourt et al., 2006). The younger (~1.08 to ~1.03 Ga) peak in igneous activity can be correlated with intrusion of the Spektakel Suite granitoids in Bushmanland (Robb et al., 1999; Clifford et al., 2004), the Keimoes Suite granitoids from Gordonia (Barton and Burger, 1983) and the Oribi Gorge Suite granitoids in Natal (Eglington et al., 2003). The Koperberg Suite of Bushmanland also formed during the interval from ~1.06 to ~1.02 Ga (Robb et al., 1999; Clifford et al., 2004). One of the major granitoids in the Okiep terrane, the Concordia Granite, has traditionally been classified as a member of the Spektakel Suite but recent zircon U–Pb dating of the unit (Clifford et al., 2004) has shown that it is older, with a date of ~1.21 Ga.

Jacobs et al. (1993) explained the structural evolution of the Namaqua-Natal Belt, in which early north-vergent folding and thrusting is succeeded by oblique transcurrent shearing, as a consequence of indentor tectonics produced by collision with the southern, wedge-shaped margin of the Kaapvaal Craton. Dating of the late-to-post-tectonic Oribi Gorge Suite at ~1.06–1.03 Ga (Eglington et al., 2003) constrains the timing of transcurrent shearing within the Natal sub-province and is consistent with Ar–Ar dates which suggest that the principal foliation-defining tectonism was concluded by ~1130 Ma in the Tugela terrane when it was thrust onto the southern edge of the Kaapvaal Craton (Jacobs et al., 1997). Further south, in the Mzumbe and Margate terranes, the regional foliation post-dates intrusion of the deformed Equeefa metabasite (1083 ± 6 Ma) in the Mzumbe terrane (Evans et al., 1987, 1988; Johnston et al., 2000) and of the deformed Glenmore granite (1091 ± 9 Ma) in the Margate terrane (Mendonidis et al., 2002) but is older than the ~1025–1060 Ma Oribi Gorge Suite (Eglington et al., 2003). The regional fabric in rocks of the Bushmanland sub-province post-dates emplacement of the Little Namaqualand Suite (~1.15 Ga) but is older than the Spektakel Suite (~1.03–1.06 Ga). Similarly, the ~1.08 Ga Keimoes Suite in the Gordonia sub-province

intruded after the regional tectonic fabric was developed. The Spektakel and Oribi Gorge Suite granitoids exhibit similar 'A-type' geochemical signatures (Thomas et al., 1996; Grantham et al., 2001) which are generally interpreted to indicate emplacement in late-to-post-tectonic tensional settings. If this is the case, and by analogy with the Oribi Gorge Suite, the Spektakel and Keimoes Suites might also be associated with late transcurrent deformation, as suggested by Thomas et al. (1996). However, it is easier to apply this model to the Natal and Gordonia sub-provinces than to the Bushmanland sub-province where the tectonic significance of transcurrent shearing is less clear.

Fig. 6 illustrates the geochronological record of higher grade metamorphism (>~500 °C) in the various sub-provinces of the Namaqua-Natal Belt. No geochronological evidence for Mesoproterozoic, high-grade metamorphism is recorded from the core of the Richtersveld sub-province. Metamorphic overprints are only evident in mineral isotope systems with closure temperatures below ~500 °C (Welke et al., 1979; Onstott et al., 1986), which record dates in the range ~1.1 Ga down to ~0.8 Ga. Mesoproterozoic (~1.05 to ~1.16 Ga) amphibolite-grade metamorphism has, however, been dated from the margins of the Richtersveld sub-province (Welke et al., 1979). Rocks of the Bushmanland sub-province preserve evidence for ~1.18 Ga metamorphism (Raith et al., 2003; Clifford et al., 2004), a strong signal of ~1.03 Ga metamorphic activity (Robb et al., 1999; Eglington and Armstrong, 2000; Raith et al., 2003; Clifford et al., 2004) and a distinct period of cooling at ~0.8 Ga. Cornell et al. (1990b) provided a 1215 ± 50 Ma Sm–Nd garnet – whole-rock date from the Kakamas terrane, Gordonia sub-province and Schmitz and Bowring (2003) provide ~1.0 Ga dates for zircons from deep lithospheric xenoliths beneath this domain. Limited dates from the lower temperature systems of the Gordonia sub-province (Barton and Burger, 1983; Cornell et al., 1990b) range from ~0.95 to ~1.1 Ga. No data are available for high-temperature metamorphism in the surface exposures of the Kheis sub-province. The lower temperature isotope systems in the Kheis sub-province and in the vicinity of Prieska, however, preserve a record from ~1.4 to ~1.0 Ga with most K–Ar and Rb–Sr mineral dates clustering close to ~1.12 Ga (Nicolaysen and Burger, 1965; Cornell, 1975; Eglington and Armstrong, 1999; Moen, 1999). Dates from Natal which reflect higher temperature metamorphism range from ~1.2 to ~0.95 Ga (Fig. 6), with subsequent cooling from ~1.0 Ga down to ~0.85 Ga. Most of the higher temperature data are from deep crustal or lithospheric xenoliths entrained in Mesozoic kimberlites from Lesotho (Schmitz and Bowring, 2003) and these appear to preserve dates ~30–50 Ma younger than results from surface exposures, as is also the case further west (Schmitz and Bowring, 2003). The younger dates in the deep crust and lithosphere presumably reflect continued high temperatures at depth, after peak temperatures had been reached at shallower levels. The only signs of Pan-African

metamorphism in the eastern sector of the Namaqua-Natal Belt come from fission track analyses in titanite (Thomas and Jacobs, 2000) and from unpublished Rb–Sr whole-rock isotope studies of unusual, sheared, riebeckite-rich alkaline rocks on the margins of the Ngoye granite complex (Eglington and Scogings, unpubl. data). High-temperature metamorphism of the various sub-provinces is illustrated graphically in Fig. 6, together with igneous activity.

Fig. 7 summarises the probable cooling histories of various domains within the Namaqua-Natal Belt, based on all the available geochronological information. The cooling histories illustrate the importance of ~1.9 Ga igneous activity in the Richtersveld sub-province and the Kaapvaal Craton east of the Dabep fault, and substantial cooling after 1030 Ma in most domains. Approximate cooling rates may be estimated for the amphibolite- and granulite-grade terranes in which sufficient geochronological data are available (Okiep, Mzumbe and Margate), based on peak temperatures of 650–800 °C at ~1030 Ma and cooling to 350 °C by 950–980 Ma. Values calculated in this way range from 4 to 9 °C per million years, suggesting that cooling was essentially isobaric.

4. Depositional age of the supracrustal gneisses

It has long been assumed that all of the supracrustal gneisses in the Bushmanland and Gordonia sub-provinces are of approximately the same age, despite geochemical evidence (Moore, 1989; Moore et al., 1990) that identified different sources for units in different terranes. The current lithostratigraphic subdivision of the supracrustal units in

Table 2
Lithostratigraphic subdivision of the supracrustal units in the different terranes according to current Council for Geoscience mapping (Macey, pers. comm.)

Sub-province	Terrane	Major supracrustal units
Richtersveld	Not subdivided	Orange River Group
Bushmanland	Aggeneys	Droeboom Group north of the Vogelstruislaagte shear zone and Aggeneys Subgroup, Bushmanland Group to the south
	Okiep	Khuris Subgroup, Bushmanland Group
	Garies	Kamiesberg Subgroup, Bushmanland Group
Gordonia	Kakamas	Korannaland Supergroup
	Areachap	Vaalkoppies Group
Kheis	Not subdivided	Brulpan Group
Natal	Tugela	Tugela Group
	Mzumbe	Mapumulo Group
	Margate	Mzimkulu Group

the Namaqua-Natal Belt is summarised in Table 2. The subdivisions are primarily based on inferred structural boundaries, lithological variations and geochemical comparisons.

Whole-rock Rb–Sr, Pb–Pb, Th–Pb, Sm–Nd and U–Pb dating of Haib Formation metavolcanics from the Richtersveld sub-province (Fig. 5) suggest extrusion at ~2.1 Ga (Reid, 1979, 1997). Although no zircon dates are available for the Haib metavolcanics, the Palaeoproterozoic age is broadly consistent with bulk-population,
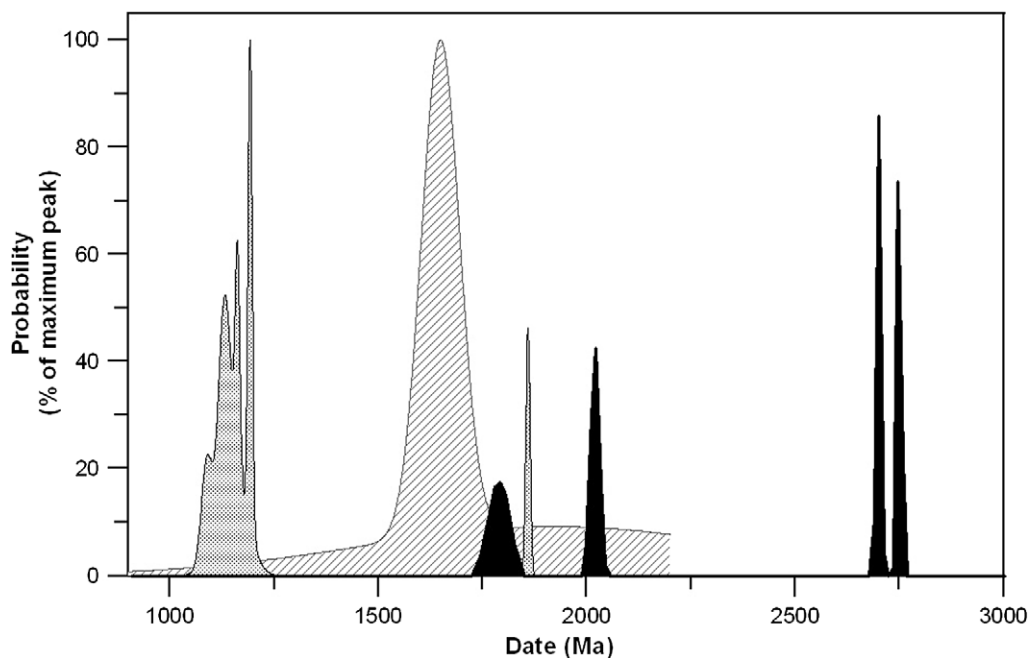

Fig. 9. Probability distribution of reported dates for metasediments from the Aggeneys terrane, Bushmanland sub-province. Detrital zircon dates shown in black, intrusive magmatism is stippled and volcanism is cross-hatched.

U–Pb zircons dates of ∼1.9 Ga for granitoids intrusive into the metalavas (Welke et al., 1979; Kröner et al., 1983).

The age of sedimentation in the Bushmanland sub-province has generally been taken to be ∼1.65 Ga, based on a Sm–Nd isochron for Koeris Formation amphibolites from central Bushmanland (Reid et al., 1987a), the only part of the supracrustal succession which had been dated. More recently, U–Pb data for detrital zircons have started to become available (Bailie and Reid, 2002; Eglington, 2002; Raith et al., 2003), some of which cast doubt on this assumption and suggest that supracrustal lithologies in the Garies terrane may have formed as recently as 1.1–1.2 Ga (Fig. 8) whilst some in the Gordonia terrane are younger than 1.2 Ga (CGS and RSES unpubl. data). In contrast, the youngest detrital zircons reported from the Aggeneys terrane are ∼1.8 Ga (Fig. 9) and Archaean grains have also been identified (Bailie and Reid, 2002; Pettersson et al., 2004). In the Aggeneys terrane, units such as the Achab Gneiss have been considered a possible basement to the supracrustal units (Watkeys, 1986), based in part on ∼2 Ga dating (Watkeys, 1986; Armstrong et al., 1988; Reid et al., 1997a). Recent zircon dating of this unit, however, shows that it is 1.16–1.19 Ga in age (Bailie and Reid, 2002; Pettersson et al., 2004) and must thus be presumed to be intrusive into the supracrustal gneisses.

Detrital zircons from supracrustal gneisses in the Tugela and Margate terranes, Natal sub-province (McCourt et al., 2006) are mostly in the range 1160–1289 Ma, although some grains from the Leisure Bay Formation, Margate terrane, are as old as 1730 Ma. Eglington et al. (1989) reported ∼1.4 Ga model $^{Nd}T_{DM}$ ages for two samples of Leisure Bay Formation metapelite, which indicate that only a very minor Palaeoproterozoic component can be present in this formation. The youngest detrital zircons reported from the Leisure Bay Formation are ∼1207 Ma (cited in McCourt et al., 2006).

SHRIMP U–Pb zircon dating of the metavolcanic Quha Formation, from the Mapamulo Group in the Mzumbe terrane, Natal sub-province, has provided an age of 1235 ± 9 Ma (Thomas et al., 1999). The Quha Formation, sampled at a different locality, has also provided a date of 1163 ± 12 Ma (Cornell et al., 1996) although this was subsequently suggested to represent some form of metamorphic overprint (Thomas et al., 1999). The metavolcanic Smouspan gneiss in the Kakamas terrane, Gordonia sub-province, provided a zircon evaporation date of 1285 ± 14 Ma (Cornell et al., 1990a) whilst metarhyolite from the Lord Hill Boundary Zone, a probable northerly extension of the Areachap terrane in southern Namibia, has been dated at 1286 ± 6 Ma (Evans et al., 2000). To date, these are the only modern, U–Pb zircon dates for Mesoproterozoic volcanic lithologies from the Namaqua-Natal Belt.

At this stage there is thus clear evidence that supracrustal gneisses from the Gordonia and Natal sub-provinces are, at most, ∼1.3 Ga in age. A similar, or younger, age may be inferred for metasediments from the Garies terrane in the Bushmanland sub-province, whereas the supracru-
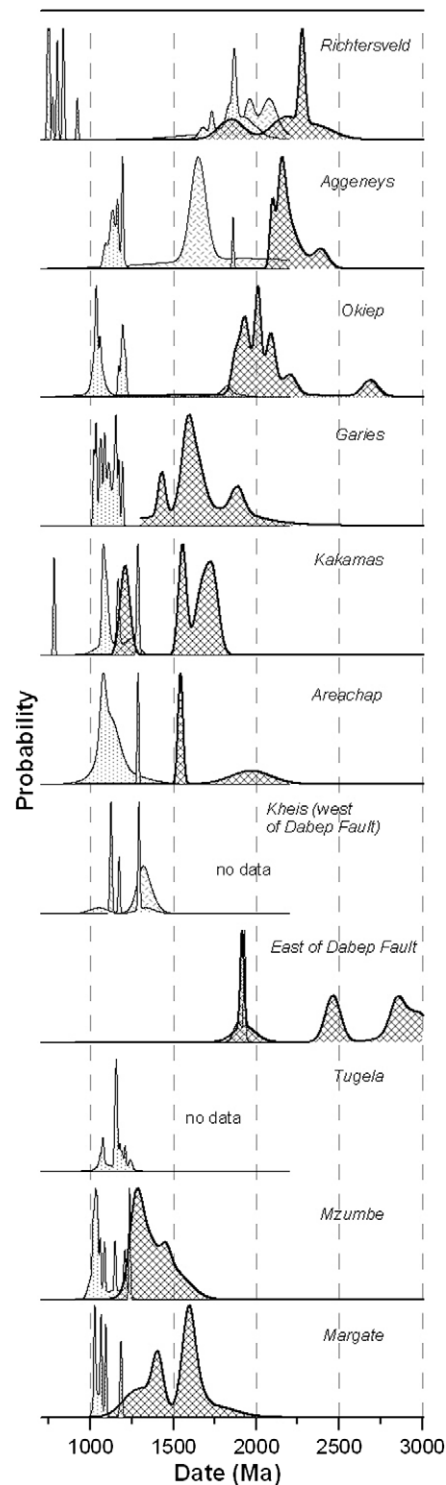

Fig. 10. Probability distribution of Sm–Nd crustal residence dates relative to emplacement ages for the period from 2200 Ma to 700 Ma. Crustal residence dates are T_{DM} based on the model of DePaolo et al. (1991). Dense pattern represents T_{DM} dates and pale stipple represents emplacement dates.

stal gneisses in the Aggeneys terrane might be as old as ∼1.65 Ga, and those in the Richtersveld sub-province formed at ∼2.1 Ga.

5. Isotope geochemistry

In addition to direct geochronological dating of the rocks and minerals in the Namaqua-Natal Belt, Rb–Sr, Sm–Nd, Pb–Pb and Re–Os isotopic data may also be used to constrain the protolith history of the Belt and its individual domains. Fig. 10 illustrates the distribution of model $^{Nd}T_{DM}$ values for the various terranes and sub-provinces.
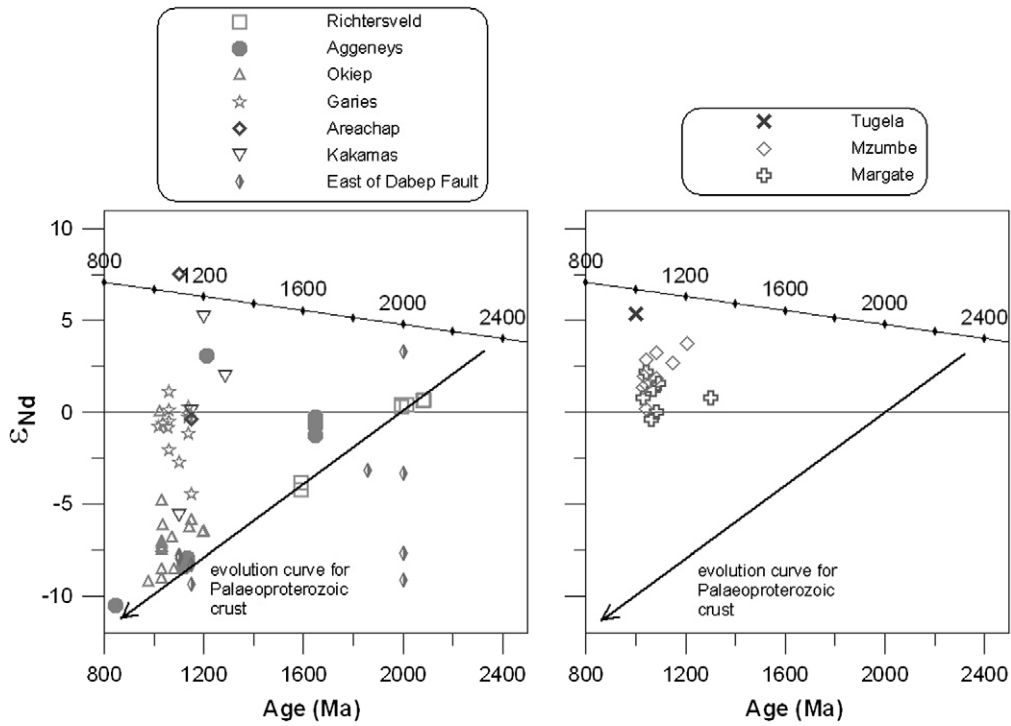

Fig. 11. Initial Nd isotope composition of units from different terranes comprising the western (Namaqua) and eastern (Natal) sectors of the Namaqua-Natal Belt relative to model depleted mantle (DePaolo et al., 1991).
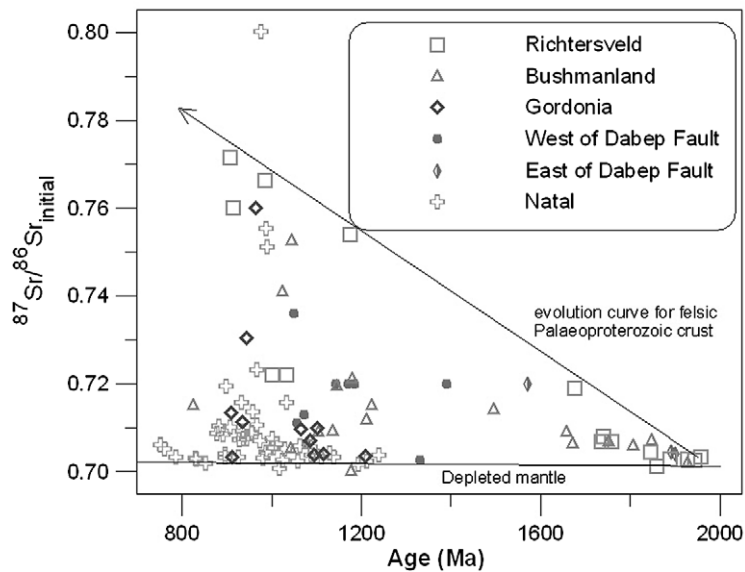

Fig. 12. Initial Sr isotope composition of units from different sub-provinces of the Namaqua-Natal Belt relative to model depleted mantle (Ben Othman et al., 1984).

The Richtersveld sub-province and the Aggeneys and Okiep terranes, Bushmanland sub-province generally exhibit older $^{Nd}T_{DM}$ ages than the Gordonia and Natal sub-provinces, consistent with the occurrence of partly reworked late Palaeoproterozoic crust in the former two sub-provinces and the absence of such older crust in the latter two. $^{Nd}T_{DM}$ model dates for the Garies terrane, Bushmanland sub-province, are younger than those for the Okiep and Aggeneys terranes, but similar to those for the Gordonia and Natal sub-provinces, indicating more juvenile contributions than further north in the Bushmanland sub-province. No Nd isotope data are available for the Kheis sub-province *sensu stricto* (west of the Dabep Fault) but are available for the Prieska region of the south-west Kaapvaal Craton (Cornell et al., 1986). Model $^{Nd}T_{DM}$ values for intrusive lithologies in this area range from ~1.2 Ga to Archaean, consistent with the extensive presence of Archaean crust in this domain and with Mesoproterozoic magmatism near the south-western margin of the Craton. $^{Nd}T_{DM}$ values are only slightly older than emplacement ages in the Gordonia and Natal sub-provinces, and in the Garies terrane, Bushmanland sub-province, indicating substantial juvenile contributions to crustal development in these areas. Similarly, the Richtersveld and Bushmanland (Okiep and Aggeneys terranes) crustal residence model age distributions suggest that significant juvenile additions occurred not long before the ~1.9 Ga magmatism. Younger magmatism within the Bushmanland sub-province appears to be dominated by reworking of older lithosphere,

since the $^{Nd}T_{DM}$ ages for this area are generally older than for the Gordonia and Natal sub-provinces, despite all three sub-provinces showing similar ages of Mesoproterozoic emplacement (Fig. 5).

The pattern of dominantly juvenile crustal addition in the Gordonia and Natal sub-provinces is also clear in Fig. 11, an alternative view of the same data, as well as in the variation in initial $^{87}Sr/^{86}Sr$ with time (Fig. 12). The general pattern in these two figures, with initial isotope compositions for the Bushmanland and Richtersveld sub-province approaching model depleted mantle with increasing age, suggests that these sub-provinces contain little, if any, significantly older (i.e. pre-2.2 Ga) protolithic material in the deep crust. Unfortunately, there are very few Nd isotope data available for the supracrustal gneisses to assess the influence of pre-existing crustal sources on these lithologies, particularly for the metasediments at Aggeneys where Archaean detrital zircons have been recorded (Fig. 9). In the few cases where Nd isotope data do exist for supracrustal lithologies (Cornell et al., 1986; Reid et al., 1987a; Eglington et al., 1989; Reid, 1997; Yuhara et al., 2001), the crustal residence model ages are similar to those obtained from younger intrusions in the same geographic areas.

Re–Os model ages derived from mantle lithospheric xenoliths entrained in Mesozoic kimberlites (Pearson, 1999) also suggest that crust within the Namaqua-Natal Belt does not have components older than about 2 Ga, quite different to the situation beneath the Kaapvaal Craton.
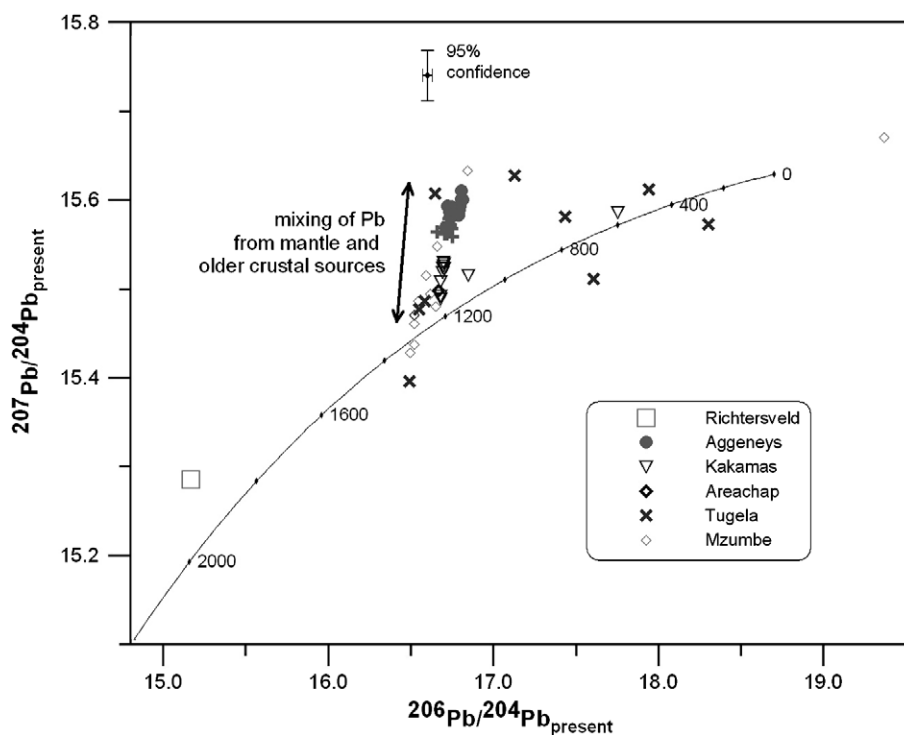

Fig. 13. Uranogenic Pb isotope composition of sulphide mineralisation from different terranes of the Namaqua-Natal Belt relative to model global ore lead (Stacey and Kramers, 1975).
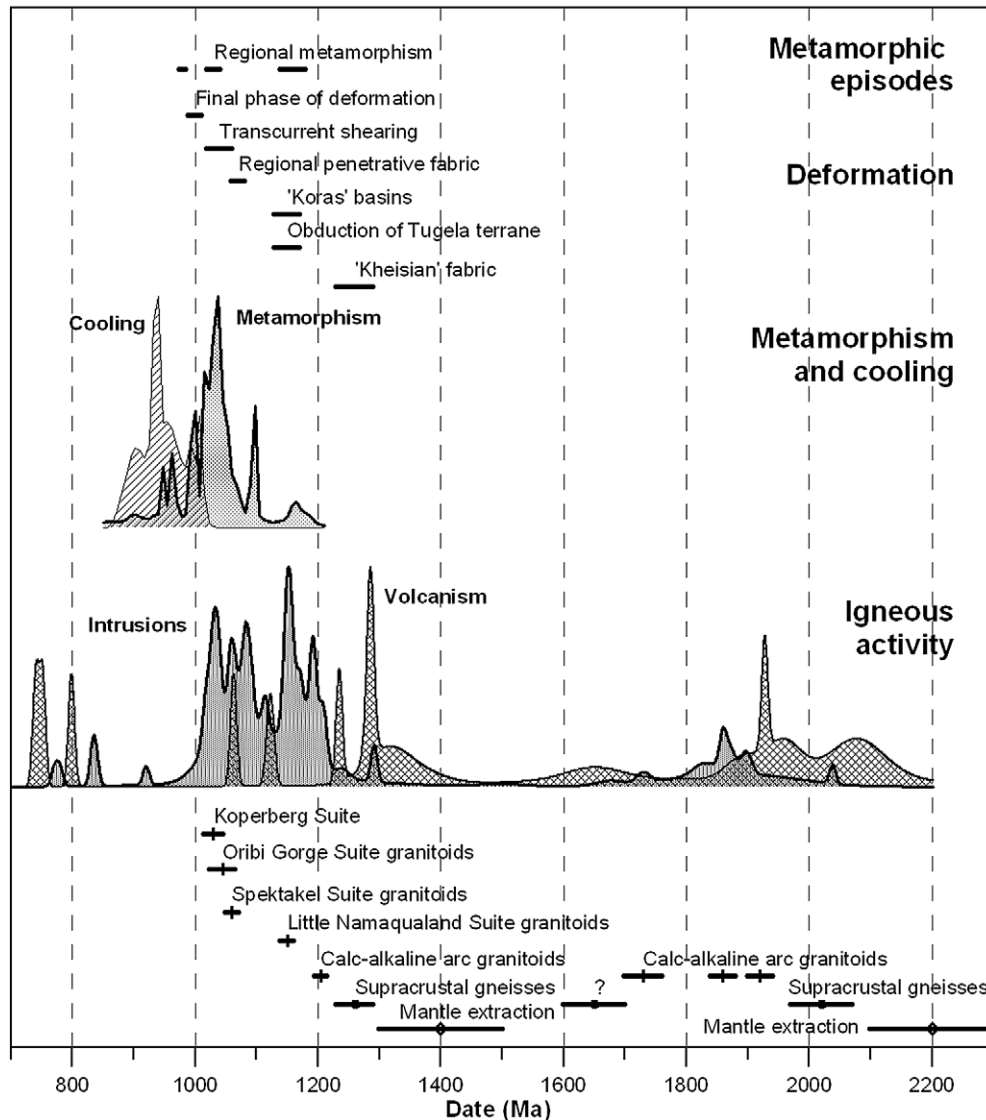
Fig. 14. Geochronological summary of the evolution of the Namaqua-Natal Belt.

Uranogenic lead isotope signatures of sulphide mineralisation from the western (Namaqua) sector (Köppel, 1980; Reid et al., 1997b; Fölling et al., 2000) and eastern (Natal) sector (Eglington et al., unpubl. data) of the Namaqua-Natal Belt are illustrated in Fig. 13. Occurrences from the Richtersveld and Bushmanland sub-provinces (Haib, Aggeneys, Gamsberg and Rosh Pinah) have much higher $^{207}Pb/^{204}Pb$ than deposits in the Gordonia sub-province (Prieska and Areachap), indicating that lead in the Richtersveld and Bushmanland sub-provinces was derived from older sources with elevated U/Pb, i.e. typical older upper crust. Pb isotope compositions of silicate lithologies are also compatible with this interpretation. No Pb isotope data are available for the Garies terrane. Lead isotope data for the Gordonia and Natal sub-provinces vary, but mostly exhibit lower $^{207}Pb/^{204}Pb$ than for the Bushmanland sub-province (Fig. 13).

6. Conclusions

Fig. 14 summarises the geochronological evolution of the Namaqua-Natal Belt. Juvenile crust formation occurred during two principal periods at ~1.4 and ~2.2 Ga with little evidence for significant contributions of older crustal sources. Significant reworking of Palaeoproterozoic lithosphere occurred in the Aggeneys and Okiep terranes of the Bushmanland sub-province but was not a major factor in the Garies terrane (Bushmanland sub-province), nor in the Gordonia and Natal sub-provinces. Palaeoproterozoic volcanism and associated intrusion of calc-alkaline granitoids is preserved in the Richtersveld sub-province and, to a much lesser extent, in the Bushmanland sub-province.

Proterozoic deformation of Archaean components is evident near the south-western margin of the Kaapvaal

Craton but there is no evidence for a significant Eburnean (~1.8 Ga) orogeny. Rather, the 'Kheisian' fabric is now dated as younger than ~1.3 Ga and represents an early phase of the Mesoproterozoic evolution of the Namaqua-Natal Belt. Associated graben formation and accumulation of the Koras lavas and sediments occurred relatively early in the history of the Belt and certainly predates most of the intrusive granitoid activity evident in other sub-provinces.

Early, juvenile, dominantly mafic to intermediate igneous units formed at ~1.2–1.3 Ga in the Kheis sub-province, Areachap and Kakamas terranes, Gordonia sub-province and the Tugela and Mzumbe terranes, Natal sub-province. Two major periods of granitoid intrusion, both of regional extent, occurred: the first at ~1.15 Ga (e.g. Little Namaqualand Suite in the Bushmanland sub-province) and the second at ~1.03–1.08 Ga (Spektakel, Oribi Gorge and Keimoes Suites). The Koperberg Suite of the Okiep terrane, Bushmanland sub-province, formed just after the intrusion of the Spektakel granitoids, at about 1.03 Ga. Igneous activity as part of the Namaqua-Natal orogenesis was concluded by ~1.0 Ga throughout the belt. Subsequent ~0.85–0.75 Ga igneous activity, evident only in the west, reflects the start of a new cycle which ultimately produced the Damara and Gariep belts.

Most geochronological evidence for metamorphism in the Namaqua-Natal Belt is concentrated in the time period from ~1.2 to ~1.04 Ga with limited evidence for ~1.15 Ga metamorphism. This does not imply that such metamorphism did not occur, only that geochronological evidence is either not preserved or that rocks which would preserve such evidence have not been studied. Development of a regional foliation occurred at ~1.07 Ga in the Mzumbe terrane, Natal sub-province, followed by regional transcurrent shearing at ~1.06–1.03 Ga in the Tugela, Mzumbe and Margate terranes. The fabric-forming event (~1.07 Ga) appears to predate the geochronological record of high-temperature metamorphism (~1.03 Ga) in the Mzumbe terrane. Similarly in Bushmanland, the regional penetrative fabric predates intrusion of the Spektakel Suite (~1.03–1.06 Ga) but peak metamorphism occurred at ~1.03 Ga.

Subsequent exhumation and cooling of the rocks of the Namaqua-Natal Belt reached temperatures as low as ~350 °C by ~0.95 Ga. Pan-African overprinting is evident in the west of the Okiep terrane, presumably associated with the development of the Gariep belt. Titanite fission-track dating records very low-grade effects (below the closure temperature for biotite K–Ar, Ar–Ar and Rb–Sr systems) of Pan-African activity in the Natal sub-province.

The ages of the supracrustal gneisses remain contentious. Early, ~2 Ga metavolcanics and metasediments in the Richtersveld sub-province are presumably also present in parts of the Bushmanland sub-province since associated granitoids occur in both sub-provinces. Koeris Formation amphibolites from the Bushmanland Group have provided a ~1.65 Ga Sm–Nd date, whereas supracrustal gneisses in the Garies terrane (Bushmanland sub-province) and the Gordonia and Natal sub-provinces contain detrital zircon grains as young as ~1.1 to ~1.3 Ga. In cases where metavolcanic lithologies from the Gordonia and Natal sub-provinces have been dated, their ages (~1.3 Ga) are consistent with the detrital zircon data. It therefore seems likely that the supracrustal gneisses of the Namaqua-Natal Belt record at least three different ages of sedimentation.

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