COMPOSITION AND AGE OF THE LOWER CRUST IN NORTH QUEENSLAND

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Lower crustal xenoliths from Hill 32 in the McBride volcanic province, north Queensland, are compositionally diverse, contrasting with xenoliths from the more southerly Chudleigh province, which are young mafic cumulates. Protoliths for the Hill 32 xenoliths include mafic igneous rocks, mafic cumulates, mafic restites as well as felsic igneous rocks and sediments. High pressure mineral assemblages (> 8 Kb) and decompression melts suggest these are fragments of the present day lower crust, rather than near-surface granulite facies rocks. This is confirmed by U-Pb zircon ion probe ages which show that all xenoliths have undergone high-grade metamorphism at ~240 Ma, with little evidence of subsequent Pb loss. The lack of substantial uplift and erosion in this region, as evidenced by the preservation of voluminous 300 Ma felsic ash flows, suggests that all zircon-bearing xenoliths (from supracrustal to mafic inclusions) have formed part of the lower crust since this time. Proterozoic zircon ages in some of the xenoliths indicate a protracted history for these rocks. The chemical and geochronologic data for the xenoliths from the two volcanic provinces show that the lower crust in north Queensland consists of magmatically and tectonically interleaved mafic through supracrustal lithologies, which formed in discrete "orogenic" events from the Proterozic through the Cenozoic.

INTRODUCTION

Young (< 5 Ma) alkali basalts in north Queensland carry numerous lower crustal xenoliths. The two volcanic provinces discussed here erupt in disinct tectonic settings: the Chudleigh province straddles the boundary of the Paleozoic Tasman fold belt and the Proterozoic Georgetown Inlier, whereas the McBride province is within the Georgetown Inlier. Crustal xenoliths from the Chudleigh province are exclusively mafic, but crustal xenoliths from Hill 32 range from felsic through mafic compositions, including metasedimentary lithologies. The Chudleigh lower crustal xenoliths are interpreted as genetically related cumulates from a basaltic melt (Rudnick et al., 1986), with correlations between major elements, trace elements and isotopic ratios reflecting simultaneous assimilation and fractional crystallization of the parental melt. The quality of the isotope-trace element correlations suggests that the xenoliths are less than 100 Ma old. This abstract deals with the composition, age and origin of the more diverse crustal xenolith suite from Hill 32.

MINERALOGY AND DEPTH OF ORIGIN

The mineralogy of the Hill 32 xenoliths is a function of their composition and P-T equilibration conditions. Unlike the Chudleigh province xenoliths, coronal textures are rare in this suite; most xenoliths are equigranular, and commonly minerals are compositionally zoned. Table 1 is a list of the mineralogy and thermobarometry determinations for the Hill 32 xenoliths. All appear to have equilibrated at high pressures (> 8 kb, where determined) and high temperatures (700-1000°C). Glass along grain boundaries, kelyphitic rims on garnets and anorthite rims on scapolite suggest the xenoliths experienced significant decompression and were rapidly transported from deep crustal levels by the host basalts.

COMPOSITION AND PETROGENESIS

The Hill 32 xenoliths are compositionally diverse and apparently unrelated to one another, so the origin of each must be considered separately. Individual compositions are a function of melt extraction, cumulate processes, and fractionation for the metaigneous xenoliths; weathering and erosion for the metasedimentary xenoliths, and high-grade metamorphism, which all xenoliths experienced. Metamorphic differentiation may be a particularly important process influencing the composition of these xenoliths because they are typically layered and small (most < 8 cm in diameter).

Fig. 1 shows REE patterns for the Hill 32 xenoliths. Intermediate xenoliths are metasediments, based upon their high $Al_2O_3/(Na_2O + CaO)$ ratios, and the presence of sillimanite in one of them. 83-157 has a REE pattern similar to PAAS, whereas the REE pattern of 85-101 exhibits an unusual HREE enrichment, probably due to preferential sampling of garnet (Fig. 1a)(this xenolith is small and contains garnet-rich layers). Felsic xenoliths (83-160 and 83-162) have REE patterns similar to dacitic and granodioritic melts (Fig. 1b), consistent with their major element compositions. Mafic xenoliths 83-159 and 85-107 have $(La/Sm)_N > 1$ and positive Eu anomalies (Fig. 1c), and are either restites or cumulates from an intermediate to felsic magma. The abundant zircon in 85-107 (1600 ppm Zr) suggests it is a restite. The HREE enrichment and positive Eu anomaly in mafic xenolith 85-114 (Fig. 1c)(a large, unlayered xenolith), is probably due to removal of a partial melt rather than metamorphic differentiation. Garnet is not a liquidus phase in intermediate to mafic melts at crustal depths, so this xenolith is not a cumulate. Two mafic xenoliths with LREE depleted patterns (83-158 and 85-106; Fig. 1d) are interpreted to be clinopyroxene-rich cumulates. Finally, three xenoliths (85-100, 85-108 and 85-120) have major element and REE patterns typical of mafic, oversaturated melts (Fig. 1e), although the high Cr and Ni (1026 and 456 ppm, resp.) and low Al_2O_3 (11.3 %) in layered xenolith 85-100, suggests preferential sampling of metamorphic orthopyroxene.

TABLE 1. Mineralogy of McBride Province Lower Crustal Xenoliths

Sample	Mineralogy	Accessories	P-T
		Metasedimentary	
83-157	Pe-Q-Gt-Opx-Ph	Rut-Cpx-Mt-Il-Ap-Zr	630°C[1], 8-10 Kb[2]
85-101	Q-Po-Gt	Sil-Rut-Opx-Il	
		Felsic	
83-160	Q-Pe-Cpx-Opx-Gt	Ph-Rut-Mt-Ap-Zr	740-860°C[1], 9-11 kb[2] 900-950°C[3], 8-16 Kb[4]
83-162	Q-Kf-Gt	Rut-Mt-Il-Ap-Zr-Py	
		Mafic	
83-158	Cpx-Gt-Pe-Opx	Amph-Il	940-1000°C[1] 7-15 Kb[4]
83-159	Cpx-Gt-Pe-Amph	Rut-Il-Zr	840-920°C[1]
85-100	Po-Opx-Cpx-Amph	Bio-Ap-Zr	960-1000°C[3]
85-106	Gt-Cpx-Scap-Pe	Amph-Mt	890-1070°C[1]
85-107	Po-Q-Gt-Cpx	Il-Ap-Amph-Zr	680 760°C[1]
85-108	Pc-Gt-Cpx-Q	Rut-Ap	810-860°[1]
85-114	Cpx-Gt-Po	Rut	830-910°C[1]
85-120	Po-Opx-Cpx	Amph-Rut-Zr	860-910°C

Minerals listed in order of relative abundances. [1]Ellis and Green (1980), [2]Perkins and Newton (1982), [3] Wells (1979). [4]Harley and Green (1982). Amph = amphibole, Ap = apatite, Bio = biotite Cpx = clinopyroxene, Gt = Garnet, Il = ilmenite, Kf = K-feldspar, Mt = magnetite, Opx = orthopyroxene, Po = plagioclase, Ph = phlogopite, Py = pyrite, Q = quartz, Rut = rutile, Scap = scapolite, Sil = sillimanite, Zr = zircon.

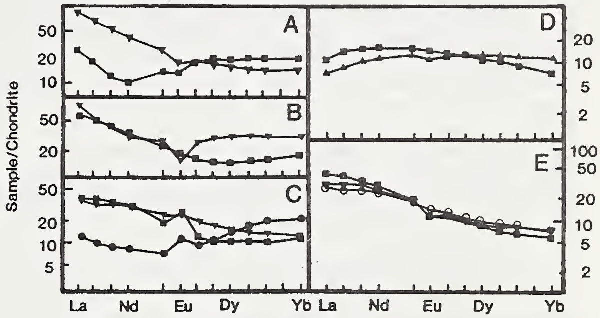

Fig. 1. REE patterns for McBride xenoliths. (A) metasedimentary (▼) = 83-157, (■) = 85-101; (B) felsic (■) = 83-160, (▼) = 83-162; (C) restitic (■) = 83-159, (▼) = 85-107, (●) = 85-114, (D) cumulate (▲) = 83-158, (■) = 85-106, and (D) possible melts (■) = 85-100, (○) = 85-108, (▼) = 85-120.

U-Pb ZIRCON CHRONOLOGY

The U-Th-Pb ages of zircons from 6 of the Hill 32 xenoliths have been measured on the SHRIMP ion microprobe. The following summarizes these data.

(1) Metasedimentary xenolith 83-157 contains zircons of two distinct morphologies: elongate, subhedral igneous zircons and round, high-grade metamorphic zircons. The igneous zircons fall into two age populations, both showing Pb loss at 240 Ma: one 2020 Ma zircon, and several zircons which define a chord between 1579 ± 6, (1 σ) and 245 ± 5 Ma. The round, metamorphic zircons are concordant at 240 ± 20 Ma.

(2) Granodioritic xenolith 83-162 has rounded zircons containing abundant CO_2 fluid inclusions in addition to apatite, feldspar and quartz. These zircons are discordant, with $^{206}Pb/^{238}U$ ages between 200 and 380 Ma. The highest, precisely measured $^{207}Pb/^{206}Pb$ age is 1650 ± 170 Ma, suggesting that, while most of these zircons grew during high-grade metamorphism (trapping CO_2 fluid inclusions), some may be Proterozoic.

(3) Rounded zircons in dioritic xenolith 83-160 mostly fall within uncertainty of concordia, and have $^{206}Pb/^{238}U$ ages between 200 to 350 Ma. It is not known whether this spread represents initial crystallization at 350 Ma with subsequent Pb loss, or continuous zircon crystallization over a 150 Ma period. One zircon is concordant at 2200 Ma, and may be an inherited grain.

(4) Mafic xenolith 83-159 has large, round zircons (up to 300 um) which contain apatite inclusions. Some zircons are nearly concordant at 240 Ma, but most show the presence of much older components. The highest $^{207}Pb/^{206}Pb$ age measured was 1600 ± 35 Ma. The data do not define a single discordance line (MSWD = 6.8). As this rock formed either as a mafic cumulate or restite, the older zircons may be xenocrysts. All zircons appear to have lost Pb at ~240 Ma.

(5) Zircons in mafic xenolith 85-100 also show a spread in ages (>1200 to 250 Ma), but all analyses are concordant. The zircons are small, and generally rounded. As this xenolith formed as a mafic melt in which zircon would not be saturated, the range in ages suggests the zircons are xenocrystic. It is possible that the melting occurred about 400 Ma ago and that the zircons were affected by metamorphism at 240 Ma.

(6) Finally, mafic xenolith 85-107 contains an abundance of zircons of variable sizes and morphologies. Elongate, igneous zircons contain inclusions of acicular apatite, clinopyroxene, pyrrhotite and Fe-Ti oxides. In addition, many of these zircons are riddled with small (~10μm) felsic melt inclusions, with an immobile vapor bubble. Round, high-grade metamorphic zircons are also found in this sample. The $^{206}Pb/^{238}U$ ages of the two distinct morphological zircon types show complete overlap, from 240 to 340 Ma. The abundant igneous zircons, which crystallized from a felsic melt, were probably left behind in the residuum during partial melting.

In summary, the zircon ages for these 6 xenoliths show that all have undergone high-grade metamorphism at ~240 Ma. The lack of zircon ages less than about 200 Ma suggests that either recent (0 Ma) Pb loss has removed a small portion of the radiogenic Pb, or the zircons have remained closed to Pb loss after cooling below their blocking temperature at the close of the late Permian orogeny. It is possible that zircon Pb loss was inhibited by the continuous annealing of radiation damage to the zircon structure that would take place in lower crustal P-T conditions.

Some xenoliths formed during the late Permian event (e.g., mafic restite 85-107; dioritic xenolith 83-160), whereas others formed in the Proterozoic, and were metamorphosed at 240 Ma (83-157, 83-162). It is not possible to determine if the older xenoliths experienced one or multiple metamorphic events. It is more difficult to constrain the age of the mafic xenoliths with apparent xenocrystic zircons (83-159, 85-100), as there are no good criteria to distinguish metamorphic from igneous zircons in these samples. Because of the predominance of ages between 400 and 240 Ma in 85-100, this melt may have intruded the deep crust at ~400 Ma and been metamorphosed later. Similarly, 83-159 has many zircons falling between 350 and 200 Ma, suggesting intrusion of this melt during the early stages of the late Permian event.

The well determined age of 1575 Ma for the igneous zircons in metasediment 83-157 and the less precise age of 1670 ±170 Ma for felsic xenolith 83-162 correspond to the timing of high-grade metamorphism and granite intrusion for the Georgetown Inlier (Black et al., 1979). Significant granite-forming events occurred during the Paleozoic at 400 Ma and 270-320 Ma (Black, 1980); the latter event is well represented in the xenolith suite, and the 400 Ma event is documented in one sample (85-100).

LOWER CRUSTAL HISTORY

The compositional and age data derived from these xenoliths can be used to construct a geological history for the lower crust. At least some of the lower crustal rocks formed during the Proterozoic at the earth's surface. These rocks were subsequently tectonically emplaced into the lower crust. The timing of this event is, as yet, poorly known, but may have accompanied the Paleozoic, granite-forming orogenies. Whatever the timing, this event did not involve double-thickening of the crust, because the rocks apparently remained in the lower crust for a considerable length of time (at least 300 Ma). The ~400 Ma granite-forming event did not appreciably affect the older rocks in this region, but one mafic xenolith may represent melt intruded into the crust at this time. The ~300 Ma granite-forming event clearly affected all of this portion of the lower crust. This event included addition of mafic, mantle-derived material to the crust and melting and metamorphism of older crust. The lack of significant erosion since ~300 Ma suggest that this orogeny was accompanied by minimal crustal thickening, but substantial heat input, most likely through intrusion of mantle-derived melts. The zircon-free mafic xenoliths within the suite may represent such material, or may be related to the Cenozoic basaltic volcanism, like the Chudleigh province xenoliths.

REFERENCES

Black, L.P. 1980. Rb-Sr systematics of the Claret Creek ring complex and their bearing on the origin of Upper Palaeozoic igenous rocks in northeast Queensland. **J. Geol. Soc. Australia** 27, 157-166.
Black, L.P., Bell, T.H., Rubenach, M.J. and Withnall, I.W. 1979. Geochronolgy of discrete structural-metamorphic events in a multiply deformed Precambrian terrain. **Tectonophys.** 54, 103-137.
Rudnick, R.L., McDonough, W.F., McCulloch, M.T. and Taylor, S.R. (1986) Lower crustal xenoliths from Queensland, Australia: evidence for deep crustal assimilation and fractionation of continental basalts. **Geochim. Cosmochim. Acta** 50.