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Nd-Pb isotopic characteristics of the Mordor Complex, Northern Territory: Mid-Proterozoic potassic magmatism from an enriched mantle source

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The Mordor Complex, a series of highly differentiated potassic rocks (phlogopite lherzolite, phlogopite wehrlite to syenite) which intrudes Precambrian gneiss and amphibolite of the Arunta Block, central Australia, is a rare example of highly potassic magmatism of pre-Phanerozoic age. Sm-Nd and U-Pb whole-rock isochrons confirm a previously published Rb-Sr emplacement age of ~ 1150 Ma. The magmas of the complex possessed a range of initial isotopic compositions, with initial $^{87}Sr/^{86}Sr$ 0.71 (from Langworthy & Black 1978), εNd from -9.5 to -11.6, initial $^{206}Pb/^{204}Pb$ from 16.33 to 16.85 and initial $^{207}Pb/^{204}Pb$ from 15.46 to 15.56, and were derived from isotopically evolved, 'enriched mantle' sources, in common with many Phanerozoic examples of potassic magmatism. Evolution of the highly negative initial εNd values requires that Sm/Nd fractionation occurred in the magma sources at least ~ 830 Ma prior to emplacement of the complex, suggesting that the Mordor sources were generated either prior to or shortly after formation of Arunta Block crust at ~ 2000 Ma. The processes generating enriched mantle sources, such as those from which many Phanerozoic examples of potassic magmatism are derived, have therefore operated since at least the mid-Proterozoic.

Key words: Arunta Block, enriched mantle, mid-Proterozoic potassic magmatism, Sr, Nd and Pb isotopes.

INTRODUCTION

Pre-Phanerozoic examples of the ultrapotassic igneous suite (with MgO >3 wt%, K_2O >3 wt% and K_2O/Na_2O >2; Foley *et al* 1987) are comparatively rare in the geological record. Of the 82 ultrapotassic rock localities from 29 countries listed in the comprehensive summary of Foley *et al* (1987), only three or four occurrences pre-date the Palaeozoic Era. This apparent scarcity suggests that prevailing conditions did not favour the generation of these chemically unusual magmas during the earlier part of Earth's history, perhaps as a result of generally higher heat-flow or the operation of a different tectonic regime. Many Phanerozoic occurrences of potassic magmatism possess unusual isotopic characteristics, with radiogenic $^{87}Sr/^{86}Sr$ and unradiogenic $^{143}Nd/^{144}Nd$ (e.g. McCulloch *et al* 1983; Vollmer *et al* 1984; Fraser *et al* 1985; Nelson *et al* 1986) indicating derivation from so-called 'enriched mantle' sources, and it is important to establish whether this is also the case for older examples, particularly if models for the generation of potassic magmatism involving sediment recycling (Nelson & McCulloch 1988) are valid. In this study, Nd and Pb isotopic data from a well preserved Proterozoic potassic intrusion are compared with the available data-base for younger examples of potassic magmatism.

The Mordor Complex

The Mordor Complex (Langworthy & Black 1978) is a sub-circular, composite intrusion of ~6 km diameter, located ~50 km east-northeast of Alice Springs in the Northern Territory (Fig. 1). It intrudes Proterozoic felsic gneisses and amphibolites of the Arunta Block, adjacent to a deep crustal fracture, the Woolanga Lineament. The complex consists of unmeta-

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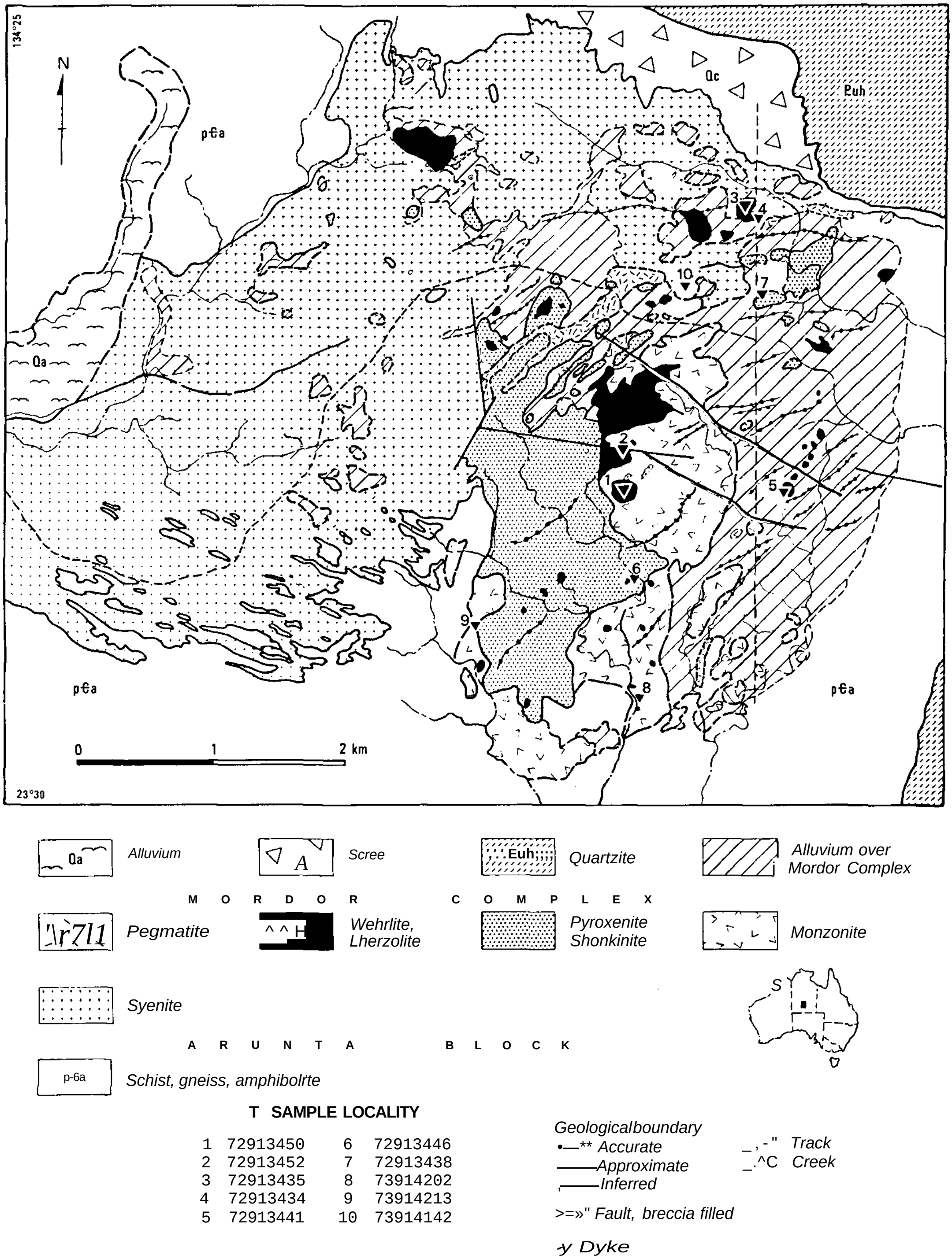

Fig. 1 Geological map of the Mordor Complex, Arunta Block (after Langworthy & Black 1978). Sample localities are shown except for 4578, which was collected from related rocks at Tephina Gorge, 10 km southwest of the Mordor Complex.

morphosed, well preserved, highly differentiated alkaline rocks ranging in composition from phlogopite-bearing werhlites and lherzolites to consanguineous monzonites and syenites. Langworthy and Black (1978) demonstrated that the Mordor rocks have a limited range in SiC>2 content (42.7-52.7 wt°/o) and display continuous smooth chemical variation which can be accounted for entirely by differentiation processes. They also argued that extensive contamination of the magmas by country rock was inconsistent with the observed geochemical and $^{87}Sr/^{86}Sr$ data. Rb-Sr whole-rock data obtained by these authors indicated an age of 1180 ± 90 Ma with an initial $^{87}Sr/^{86}Sr$ ratio of 0.7106 ± 0.0006. The high initial $^{87}Sr/^{86}Sr$ ratio, also indicated by two internal (mineral) isochrons (0.7111 ±0.0002 and 0.7106 ±0.0001), was interpreted by Langworthy and Black (1978) as a primary feature of the source magma from which the complex differentiated.

This study was undertaken in order to evaluate the assertion that the high initial $^{87}Sr/^{86}Sr$ of the complex is a primary feature and therefore indicates derivation of the magmas of the complex from an enriched mantle source. As extensive differentiation of the complex resulted in a relatively wide range in Sm/Nd ratios, the Sm/Nd technique has been applied to obtain the initial $^{143}Nd/^{144}Nd$ composition of the complex and an independent estimate of its age of crystallization. Sm and Nd are considerably less mobile than Rb and Sr during low temperature alteration, allowing the possibility of post-emplacement resetting of the Rb-Sr isotopic system to be evaluated. Selected whole-rock samples have also been analysed for U and Pb concentrations and Pb isotopic compositions to determine the initial Pb isotopic characteristics of the complex.

ANALYTICAL PROCEDURE

The samples were crushed in an agate Siebtechnik mill. About 500 mg of the sample powders were dissolved in concentrated HF-$HC1O_4$ in teflon pressure capsules at 200°C for at least 48 h, the resulting solutions evaporated and the samples redissolved in 6 N HC1 in teflon pressure capsules for a further 24 h. Each sample was then redissolved in 1 N HC1 and split into three aliquots, two of which were respectively mixed with ^{147}Srn-^{150}Nd (for Sm-Nd concentration and Nd isotopic composition analysis) and 235Tj_208pD (for U and Pb concentration analysis) spikes, and the third used for Pb isotopic composition analysis. The remaining analytical procedures are described more fully in Nelson *et al* (1986). Total processing blanks were **<1** ng for Nd and <5 ng for **Pb.**

RESULTS

Sm-Nd isotopic analysis

Nd/Sm ratios in the Mordor rocks (Table 1) vary from 4.7 to 6.2 (chondritic«3), indicating moderate light rare earth element (LREE) enrichment. Measured £Nd(0) values range from — 19.9 to —24.3. The results define a poorly constrained Sm-Nd isochron (Fig. 2), indicating an age of 1100 ± 280 Ma (all quoted errors are at the 95% confidence level) and an initial 6Nd of -10.3 ±3.1. One sample (3435) with higher $^{147}Sm/^{144}Nd$ is not within experimental error of the line defined by the other points and has been omitted from the regression (see discussion of excess scatter of data points about the isochrons). The large uncertainties in the age and initial ratio of the Sm-Nd isochron are due mainly to the limited spread in the measured $^{147}Srn/^{144}Nd$ and $^{143}Nd/^{144}Nd$ ratios, as the low mean square of weighted deviates (MSWD) of 0.53 indicates that the remaining points fit the isochron within their assigned analytical error. The Sm-Nd isochron age is in general agreement with the whole-rock Rb-Sr isochron age of 1180 ± 90 Ma and the mineral isochron ages of 1128 ± 20 Ma and 1118 ± 17 Ma obtained by Langworthy and Black (1978) (after recalculation using the revised ^{87}Rb decay constant of Steiger & Jaeger 1977).

The unradiogenic initial $^{143}Nd/^{144}Nd$ and radiogenic initial $^{87}Sr/^{86}Sr$ may be due to crustal contamination processes. However if contamination took place during emplacement at 1150 Ma by bulk assimilation of typical continental crustal material with ~ 30 parts/10^6 Nd and £Nd » — 10 to — 20, then a mantle-derived magma with 50 parts/10^6 Nd and £Nd of +5 would need to assimilate an amount of crustal material substantially greater than its own original mass to acquire an £Nd of —10. There is no evidence of such extensive crustal contamination in the major- or trace-element

Table 1 Samarium-neodymium isotopic data for the Mordor Complex.

Sample		Sm parts/10^6	Nd parts/10^6	'^{4}7Sm/'^{44}Nd*	i«Nd/'^{44}Ndt	£Nd(0)	£Nd*
3434	phlog. lherzolite	3.25	16.82	0.1167	0.51073 ± 2	-21.7	-10.2
3435	phlog. lherzolite	11.9	56.0	0.1283	0.51074 ± 2	-21.4	-11.6
3438	phlog. hy. shonkinite	6.13	78.0	0.1070	0.51066 ± 3	-23.1	-10.2
3441	phlog. lherzolite	12.2	63.5	0.1158	0.51073 ± 3	-21.5	-9.9
3446	phlog. shonkinite	16.7	95.7	0.1057	0.51068 ± 2	-22.5	-9.5
3450	phlog. wehrlite	8.32	40.3	0.1248	0.51082 ±2	-19.9	-9.6
3452	phlog. wehrlite	12.5	72.2	0.1259	0.51079 ± 3	-20.4	-10.2
4142	syenite	9.73	60.4	0.0975	0.51060 ±3	-24.1	-9.9
4202	melamonzonite	21.9	128.1	0.1035	0.51064 ±2	-23.3	-9.9
4213	monzonite	28.2	170.4	0.1002	0.51063 ±2	-23.5	-9.7
4578	shonkinite	11.4	68.4	0.1010	0.51059 ±2	-24.3	-10.6

•Uncertainty in >^{4}7Sm/'^{44}Nd is 0.1% (2<r).
tNd isotopic ratios normalized using ^{146}Nd/^{142}Nd=0.636151. The value obtained for BCR-1 standard is 0.511833 ±20.
$\varepsilon_{Nd}(0)$ = (^{M3}Nd/^{144}Nd$_{rae}$as/^{M3}Nd/^{144}NdcHUR-l)X 10" where ^{143}Nd/'^{44}Nd$_{CHU1!}$ = O.511836.
*£Nd calculated at 1150 Ma using ^{147}Sm/i^{44}Nd$_C$Hun = 0.1967.

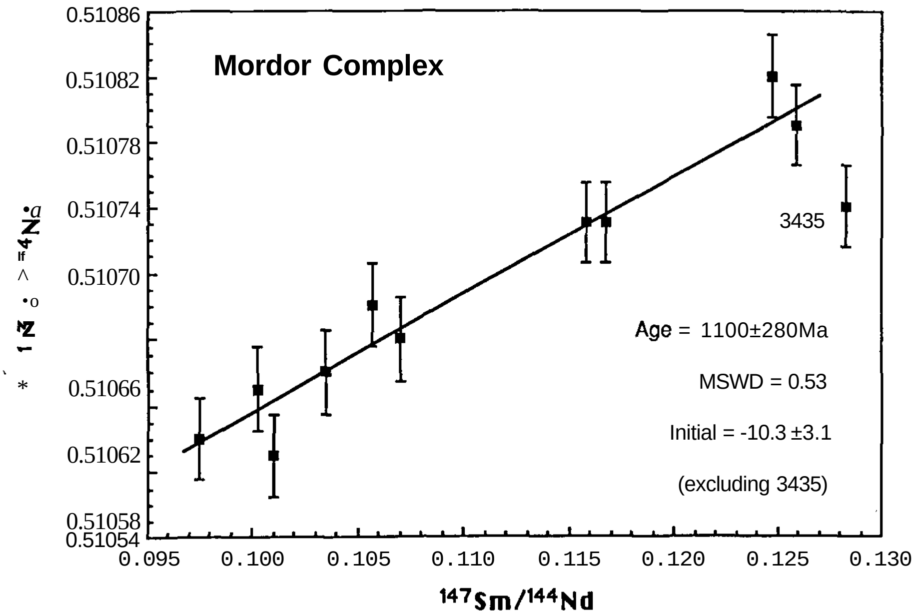

Fig. 2 ^{147}Sm/^{144}Nd-^{143}Nd/^{144}Nd isochron diagram for the Mordor Complex.

characteristics of the Mordor rocks. Furthermore, no correlations exist between differentiation parameters, such as Mg/(Mg + Fe), and £Nd, as might be anticipated if the complex assimilated large amounts of continental crust during its differentiation. The negative initial £Nd therefore suggests that the rocks of the complex were derived from a source having long-term low Sm/Nd (i.e. enriched in the LREE) prior to their emplacement, consistent with the assertion of long-term high Rb/Sr in the source made by Langworthy and Black (1978) from consideration of Rb-Sr isotopic systematics.

U-Pb isotopic analysis

Measured U/Pb ratios in the Mordor Complex rocks are generally low (^{238}U/^{204}Pb<6.45; Table 2). Measured Pb isotope ratios have a restricted range, with ^{206}Pb/^{204}Pb varying from 16.639 to 17.645 and ^{2}<>7pb/^{204}Pb from 15.46 to

Table 2 Uranium-lead isotopic data for the Mordor Complex.

Sample		U* parts/10^6	Pb parts/10^6	238TJ/204Pb	$^{206}Pb/^{204}Pb$† meas.	(initial)	$^{207}Pb/^{204}Pb$ meas.	(initial)	$^{208}Pb/^{204}Pb$ meas.
3434	phlog. lherzolite	0.251	5.69	3.13	16.942	(16.33)*	15.517	(15.47)	38.162
3435	phlog. lherzolite	0.919	21.1	3.10	16.963	(16.36)	15.537	(15.49)	38.237
3438	phlog. hy. shonkinite	1.13	24.2	3.32	17.088	(16.44)	15.551	(15.50)	38.198
3441	phlog. lherzolite	0.978	25.2	2.79	17.397	(16.85)	15.601	(15.56)	38.293
3446	phlog. shonkinite		12.0		16.979		15.498		37.715
3450	phlog. wehrlite		3.44		16.902		15.491		37.289
3452	phlog. wehrlite	0.064	3.34	1.13	16.666	(16.45)	15.480	(15.46)	37.233
4142	syenite		35.5		16.639		15.457		36.826
4202	melamonzonite	1.19	36.0	2.34	17.027	(16.57)	15.523	(15.49)	37.713
4213	monzonite	0.223	9.8	1.60	16.882	(16.57)	15.560	(15.54)	37.509
4578	shonkinite	3.22	36.6	6.45	17.645	(16.39)	15.587	(15.49)	39.669

*U and Pb concentrations determined by isotope dilution mass spectrometry. Uncertainty in $^{238}U/^{204}Pb$ is estimated at <0.5% (2σ).

†All Pb isotopic analyses obtained in duplicate. Errors (based on two-way analysis of variance of duplicate analyses) at the 1σ level; $^{206}Pb/^{204}Pb$ ± 0.011, $^{207}Pb/^{204}Pb$ ± 0.014, $^{208}Pb/^{204}Pb$ ± 0.033. The values obtained for NBS-981 during this study are: $^{206}Pb/^{204}Pb$ = 16.927 ± 0.009, $^{207}Pb/^{204}Pb$ = 15.486 ± 0.013, $^{208}Pb/^{204}Pb$ = 36.668 ± 0.044.

*Age-corrected Pb isotopic ratios (in parentheses) calculated using an emplacement age of 1150 Ma.

15.60 (Table 2). The Pb isotopic compositions form an approximately linear array (Fig. 3) with a slope of 0.130, corresponding to an age of ~2100 Ma. This is ~ 1000 Ma older than the emplacement age of the Mordor Complex indicated by Rb-Sr and Sm-Nd isochrons. The degree of variation of the Pb-Pb correlation from a linear array is greater than can be explained by experimental error alone (i.e. MSWD = 3.3).

Regression of ^{238}U/$^{2(}$>4pb against ^{2}<>6pb/^{204}Pb (Fig. 4) gives a McIntyre *et al* (1966) model 3 age of 1000 ± 240 Ma, in agreement with the ages obtained by Rb-Sr and Sm-Nd methods, with a poorly defined $^{206}Pb/^{204}Pb$ initial ratio of 16.52 ± 0.19. The model 3 fit indicates that the

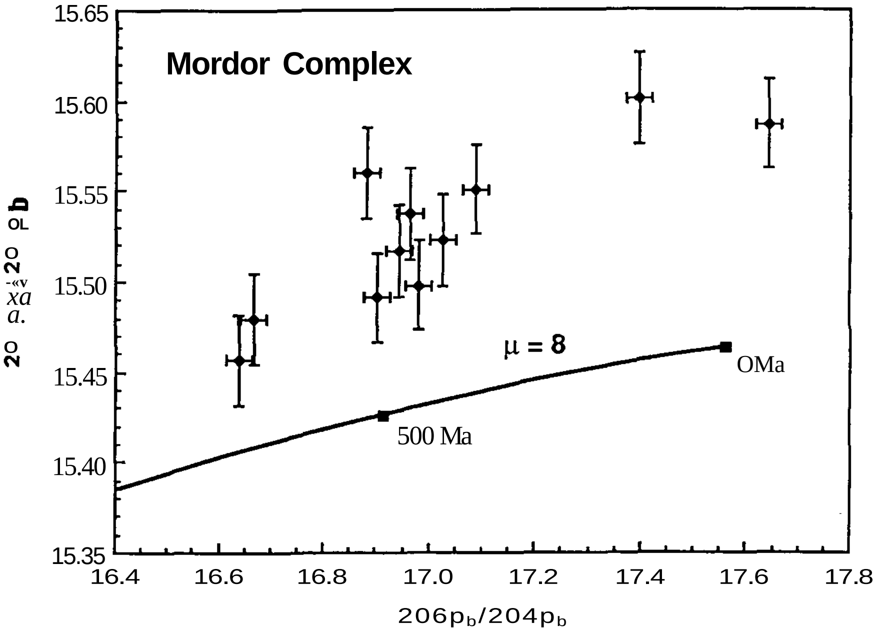

Fig. 3 Measured $^{207}Pb/^{204}Pb$ versus $^{206}Pb/^{204}Pb$ for the Mordor Complex. The single-stage growth curve with *H* = $ (which approximates the Pb isotopic evolution of the earth's mantle) is shown for comparison.

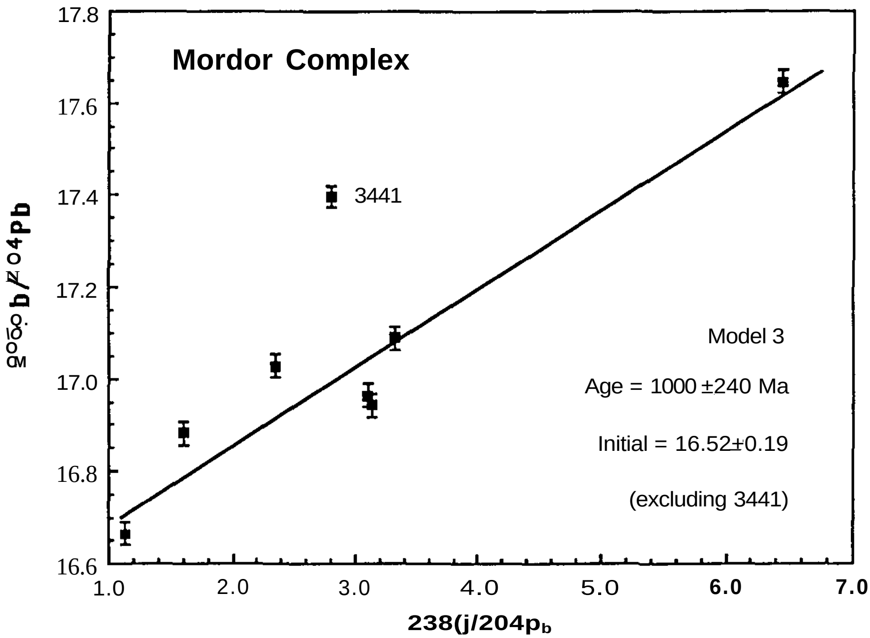

Fig. 4 $^{238}U/^{204}Pb$–$^{206}Pb/^{204}Pb$ isochron diagram for the Mordor Complex.

error in the regression is independent of the U/Pb variation and is more likely to be due to variability in the initial ratio rather than post-emplacement mobility of U or Pb. Langworthy and Black (1978) also argued that the complex was isotopically heterogeneous at the time of emplacement. Sample 3441, which has considerably higher $^{207}Pb/^{204}Pb$ than the other samples, does not lie on the ^{238}U–^{206}Pb isochron. As the ^{238}U–^{206}Pb system has (at least partly) recognized the ~ 1150 Ma emplacement event, it is unlikely that the 2100 Ma age indicated by the Pb-Pb correlation has any direct chronological meaning. Instead, the Pb-Pb array probably reflects variation in the initial Pb isotopic compositions, particularly the initial $^{207}Pb/^{204}Pb$ (see below for further discussion).

The initial $^{206}Pb/^{204}Pb$ and $^{207}Pb/^{204}Pb$ ratios calculated using the measured $^{238}U/^{204}Pb$ ratios and an age of 1150 Ma are given in Table 2. Apart from sample 3441, the calculated initial ratios lie within a relatively narrow range of 16.33-16.57 for $^{206}Pb/^{204}Pb$ and 15.46-15.54 for $^{207}Pb/^{204}Pb$. This is considerably more radiogenic than values estimated for the mid-ocean ridge basalt (MORB) mantle reservoir (which may be approximated by a single stage curve with $\mu \approx 8$) at 1150 Ma, but is comparable with the values indicated by the Cumming and Richards (1975) model 3 Pb ore growth curve at that time.

DISCUSSION

Analysis of excess scatter in isochrons of the Mordor Complex

All three geochronological systems applied to the Mordor Complex display evidence of scatter in excess of that attributable to experimental error. This 'geological scatter' probably reflects either: (1) variation in the initial isotopic characteristics of the complex; or (2) the partial resetting of the isotope systems following its emplacement. If misinterpreted, this geological scatter can cause substantial shifts in the slopes of isochrons and, consequently, incorrect age dates. The following discussion presents the results of a mathematical analysis of geological scatter in isochrons of the complex.

If the geological scatter is due to variation in the initial isotopic compositions of rocks, it might be anticipated that variation in initial $^{87}Sr/^{86}Sr$ and initial $^{143}Nd/^{144}Nd$ is somehow correlated. This possibility has been examined as a function of age using two independent parameters. The MSWD is commonly used as a measure of the scatter of points about a line. Normally, points are weighted inversely as the square of their analytical error. However because the internal (or within-run) analytical error of all isotopic analyses examined here is similar to or less than the external error (based on analytical reproducibility of the analyses), all points have been weighted equally in the calculation of an analogous parameter, the mean square of unweighted deviates (MSUD). As with the MSWD, this parameter cannot distinguish between scatter about a line and scatter around a point. Consequently, a second parameter, the correlation coefficient (r), has also been used as a measure of the degree of linearity of the age-corrected data array. Because different geological processes may be responsible for scatter in whole-rock and mineral data (e.g. crustal assimilation by a magma operates on a whole-rock scale, whereas scatter on a mineral scale is generally due to post-emplacement processes), only whole-rock data have been used in the following analysis. Uncertainties in $^{87}Rb/^{86}Sr$ and $^{147}Sm/^{144}Nd$ have not been taken into account in the calculations. Although the uncertainty in the initial $^{87}Sr/^{86}Sr$ and $^{143}Nd/^{144}Nd$ due to error in these ratios will increase with emplacement age, this is unlikely to significantly affect the results of the analysis over the narrow age range examined.

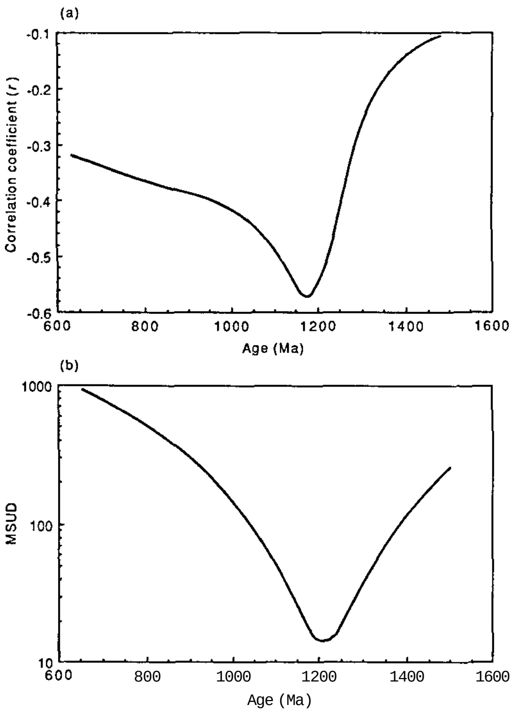

Fig. 5 (a) Correlation between age-corrected values of $^{87}Sr/^{86}Sr$ and $^{143}Nd/^{144}Nd$ plotted against age. The correlation coefficient *(r)* is used here as a measure of the linearity of the age-corrected values. The age-corrected array is most linear at —1180 Ma. (b) Correlation between age-corrected values of "Sr/s^Sr and i«Nd/^{144}Nd plotted against age. The mean square of unweighted deviates (MSUD) is used here as a measure of the deviation of the age-corrected values from a single line or point (note log scale). The diagram demonstrates that the age-corrected array clusters, or is most linear, at —1210 Ma.

The results of the analysis of covariation between initial $^{87}Sr/^{86}Sr$ (data from Langworthy & Black 1978) and initial $^{143}Nd/^{144}Nd$ with age are presented in Fig. 5. The age-corrected $^{87}Sr/^{86}Sr$ and $^{143}Nd/^{144}Nd$ ratios are most strongly correlated at ~1200 Ma, which is within the error of the whole-rock Rb-Sr and Sm-Nd isochron ages. Exclusion from the analysis of sample 3435, which has significantly different initial $^{143}Nd/^{144}Nd$, produces similar results, with MSUD and correlation coefficient minima occurring at times which are within the error of the whole-rock Rb-Sr and Sm-Nd isochron ages. This analysis implies that the Mordor Complex possessed a range of initial $^{87}Sr/^{86}Sr$ and initial $^{143}Nd/^{144}Nd$ compositions which were negatively correlated. The age-corrected $^{87}Sr/^{86}Sr$ and $^{143}Nd/^{144}Nd$ array at 1150 Ma is given in Fig. 6b. Although mixing processes will usually generate curved rather than linear arrays on an $^{87}Sr/^{86}Sr$-$^{143}Nd/^{144}Nd$ diagram, it is evident from Fig. 6 that, because of the limited range in initial $^{87}Sr/^{86}Sr$ and initial $^{143}Nd/^{144}Nd$ values compared with the analytical uncertainty, the age-corrected array can be regarded as linear.

A similar analysis can be undertaken using the U-Pb data. If the scatter in the 2o7Pb/^{204}Pb-206pb/204Pb array (Fig. 3) is due to post-emplacement redistribution of U and Pb, this excess scatter in the age-corrected array should disappear at the simulated time of the redistribution event. However throughout the age range 1550Ma-0Ma examined, both the MSUD and the correlation coefficient *r* remain virtually constant. The total variation in *r* is

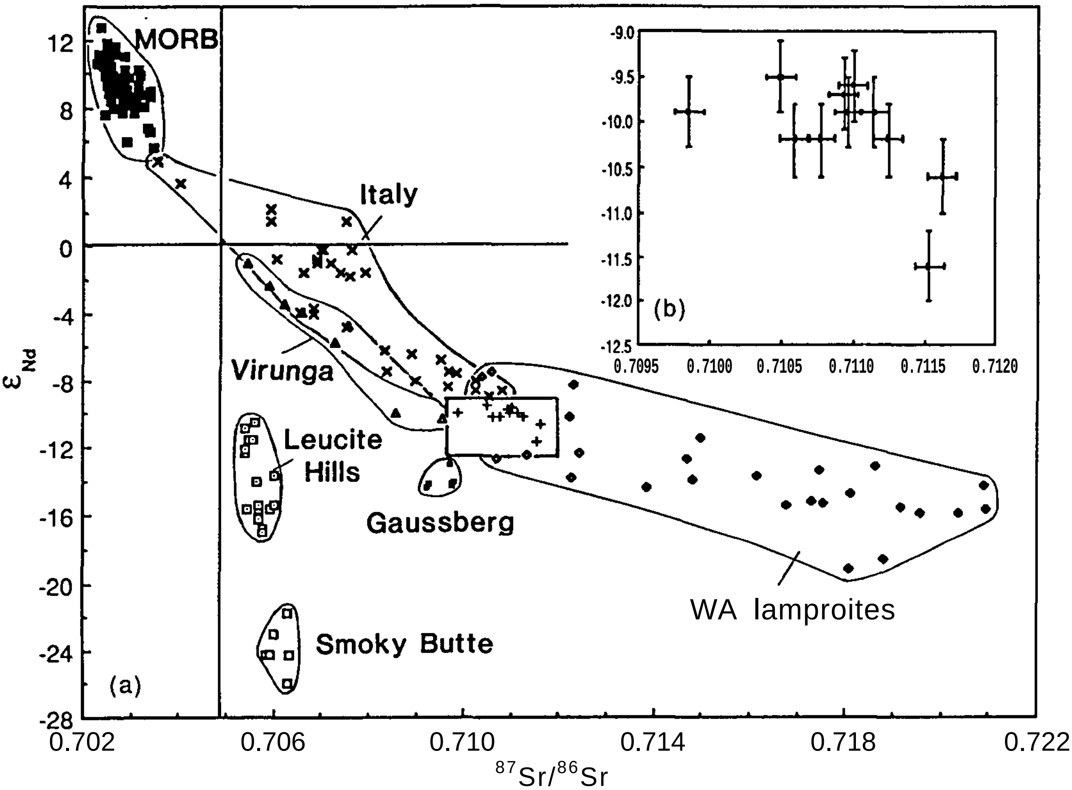

Fig. 6 (a) Initial Sr-Nd isotope plot for the 1150 Ma Mordor Complex compared with data for modern-day MORB and selected potassic igneous rocks. Additional data sources — MORB: Cohen and O'Nions (1982), White and Hofmann (1982); potassic suites: Collerson and McCulloch (1983), McCulloch *et al* (1983), Vollmer and Norry (1983), Smith (1983), Vollmer *et al* (1984), Fraser *et al* (1985), Nelson and McCulloch (1988). (b) Age-corrected (1150 Ma) array of $^{87}Sr/^{86}Sr$ versus $^{143}Nd/^{144}Nd$ for the Mordor Complex. Error bars are 2σ analytical uncertainty limits: no account has been made of error introduced by the age correction.

from 0.865 at 1500 Ma to a minimum of 0.829 at 1200 Ma, with the present-day (i.e. 0 Ma) value being 0.846. The scatter is therefore virtually independent of the present-day U/Pb ratio of the rocks, suggesting that it is due to variation in their initial Pb isotopic compositions or that a redistribution event recently disturbed the U-Pb systematics of the complex.

The slope on the $^{207}Pb/^{204}Pb$-$^{206}Pb/^{204}Pb$ array at the emplacement age of ~ 1150 Ma is 0.159, which corresponds to a Pb-Pb age of ~2440 Ma. The slope of the array is relatively sensitive to the assumed emplacement age. For example, an error of ± 100 Ma in the emplacement age translates to an error of ± 0.0147 in the slope of the array or ±160 Ma in the corresponding Pb-Pb age. Uncertainty in the slope of the age-corrected array because of propagation of analytical error is also likely to be substantial. As the correlation in the age-corrected $^{87}Sr/^{86}Sr$-$^{143}Nd/^{144}Nd$ array is probably due to mixing, it is likely that the $^{207}Pb/^{204}Pb$-$^{206}Pb/^{204}Pb$ array is also the result of mixing and has no age significance.

Phlogopite wehrlite sample 3435 does not plot on the Sm-Nd isochron, yet it plots on the ^{238}U-^{206}Pb isochron, whereas phlogopite lherzolite sample 3441 does not plot on the ^{238}U-^{206}Pb isochron but plots on the Sm-Nd isochron. This suggests that the initial $^{206}Pb/^{204}Pb$ (and presumably also initial $^{207}Pb/^{204}Pb$) variation was not simply correlated with variation in initial $^{87}Sr/^{86}Sr$ and $^{143}Nd/^{144}Nd$. A similar lack of correlation between initial Pb and initial Sr-Nd isotopic characteristics is also found in some Phanerozoic potassic intrusions, such as the Western Australian lamproites (e.g. Nelson *et al* 1986).

Initial isotopic characteristics of the Mordor Complex

The isotopic data indicate that the Mordor Complex had the following range in isotopic characteristics during emplacement — 1**150** Ma: initial $^{87}Sr/^{86}Sr$ = 0.710-0.711, e_Nd ~ -9.5- -11.6, initial $206_{Pb}/204_{Pb}$ « 16.33-16.85 and initial $^{207}Pb/^{204}Pb$ » 15.46-15.56. The Mordor Complex rocks plot within the 'enriched' quadrant on an initial Sr-Nd isotope diagram and within the array defined by other (Phanerozoic) examples of potassic magmatism (Fig. 6). The initial Sr and Nd isotopic compositions are similar to those of potassic lavas from Sabinyo (Vollmer & Norry 1983) and the Roman province (Hawkesworth & Vollmer 1979).

The scatter in the Sr, Nd and Pb isochrons of the complex is probably not caused by post-emplacement disturbance because (1) there is good agreement between the ages indicated by mineral and whole-rock Rb-Sr isochrons obtained by Langworthy and Black (1978) and the Sm-Nd isochron of this study; (2) different initial $^{87}Sr/^{86}Sr$ ratios are indicated by the mineral isochrons of Langworthy and Black (1978); (3) a correlation exists between initial $^{87}Sr/^{8}$«Sr and initial $^{143}Nd/^{144}Nd$; and (4) the complex is unmetamorphosed. The scatter is therefore probably due to either minor crustal contamination during differentiation or to isotopic variation in magmas introduced, as separate pulses, into the magma chamber of the Mordor Complex. The absence of any correlation between differentiation parameters, such as Mg/(Mg + Fe), and £Nd, favours the latter alternative. However, as discussed earlier, the highly radiogenic initial $^{87}Sr/^{86}Sr$ and unradiogenic initial $^{143}Nd/^{144}Nd$ of the Mordor Complex were unlikely to have been acquired by assimilation of continental crust but were probably inherited from the magma source.

Tectonic setting and origin of the Mordor Complex

The Mordor Complex is situated within the Arunta Block, an Early Proterozoic ensialic mobile belt composed principally of medium- to high-grade metamorphosed sediments, mafic rocks and granites. The tectonic evolution of the Arunta Inlier has been summarized by Black *et* a/(1983), Stewart e*a/(1984), Shaw efa/(1984) and Windrim and McCulloch (1986). According to Shaw *et al* (1984), it commenced with mafic and felsic magmatism and deposition of shale and limestone within an east-west-trending rift basin, followed by rapid deformation and regional metamorphism during the Strangways Event, approximately 1800 to 1750 Ma. Black and McCulloch (1984) derived a regional Sm-Nd isochron age of 1980 ± 190 Ma and an initial £Nd of —0.51 ± 3.1 for the oldest known rocks (division 1) within the inlier. Windrim and McCulloch (1986) obtained a regional Sm-Nd isochron of 2070 ± 125 Ma for both felsic and mafic granulites from a more restricted area in the Strangways Range. Both sets of data are consistent with an age of about 2000 Ma (i.e. mantle extraction age) for the formation of Arunta Block crust. The initial £Nd of —h1.5 obtained by Windrim and McCulloch (1986) for both felsic and mafic rock populations regressed separately was interpreted as indicating a short crustal prehistory for the felsic rocks and led these authors to speculate that the protoliths of the felsic rocks were melts of a young mafic protocrust generated during rifting and attenuation. Four subsequent stages of deformation, metamorphism and granitic intrusion have also been recognized (Black *et al* 1983). One of these stages of deformation affected the southern part of the Arunta Block at about the same time as emplacement of the Mordor Complex (L. P. Black unpubl. data). The Arunta Block is cut by several major northwest-trending gravity lineaments which are believed to represent deep crustal fractures. The Mordor Complex and the Late Proterozoic Mud Tank Carbonatite (Black & Gulson 1978) were emplaced adjacent to the Woolanga Gravity Lineament, a major structural, gravity and magnetic lineament which can be traced for several hundred kilometres.

The initial £Nd of —10 indicates an extensive prehistory of low Sm/Nd (i.e. enrichment in LREE) for Mordor Complex magma sources prior to emplacement at — 1**150** Ma. If the Sm/Nd ratios of the Mordor magmas were not substantially modified by crystal fractionation, an estimate of the minimum period of source LREE enrichment may be obtained by assuming a Mordor source Sm/Nd ratio equivalent to that of the highest Sm/Nd ratio of the Mordor rocks. This is because magma extraction is likely to decrease the Sm/Nd ratio, and the highest

Sm/Nd ratio observed in the (undifferentiated) Mordor rocks therefore provides a minimum estimate of the source Sm/Nd. None of the Mordor rocks can be regarded as undifferentiated, and the cumulate rocks contain apatite and clinopyroxene which may have preferentially partitioned the heavy rare earth elements and increased the Sm/Nd ratio of the cumulate rocks relative to that of the parent melt. Therefore the highest Sm/Nd ratio of the felsic differentiates, corresponding with ^{147}Sm/^{144}Nd of ~0.103 for melamonzonite 4202, provides the most reasonable estimate of that of the parent melt and an upper limit to that of the magma source. Assuming that the Mordor source had a ^{147}Srn/^{144}Nd ratio >0.103, an ε_{Nd} of —10 would require a time period of at least ~830 Ma to evolve from a source with $\varepsilon_{Nd} = 0$. This time estimate is regarded as highly conservative, as it is likely that the Sm/Nd ratios of the sources of the Mordor magmas were significantly higher than those observed in the melts themselves, and the required time period is further increased if evolution from an initially depleted mantle source is assumed. If the Mordor Complex magma sources were derived from Arunta Block crust with ^{87}Sr/^{86}Sr of 0.703 and ε_{Nd} of +1.5 at 2070 Ma, an ^{87}Rb/^{86}Sr of 0.56 and ^{147}Sm/H4Nd of 0.093 would be required to generate the observed ^{87}Sr/^{86}Sr of 0.71 and *end* of -10.3 at 1150 Ma. The Rb/Sr ratio required is = 6 times the estimated mantle ratio. The required ^{147}Sm/^{144}Nd ratio is lower than the values typical of upper crustal rocks (which commonly possess ^{147}Sm/^{144}Nd ratios between 0.10 and 0.13) and the values observed in the Mordor rocks. If the Mordor magma sources evolved entirely within the lithosphere of the Arunta Block, these considerations suggest that Sm/Nd fractionation within the sources must have taken place shortly after (i.e. within ~50 Ma of) formation of the Arunta Block crust.

Alternatively, the radiogenic Sr and unradiogenic Nd of the Mordor sources may have evolved to some extent prior to their incorporation into Arunta Block lithosphere. For example, Nelson and McCulloch (1988) proposed that subducted sedimentary material is involved in the generation of enriched mantle sources. Although a model advocating the involvement of subducted sedimentary material in the generation of the Mordor Complex sources eliminates the difficulties associated with evolution of the ε_{Nd} of —10 in only ~850 Ma since the formation of the Arunta Block crust, it requires the existence of nearby pre-existing continental crust, from which the sediments would have been derived, during formation of the Arunta Block.

The Mordor Complex therefore represents a further example of intracratonic potassic magmatism which has been derived from an enriched mantle source, and provides convincing evidence that the processes generating enriched mantle sources, such as those from which many Phanerozoic examples of alkaline magmatism are derived, have operated at least since the mid-Proterozoic.

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