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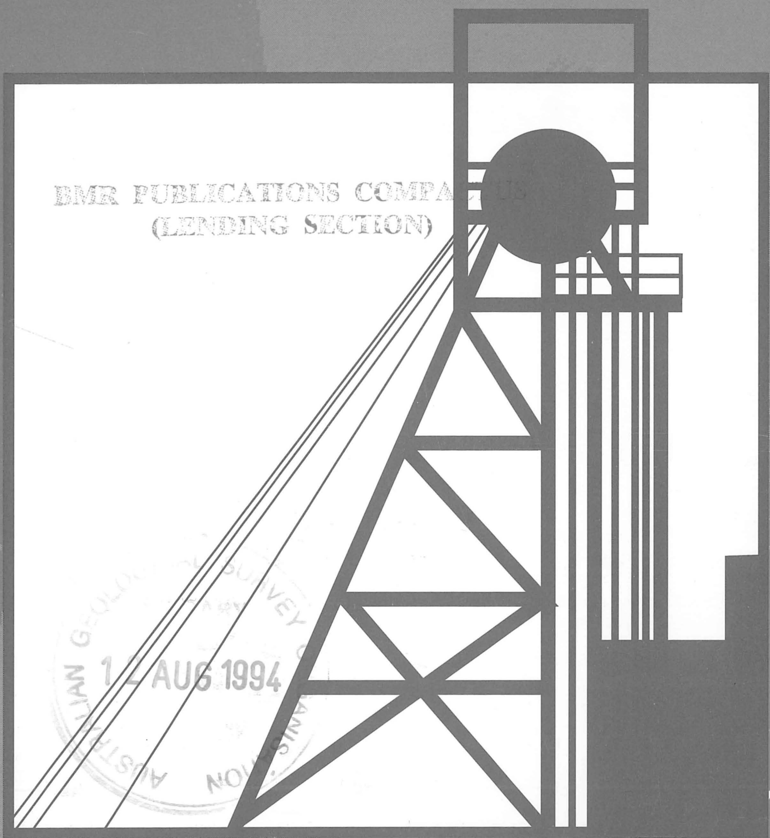
U–Pb zircon ion-microprobe ages from the northern Drummond Basin, northeastern Queensland

L P Black



Record 1994/34

MINERALS AND LAND USE PROGRAM

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L.P. Black

DEPARTMENT OF PRIMARY INDUSTRIES AND ENERGY

Minister for Resources: Hon. David Beddall, MP
Secretary: Greg Taylor

AUSTRALIAN GEOLOGICAL SURVEY ORGANISATION

Executive Director: Harvey Jacka

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ABSTRACT

This study presents ion-microprobe U-Pb zircon isotopic data for nine rocks from the northern Drummond Basin. Precise crystallisation ages could be derived from only seven of those rocks. One of the remaining rocks, of Devonian-Carboniferous age, yielded just two grains of possible syn-magmatic zircon; the other Devonian-Carboniferous volcanic yielded none at all. Although the data conflict with some previously held views on the sequence of igneous events, persuasive arguments are presented in support of the veracity of the data and their geological interpretation.

Late Palaeozoic magmatism within the Bulgonunna Volcanics appears to have occurred over an approximately 15 Ma time range spanning the Carboniferous-Permian boundary. The earliest identified activity was the formation of the Locharwood Rhyolite and correlated felsic volcanics at 304.7± 3.2 Ma (pooled age from two samples). Dacitic andesite and dacitic ignimbrite crystallised significantly later, at 297.4±2.9 Ma (pooled age from two samples). The 293.5±5.6 Ma Arundel Rhyolite is also significantly younger than the Locharwood Rhyolite. Igneous activity ceased with the emplacement of coeval potassic and sodic granites at 289.4±4.0 Ma (pooled age from two samples). Their similar age and initial $^{87}Sr/^{86}Sr$ (0.7045) indicate that these granites are co-magmatic.

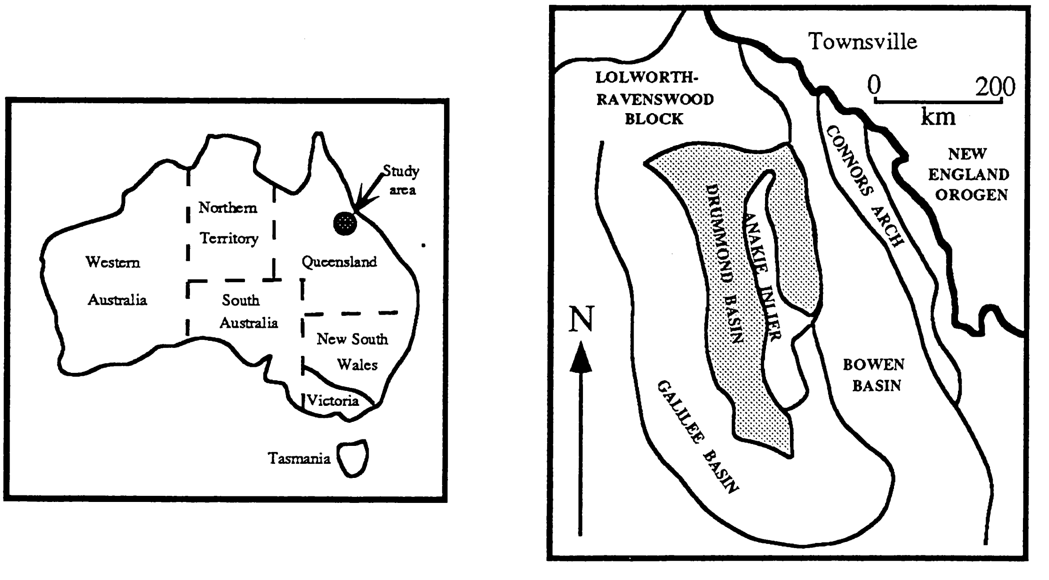

Fig. 1. Map showing the regional setting of the Drummond Basin (after McPhie et al., 1990).

INTRODUCTION

Until now, only a limited amount of isotopic dating had been done on the rocks of the northern Drummond Basin. Initially, Webb & McDougall (1968) published a Rb-Sr whole-rock isochron age of 297 Ma for isolated outcrops of the Bulgonunna Volcanics. Granites intruding the volcanics yielded a similar age of 308±25 Ma by the same technique, and a range of K-Ar biotite and hornblende ages (averaging 295 Ma) from 288 Ma to 303 Ma. A granite intruding the Drummond Basin to the west of Anakie yielded K-Ar biotite and hornblende ages ranging from 297 Ma to 312 Ma.

Most of the more recent work has concentrated on mineralised areas, has involved only K-Ar and Rb-Sr mineral dating, and has been published solely in summary form. Without the presentation of analytical data, and in the absence of detailed geological descriptions it is very difficult to assess the significance of such ages, especially as a distinct spread of ages has been reported (e,g., from 283 Ma to 334 Ma - Ewers & others, 1990). For instance, both of those isotopic systems are relatively susceptible to isotopic resetting, and this factor has to be considered in any interpretation of those data.

The current study has been restricted to the U-Pb zircon technique, in order to minimise the effects of isotopic resetting. In order to circumvent the problems associated with bulk grain analyses of zircon, which commonly include the production of meaningless ages through the inadvertant grouping of grains with different ages or histories, all analyses were obtained on the RSES ion-microprobe SHRIMP. This instrument is particularly useful for the selective analysis of parts of individual grains, thereby avoiding metamict or cracked areas which might well not have preserved closed U-Th-Pb systematics since their original crystallisation. SHRIMP also allows the separate analysis of cores and rims within a single grain. The U-Pb zircon data obtained in this study are listed in Table 1 and presented pictorially in Figures 1 to 8.

GEOLOGICAL SETTING

The analysed rocks came from the Burdekin Falls area (mainly covered by the Glendon 1:100 000 Sheet area) of northeastern Queensland, approximately 150 km southeast of Charters Towers. This region (Figs. 1, 2) forms the northern part of the Drummond Basin, a major structural element within the Tasman Fold Belt. At its western and eastern margins, the Drummond Basin is overlain by the continental sediments and acid to intermediate volcanics and volcaniclastics of the Permian to Triassic intracratonic Galilee and Bowen Basins, respectively. The latter, however, also contains extensive shallow marine deposits. Still further to the east is the northernmost extension of the New England Orogen (known here as the Yarrol Province - Day & others, 1978), the easternmost and youngest (Devonian to Permian) component of the Tasman Fold Belt. The Drummond Basin is bounded to the north by the Lolworth - Ravenswood Subprovince, a generally amphibolite-grade, complexly deformed terrane of Lower Palaeozoic or Precambrian age. The subprovince is extensively intruded by granitic rocks (in the Lolworth and Ravenswood Batholiths) of probable Middle Ordovician and Late Silurian age (Webb, 1969, 1970, 1971), and also contains the acid to intermediate Cambro-Ordovician Mount Windsor Volcanics. Broadly comparable (presumed basement) rocks to those in this subprovince also occur in the Anakie Subprovince, which occupies a central band within the Drummond Basin.

The Drummond Basin is a 25 000 km^2 intracratonic basin unconformably overlying Early Palaeozoic basement and consisting of moderately folded Late Devonian to Early Carboniferous sedimentary rocks. With the exception of shallow water marine sequences at its base, the rocks within the basin are almost exclusively of continental origin. Both volcanic (currently assigned to Stones Creek Volcanics, Bimurra Volcanics, and an un-named unit within the Star of Hope Formation - Oversby, personal communication 1994) and volcanogenic representatives are present. The former consists of porphyritic two-pyroxene andesitic lava flows, minor dacitic ignimbrite and rhyolitic lava, and the latter of conglomerate and lithic and feldspathic sandstone derived from andesitic rocks. Most of the sediments were deposited near the eruptive source of their parent igneous rocks (McPhie & others, 1990).

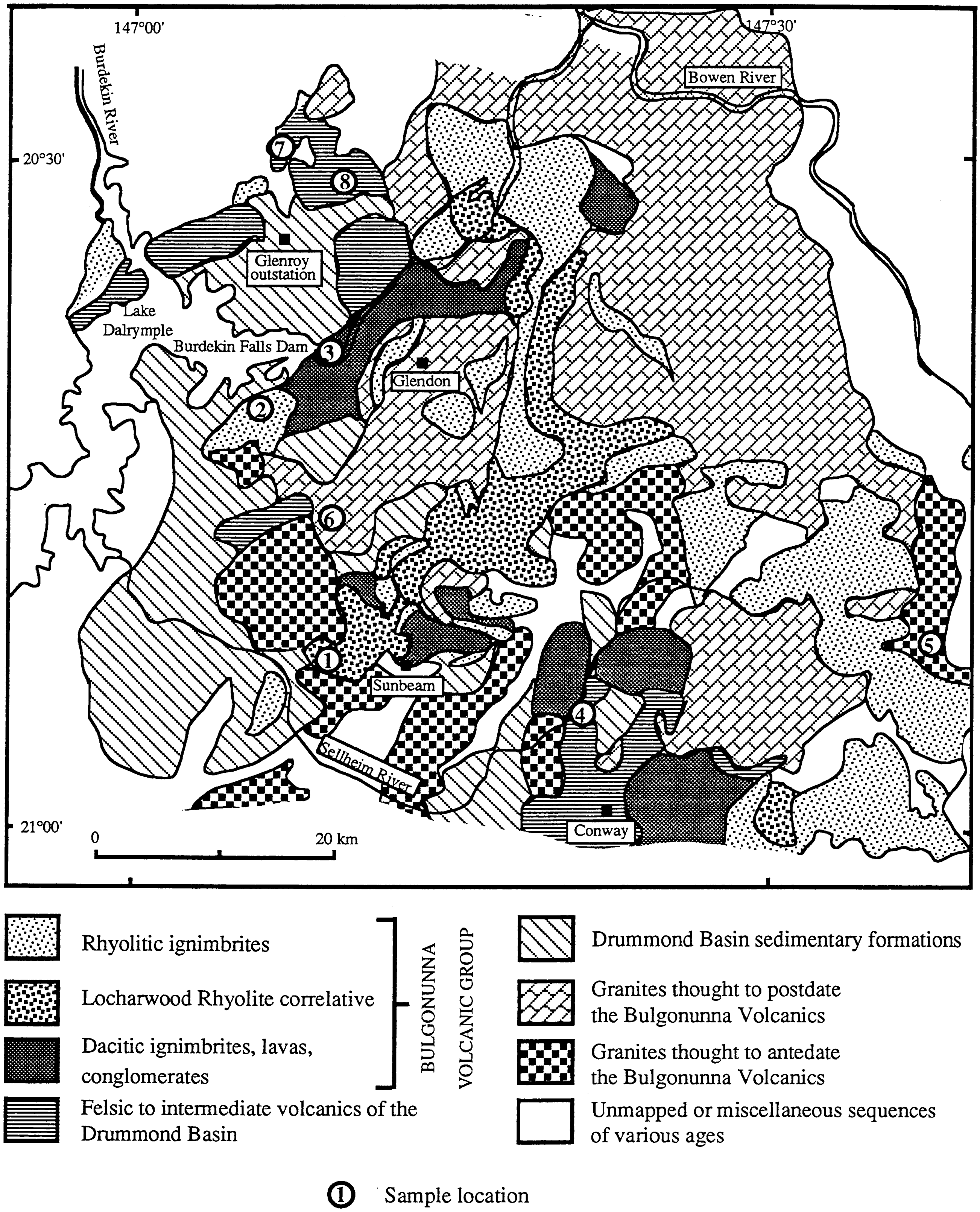

Fig. 2. Geology of the northern part of the Drummond Basin (after McPhie et al. (1990) showing sample localities. 1. 88503170, 2. 89303028, 3. 88502031, 4. 89302132, 5. 89302108, 6. 88302095, 7. 88503023, 8. 89503064. Sample 88502032 was collected from the Byerwen Sheet area, to the southeast of that illustrated.

The two earlier episodes of volcanism were followed by a third, in Permo-Carboniferous times. Although the evidence for the three episodes of volcanic activity is clear enough, it has not always been easy to determine to which of them the rocks of a particular outcrop belongs. However, in association with the results of the current study, it is possible to show that the Permo-Carboniferous volcanics are composed of two broadly different rock associations. One of these is compositionally and texturally quite varied, consisting dominantly of dacitic ignimbrite, lava and conglomerate, but also including rhyolitic ignimbrites and andesites. The other association is dominated by rhyolitic ignimbrites. Apart from an absence of andesites, the rhyolite-dominated association is characterised by quartz and biotite (hornblende is common in the dacite-rhyolite association), and a generally lower degree of deformation. A more detailed discussion of these and other differences, and the aerial distribution of the two associations, is given in McPhie & others (1990).

U-Pb ZIRCON ANALYTICAL DATA

88503170, a welded rhyolitic ignimbrite (G.R. Glendon 157929) from the main volcanic unit in the "Ukalunda" homestead region is considered to be a direct correlative of the Locharwood Rhyolite (discussed next) which occurs to the south (Oversby & others, 1991; Oversby, personal communication 1994). Zircons within this ignimbrite preserve typically igneous forms, with simple prismatic and pyramidal faces, and length:breadth ratios averaging about 3:1. Foreign inclusions and zircon cores are quite common; pronounced zonation was not observed. A total of 22 analyses were made, on 21 different grains. In common with this and other SHRIMP studies, ^{208}Pb correction for common Pb produces a slightly normally discordant mean value for the isotopic data array (Fig. 3), though this is not obvious from the errors associated with individual analyses. As this effect would lead to the calculation of slightly excessive ^{206}Pb/^{238}U ages, the ^{207}Pb common Pb correction technique (which assumes that data points are concordant) has been used for the derivation of ages for all Palaeozoic grains. Common Pb correction for Precambrian (xenocrystic) grains has been made by means of the ^{204}Pb isotope.

Analysis 19.1 has the isotopically most aberrant composition. There are several possible reasons for its extreme composition. First, it represents a clearly defined core which might be significantly older than the enclosing syn-magmatic zircon. But several other cores of this type (16.2 and 18.1) are no older than the general population, and it is therefore possible that these cores are merely a feature of early magmatic crystallisation and are neither xenocrystic nor restitic in nature. A more compelling demonstration of the uniqueness of grain 19.1 is provided in Table 1 which shows that it has by far the highest U, Th and Th/U of all the analysed zircons. Most significantly, this grain has an extremely high common Pb component (^{206}Pb/^{204}Pb is only 32). The combination of these characteristics is consistent with the formation of a highly radiation-damaged lattice from which radiogenic Pb was lost and into which common Pb found easy access. It is exceptionally difficult to quantitatively correct for the very high common Pb in this core, leading to enormous uncertainty in the calculated radiogenic composition.

Deletion of the highly distinctive grain 19.1 does not remove all elements of scatter from the distribution of ^{206}Pb/^{238}U ages, the observed spread being about twice that expected from statistical considerations. However, a data array in which observed error does not exceed expected error is obtained with the additional deletion of grains 8.1 and 10.1. There are no convincing independent criteria to justify the exclusion of these two analyses other than the relatively high U, Th and Th/U of grain 10.1. Notwithstanding, the conformation of 19 of the 22 analyses to a single ^{206}Pb/^{238}U composition is strong evidence that their age of 304.7±4.0 Ma is geologically meaningful, temporally documenting the crystallisation of this ignimbrite.

88502032, from the "type" area (G.R. Byerwen 715376) of the Locharwood Rhyolite (Hutton & others, 1991) 18 km ESE of Bulgonunna Peak (to the SE of the area depicted in Fig. 2) is lithologically similar to, and stratigraphically correlated with, the previously discussed sample. Included zircons are also morphologically comparable to those in 88503170, except that cores are not as common and there is a larger range of elongation ratios (up to about 5:1). All but one of the 19 analysed grains conform to a statistically ideal population in terms of ^{206}Pb/^{238}U (Fig. 4). The exception, grain 1.1, is neither

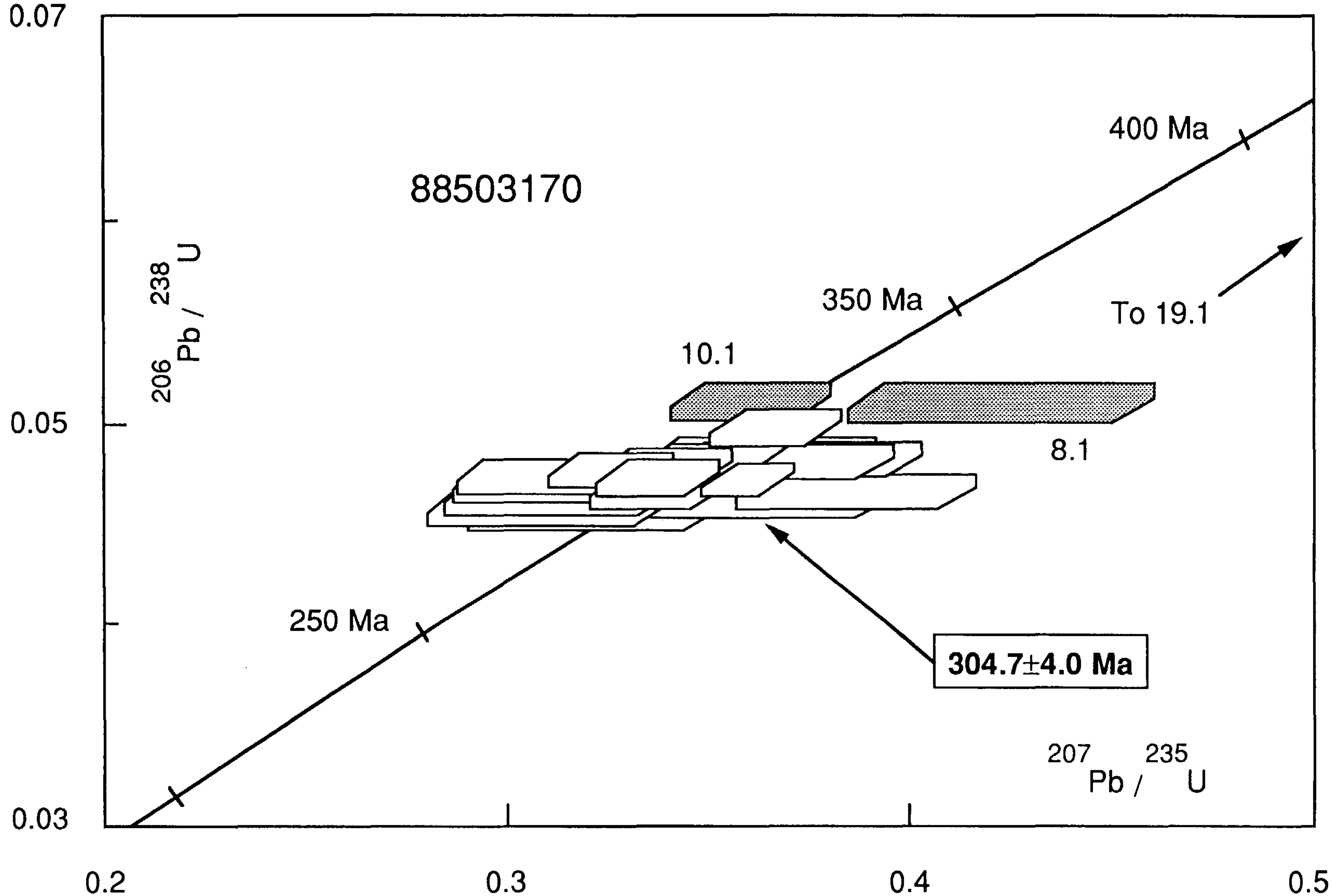

Fig. 3 U-Pb concordia diagram for zircons from 88503170, a correlative of the Locharwood Rhyolite. The 304.7±4.0 Ma crystallisation age is obtained from a statistically tight grouping of 19 ^{207}Pb-corrected ^{206}Pb/^{238}U analyses following the exclusion of analysis 19.1 (see text).

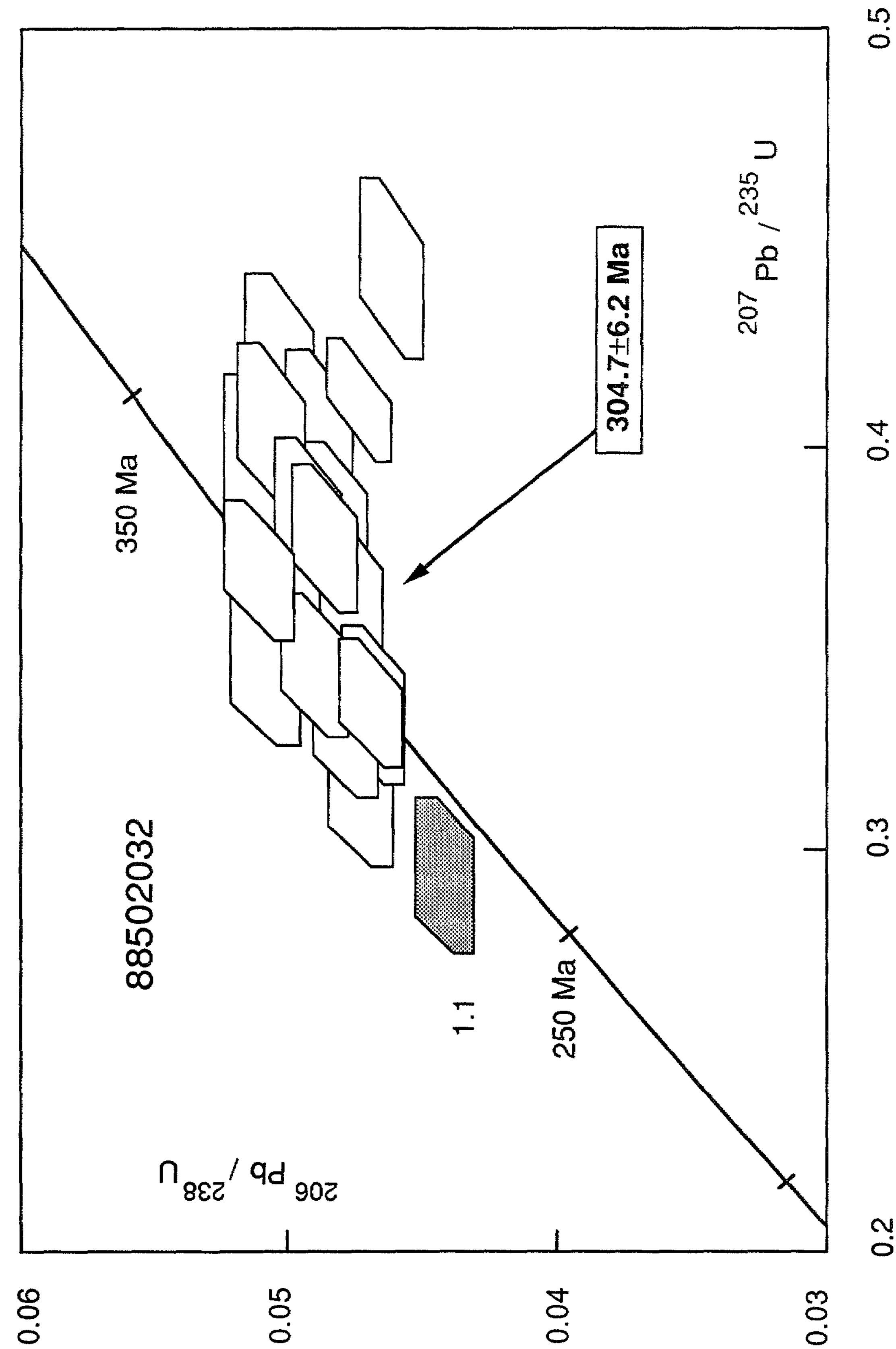

Fig. 4. U-Pb concordia diagram for zircons from 88502032, from the "type" Locharwood Rhyolite. The 304.7±6.2 Ma crystallisation age is obtained from a statistically tight grouping of 18 ^{207}Pb-corrected $^{206}Pb/^{238}U$ analyses following the exclusion of analysis 1.1 (see text).

morphologically nor geochemically distinctive. Its isotopic individuality is considered to be a consequence of analytical conditions, for this analysis is characterised by the lowest measured UO/U of all the zircons analysed from this rock. UO/U is the parameter used to correct Pb/U ratios, and an anomalously low measured UO/U is likely to yield erroneously low Pb/U ages. It is important to note in this respect that the first analysis of the standard on that day (i.e., the immediately preceeding analysis) is also low. Rather than make a somewhat arbitrary upward adjustment to the age of analysis 1.1 in order to minimise this effect, this analysis has been deleted entirely from further calculations. The preferred crystallisation age of 304.7±6.2 Ma for this sample of Locharwood Rhyolite, derived from the remaining 18 zircon grains, is the same as that produced above for its lithologically similar correlative.

89503028, a representative of the Arundel Rhyolite (G.R. Glendon 101137), contains zircons of generally similar morphology to those in Locharwood rhyolite sample 88503170, except that it is mostly somewhat finer, averaging only about 50 μm across. Unlike those in most of the analysed rocks, the zircons in this sample yield a pooled array of concordant ^{208}Pb-corrected data (Fig. 5). Nevertheless, to maintain consistency of detail, ^{207}Pb-corrected data are once again used for $^{206}Pb/^{238}U$ age calculations. All 14 analyses conform to an ideal statistical grouping which yields a crystallisation age for these zircons and their host rock of 293.5±5.6 Ma.

Sample **88502031** (G.R. Glendon 145169) is a welded Smedley Dacite (Oversby, personal communication 1994) from rock pavement at the foot of the Burdekin Falls dam. This unit has also informally been known as the "Dam Ignimbrite" (Oversby & others, 1991). In common with the previously discussed samples, zircons in this rock mostly have simple prismatic and pyramidal faces and commonly contain inclusions. Although core and overgrowth relationships were observed in some samples, it was not possible to detect a significant age difference between these two phases.

Two zircons produce isotopic outliers on Fig. 6. Neither zircon grain is morphologically unique; analysis 15.1 represents a somewhat rounded core, whereas analysis 17.1 was derived from the tip of a perfectly euhedral, apparently single phase grain. The high common Pb content (Table 1, note that $^{206}Pb/^{204}Pb$ is only 91) makes it difficult to quantitatively define the radiogenic Pb component of grain 15.1, for the same reasons given above for the isotopically most aberrant grain in 88503170. The distinctive ^{208}Pb-corrected composition of grain 15.1 merely reflects undercorrection of the common Pb component. ^{207}Pb-corrected data (shown in the last two columns of Table 1) overcome uncertainties arising from this factor, and show that this grain is of similar age to all but analysis 17.1, which has the second highest common Pb content. The reason for the anomalously old age of grain 17.1 is not clear, especially as the analysis was conducted at its extreme outer margin. The remaining 21 analyses yield a ^{207}Pb-corrected $^{206}Pb/^{238}U$ age of 297.3±4.8 Ma (Fig. 6), which represents the time of igneous crystallisation.

89302132 (G.R. Glendon 394906) is a dacitic andesite flow (?) from about 10 km north of "Conway" homestead. This rock was originally thought to be a southeastern representative of DCv (Oversby & others, 1991), which is equivalent to the Bimurra Volcanics of Oversby (personal communication 1994). However, it is now tentatively placed by Oversby (personal communication 1994) into the "Smedley" association of the Bulgonunna Volcanic Group. A total of 31 zircon grains were analysed. Three of these (5.1,13.1 and 17.1) are of Precambrian age. Another (14.1), of Palaeozoic age, is about 50 Ma older than the general population in this rock. There are no obvious morphological criteria to distinguish between the different zircon generations. Thus, although some anhedral and some relatively equant, multifaceted grains occur in the dominant young population, euhehral grains of relatively simple form are not exclusive to this group. The groups might, however, be separable on geochemical grounds, for the Precambrian grains appear to have low Th/U (Table 1). These grains are discussed below, in conjunction with similarly old grains found in other rocks of the area. The 27 grains forming the main population (Fig. 7), which is clearly isotopically isolated from the older grains, contain no statistical outliers and yield an age of 297.4±3.9 Ma for the crystallisation of this rock. That age is indistinguishable from that of the Smedley Dacite (see above).

Based on field relationships and geochemical criteria (D. Wyborn, pers. comm. 1990), sample **89302108**, a quartz monzodioritic phase of the relatively K-rich Nostone Creek Granodiorite (G.R.

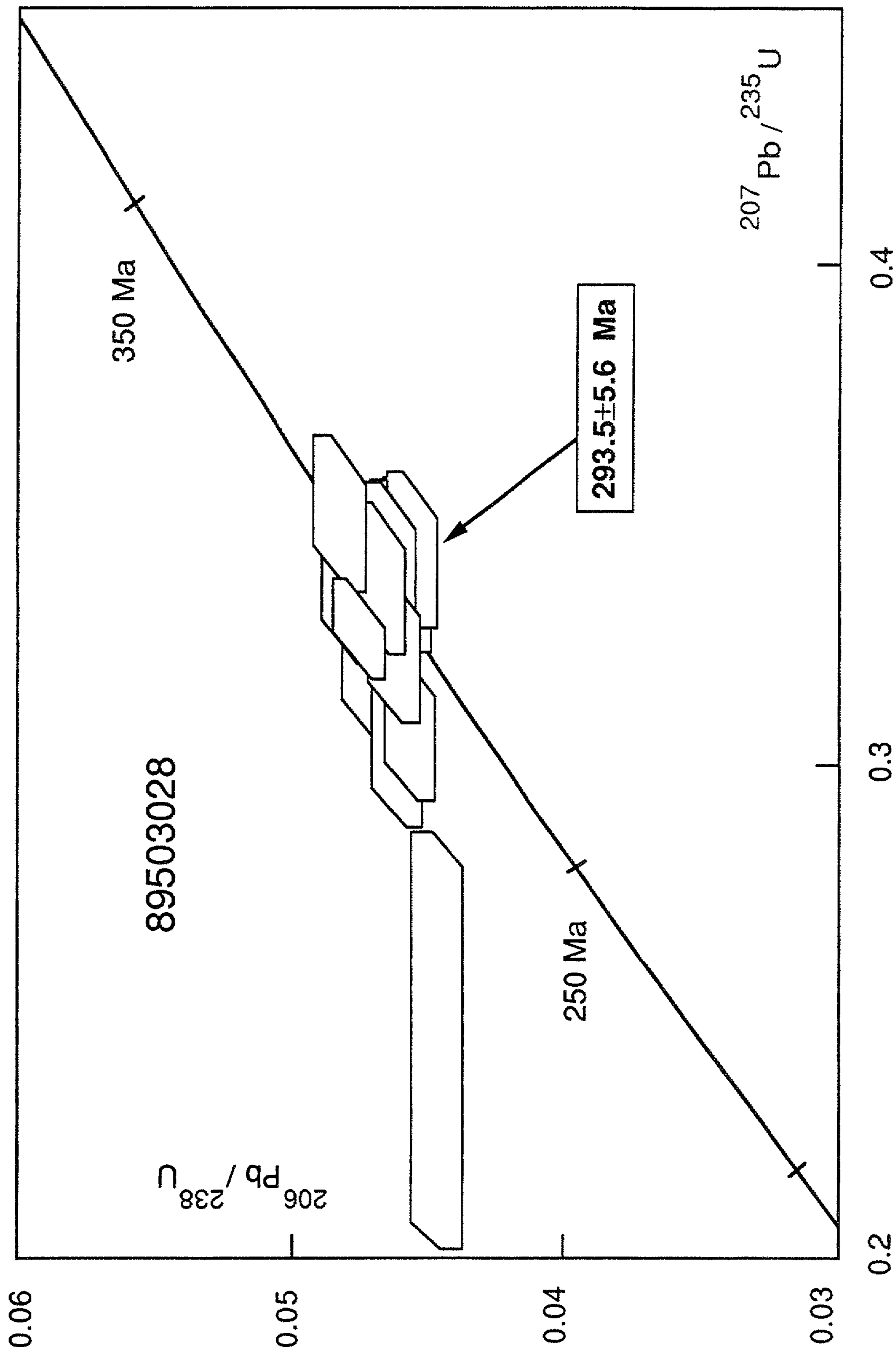

Fig. 5. U-Pb concordia diagram for zircons from 89503028, the Arundel Rhyolite. The 293.5±5.6 Ma crystallisation age is obtained from a statistically tight grouping of all 14 ^{207}Pb-corrected $^{206}Pb/^{238}U$ analyses (see text).

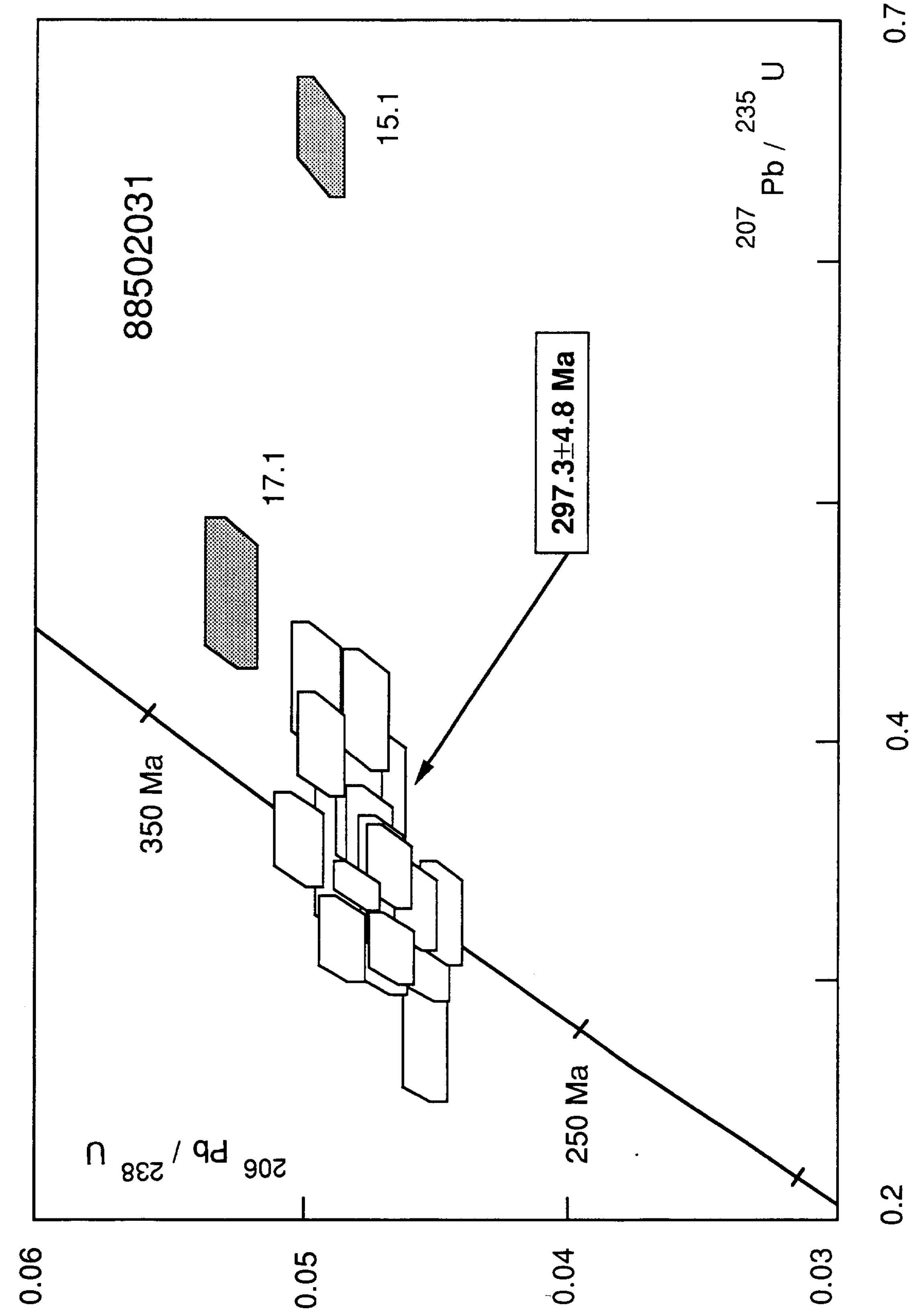

Fig. 6. U-Pb concordia diagram for zircons from 88502031, Smedley Dacite at Burdekin Falls Dam. The 297.3±4.8 Ma crystallisation age is obtained from a statistically tight grouping of 21 of the ^{207}Pb-corrected $^{206}Pb/^{238}U$ analyses. Only analysis 17.1 is deleted from the pooled age. The displacement of analysis 15.1 from the main group is a consequence of its high common Pb (see text).

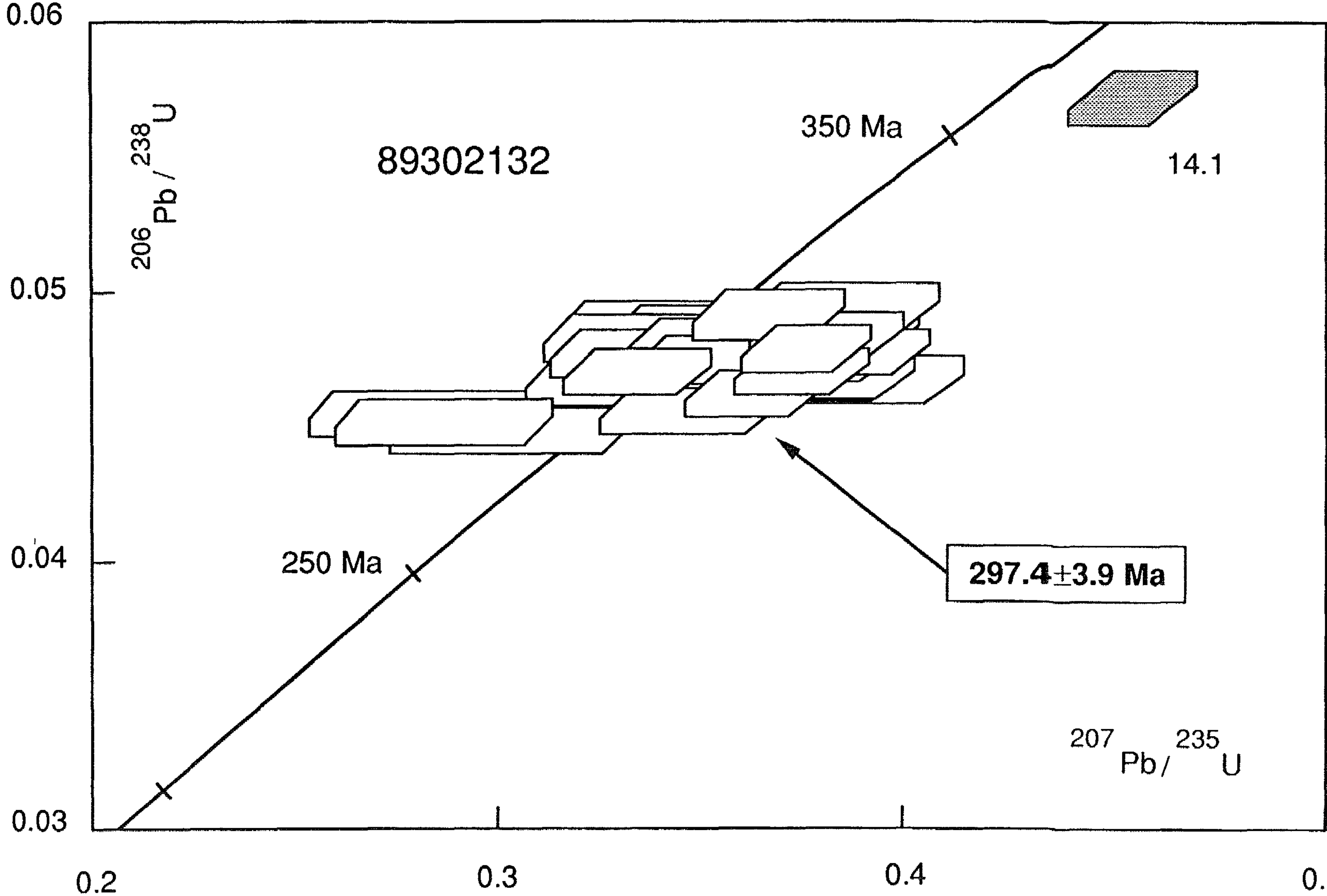

Fig. 7. U-Pb concordia diagram for zircons from 89302132, a dacitic andesite from the "Conway" homestead area. The 297.4±3.9 Ma crystallisation age is obtained from a statistically tight grouping of 27 ^{207}Pb-corrected $^{206}Pb/^{238}U$ analyses. There are no analytical outliers (see text).

Collinsville 655932) is thought to be the oldest granitoid in the region (Mcphie & others, 1990). Zircons in the granodiorite are of coarser grain size than those in the volcanics, commonly being 100-200 μm across. Many of the analysed grains are now broken, but those which are not have mostly first order prismatic faces and bipyramidal terminations. Inclusions and generally rounded cores are common. Zonation is often evident, particularly at the margins of grains.

On Fig. 8 it can be seen that the ^{208}Pb method has produced more of an undercorrection of the common Pb component than was the case for the previously discussed samples, the mean point of the data array clearly plotting below concordia. The bias in ^{206}Pb/^{238}U age from this effect is minimised by the use of ^{207}Pb correction (used throughout this study), which yields an emplacement age for this granodiorite of 289.3±5.9 Ma. It is important to note that all of the 19 individual analyses have indistinguishable ages, regardless of the type of zircon they represent, e.g., zoned or homogeneous, core or rim.

Sample **88302095** is from the type locality (G.R. Glendon 167041) of the Easter Granodiorite (Oversby, personal communication 1994). At the time of its collection this "Bells Creek" granodiorite (as it was then informally called - Oversby & others, 1991) was a presumed representative of the youngest intrusives in the area. Although its particular field relationships are not definitive, sodic granitoids are seen elsewhere to intrude both the Bulgonunna Volcanics and K-rich granitoids. Zircons in the sodic granite are morphologically similar to those in the previously discussed granitoid, except that they are on average only about half their grainsize, apparently contain no cores, and are not as commonly zoned. The latter feature can be equated with generally lower U and Th contents (Table 1).

As was the case with sample 89302108, the isotopic data show a noticeable undercorrection for common Pb if the ^{208}Pb technique is used (Fig. 9). One analysis in particular (6.1) is well displaced to the right of concordia. Nevertheless, irrespective of common Pb correction technique, the data define statistically tight ^{206}Pb/^{238}U age groupings, with ^{207}Pb-corrected data yielding an age of 289.6±6.1 Ma for the emplacement of this granite.

In addition to the seven rocks described above, U-Pb zircon dating was also attempted (with different degrees of success) on two geographically separated samples of intermediate volcanics which occur within the Devonian-Carboniferous Drummond Basin sequence. The first of these samples, **89503064** (G.R. Glendon 174311) is an intensely altered dacitic to andesitic ignimbrite from the Stones Creek Volcanics (Oversby , personal communication 1994), previously known informally as the Stones Creek formation (Oversby & others, 1991). The sample yielded only four grains of zircon, which were subhedral to anhedral. Two of those grains (5.1 and 6.1) are distinctly darker than the others, presumably because of enhanced radiation damage to their crystal lattices as a result of their markedly higher U contents and considerably older ages (Table 1, Fig. 10). The significance of the approximate 1550 Ma ages of these obviously xenocrystitic or restitic grains is discussed below.

The two low-U grains (they also have considerably higher Th/U) are apparently coeval (Table 1), and yield a pooled mean age of 357 Ma. There is an inherent danger in deriving a mean age from such a small number of analyses. In addition, as neither of the two grains are euhedral, it cannot be guaranteed that they crystallised directly from their host rock, and it is possible that they were derived from a still older rock. Nonetheless, 356 Ma is consistent with the Devonian to Carboniferous age ascribed to this rock on the basis of fossils in interbedded sedimentary units (The most up-to-date temporal estimate for the base of the Carboniferous is 353.2±4.0 Ma - Claoue-Long & others, 1992). Some support for an event of this age is provided by the 356 Ma grain (14.1) from the dacitic andesite 89302132 in the Conway area, although it does not diminish the argument that the grains of that age in sample 89503064 might not be syn-magmatic with their host.

Stones Creek Volcanics sample 88503023 (G.R. Glendon 118329) is a very altered dacite or andesite which yielded only four grains of zircon, and proved even less suitable for dating. All of the recovered grains are of Precambrian age (Table 1, Fig. 10) and obviously could not have crystallised from their host rock. The combination of these data and those for the previously discussed sample show that it will be difficult to obtain a convincing age for the Stones Creek Volcanics, a unit which is generally lacking, or perhaps even void, in syn-magmatic zircon.

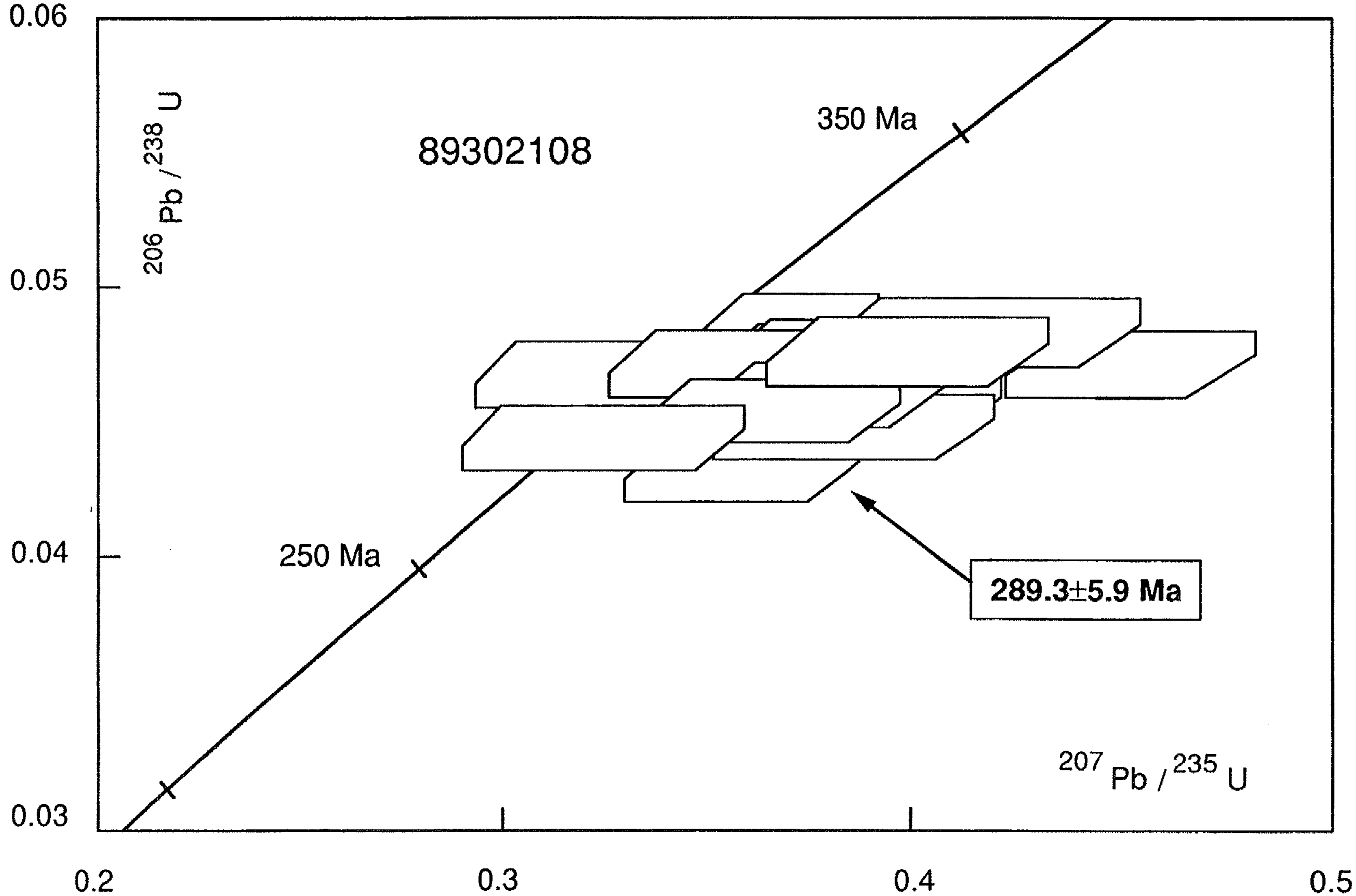

Fig. 8. U-Pb concordia diagram for zircons from 89302108, the Nostone Creek Granodiorite. The 289.3±5.9 Ma crystallisation age is obtained from a statistically tight grouping of all 19 207Pb-corrected 206Pb/238U analyses. No data have been excluded (see text).

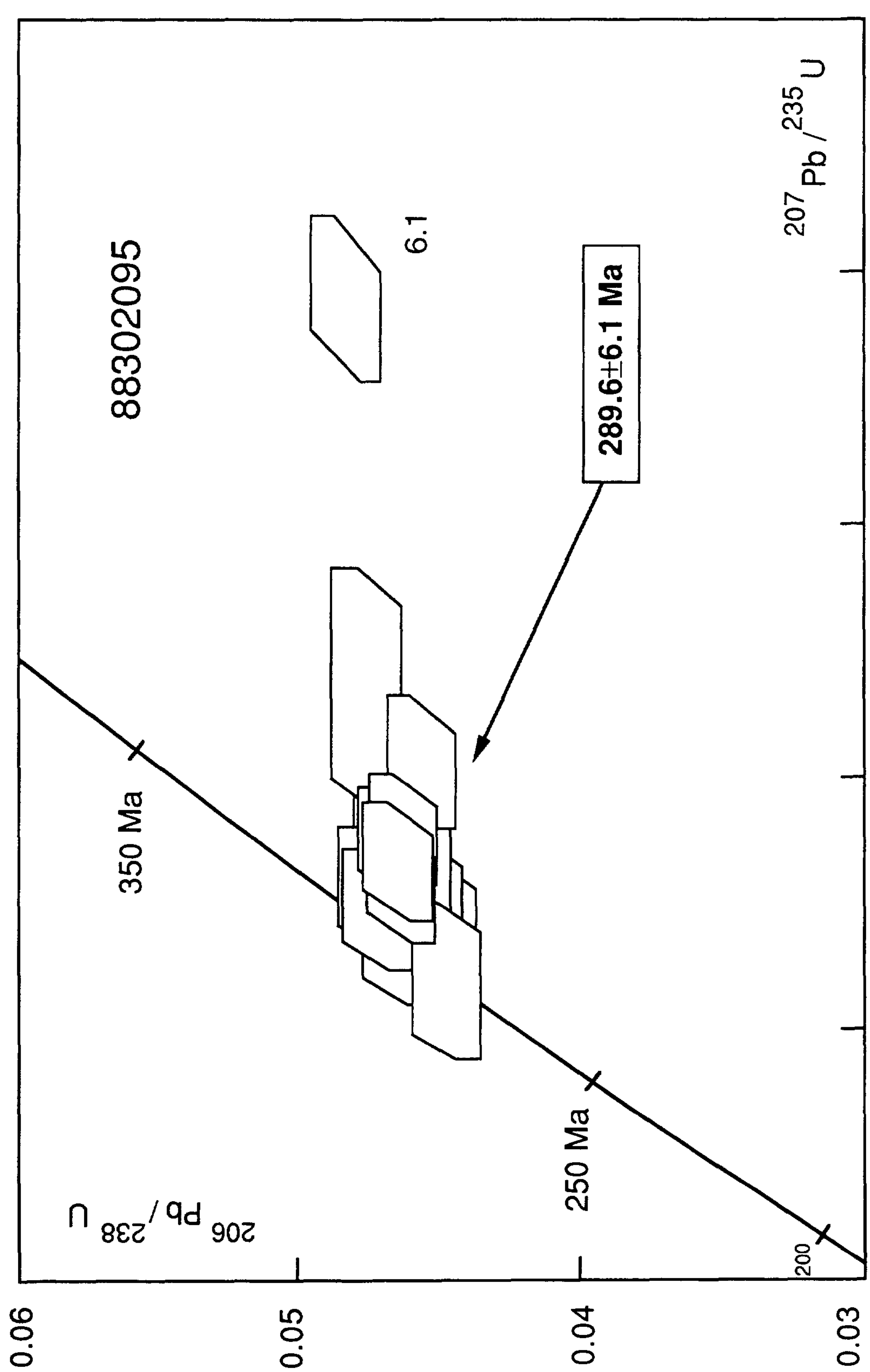

Fig. 9. U-Pb concordia diagram for zircons from the type Easter Granodiorite, 88302095. The 289.6±6.1 Ma crystallisation age is obtained from a statistically tight grouping of all 17 ^{207}Pb-corrected $^{206}Pb/^{238}U$ analyses. No data have been excluded (see text).

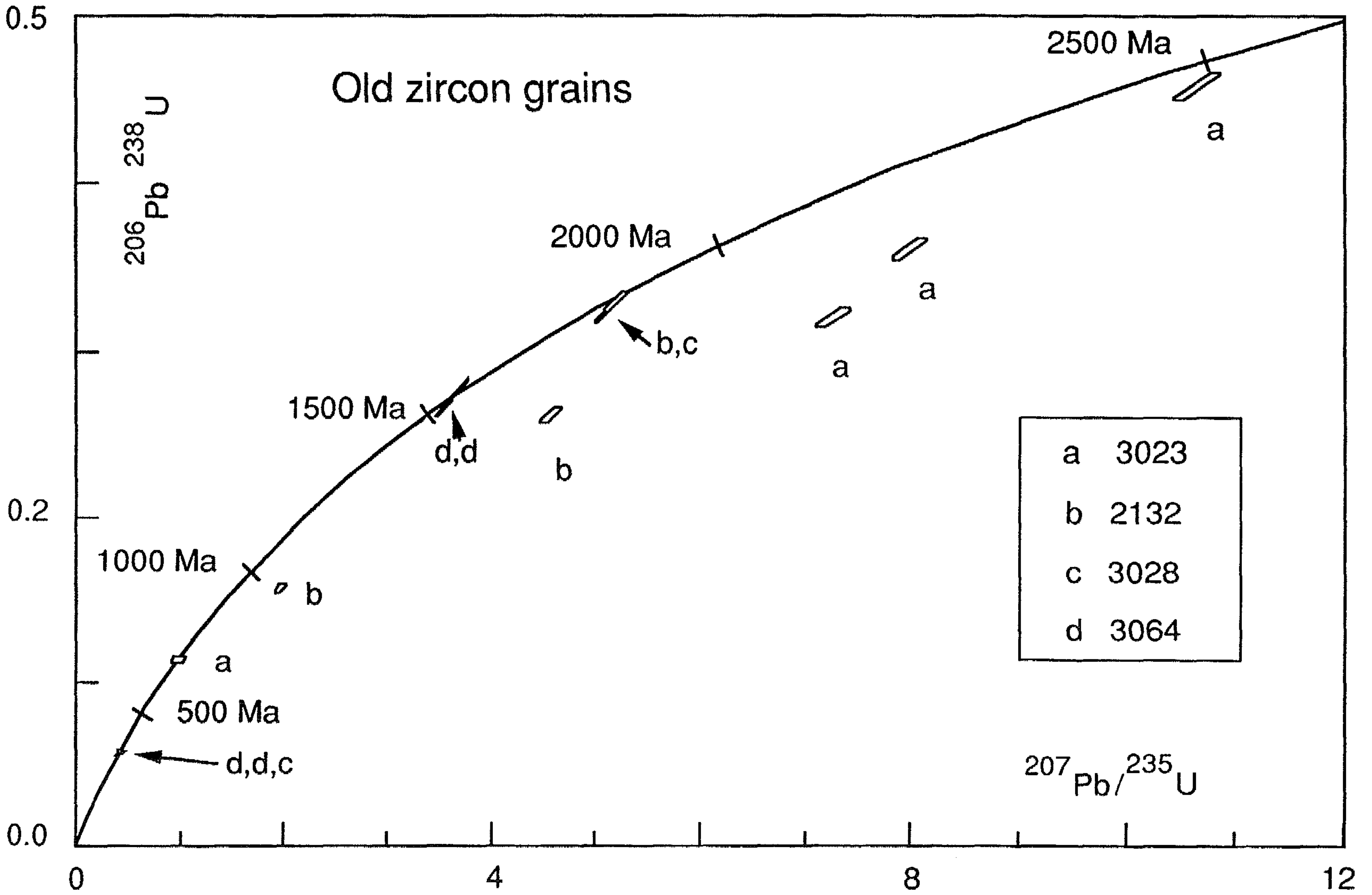

Fig. 10. U-Pb concordia diagram showing all the pre-Late Carboniferous zircon analyses of this study, and the sample numbers of the rocks from which they were derived.

INITIAL $^{87}Sr/^{86}Sr$ COMPOSITIONS

Initial $^{87}Sr/^{86}Sr$ compositions are presented for three of the analysed rocks (Table 2), all of which have relatively low (for felsic rocks), similar values. The Arundel Rhyolite has an initial $^{87}Sr/^{86}Sr$ of 0.7049, possibly a little higher than that of the other two samples. The values for the two granites of 0.7046 (88302095) and 0.7044 (89302108) are not distinguishable from each other. This and the U-Pb zircon data indicate that although these samples are extreme representatives of the local granites in terms of geochemical properties, they are in fact closely related to each other.

SIGNIFICANCE OF THE PRECAMBRIAN AGES

Precambrian zircon was detected in four of the analysed rocks, namely the two samples of Stones Creek Volcanics, the dacitic andesite near "Conway", and the Arundel Rhyolite. These old zircon grains indicate either that Precambrian crust underlay the region during the Carboniferous (and probably also still does), and might well have represented at least part of the source from which the Palaeozoic magmas were melted, or that Precambrian detritus contributed to the sediments of the Drummond Basin and was accidentally incorporated into the Palaeozoic magmas.

The oldest identified inheritance occurs in sample 88503023 (Stones Creek Volcanics) where three of the four grains appear to be a little over 2500 Ma in age. The nearest terrane yielding a significant proportion of zircons of that age is the Georgetown Inlier (Black & Withnall, 1993; Black, unpublished analyses), but the zircons in that region are of detrital (in paragneissic units) and xenocrystic (in igneous rocks) origin. The depositional age of the Georgetown Inlier is considerably younger, at about 1570 Ma (L.P. Black, unpublished U-Pb zircon SHRIMP data). The nearest known ~2500 Ma rocks are found about 1000 km distant, in the Pine Creek and Litchfield inliers of the Northern Territory (Page & others, 1984).

Two concordant grains from 89302132 (dacitic andesite) and 89503028 (Arundel Rhyolite) reveal the presence of local 1800 Ma crustal components. Rocks of that age have not yet been reported from the Georgetown Inlier, although some xenocrystic and detrital grains have been found (Black & Withnall, 1993: L.P. Black, unpublished U-Pb zircon SHRIMP data). The nearest known outcrops of that age are further westwards, in the Bottletree and Argylla Formations of the Mount Isa Inlier (Page, 1983).

Two concordant 1550 Ma zircon grains in 89503064 (Stones Creek Volcanics) are the same age as at least most of the Precambrian igneous and metamorphic activity within the Georgetown Inlier (Black & McCulloch, 1990: Black & Withnall, 1993). A single zircon grain from 88503023 (Stones Creek Volcanics) yields an unusual age (700 Ma) for northern Queensland.

Many of the Precambrian zircon grains found within the analysed rocks could therefore have been derived from either the nearest Precambrian shield (Georgetown Inlier) or from rocks of similar age below the Drummond Basin (such as the Anakie Inlier?). Current geochronological knowledge of the more northerly Yambo Inlier is so limited that its role in the generation of the Precambrian zircons cannot be assessed. However, many of the Middle and Late Palaeozoic granites of the Coen Inlier contain xenocrystic zircons with a similar age range to that found in this study (Black & others, 1992).

SIGNIFICANCE OF THE PALAEOZOIC AGES

The initial results from this isotopic study resulted in a reinterpretatation of the extent of Late Devonian ' Early Carboniferous igneous activity in this region (Black & others, 1990). The complete results (summar.. ed in Table 3) now lead to a further reduction of the known aerial extent of such rocks. Although some of the ages do not fit with earlier held ideas, their internal consistency gives them considerable credibility. The data do not contradict the one instance where an unequivocal field relationship is observed (i.e., between the Smedley Dacite and the Arundel Rhyolite). It is therefore most unlikely that they define anything other than the age of magmatic crystallisation. Although zircons of hydrothermal origin have at times been recognised, there is no evidence to suggest that they occur in the analysed rocks. For instance, such zircon in mafic volcanics at Mount Isa is anhedral in form (Page, personal communication 1991), totally unlike the euhedral grains analysed here, which are typical of magmatically crystallised zircon. Neither is there evidence for unusually intense alteration in the analysed northern Drummond Basin rocks, the propylitic alteration present being typical of that found in intermediate and felsic volcanics. It can also be argued that if the analysed Permo-Carboniferous grains were of hydrothermal origin, what has become of the originally magmatic grains? The rocks were sufficiently siliceous to have crystallised zircon. It would be virtually impossible that pre-existing zircon grains could have been dissolved by hydrothermal activity that also caused new zircon to grow, particularly when xenocrystic or restitic zircon is still present in at least some of these rocks (note that, as syn-emplacement grains were preferentially targetted for analysis, they must be over-represented by the analyses). There is thus no reason to question the quality of the analytical data or the geological significance attached to them, as Klootwijk & others (1993) have done, based on their interpretation of palaeomagnetic data. Moreover, their evidence for magnetic overprinting in critical rocks (such as the Smedley Dacite) is not direct, but is inferred from the observation that their data disperse rather than concentrate after "unfolding". As no earlier magnetic fabric is observed in the dacite, it is conceivable that the observed fabric is primary, and that sagging/collapse/folding of the rocks occurred before they cooled below the Curie temperature.

Two of the isotopically analysed samples, 89503064 and 88503023 (both from the Stones Creek Volcanics), are part of the Drummond Basin sequence and are of probable Devonian-Carboniferous age. Although the new data do not unequivocally define the age of these rocks, they are entirely consistent with their (poor) biostratigraphic control. Most of the zircons in these rocks are clearly xenocrystic or restitic, and therefore provide only an older age limit for their host rock. In contrast, two grains (from 89503064) with a mean U-Pb zircon age of 357 Ma are suitably young to have crystallised from their host. That age is also consistent with a xenocrystic origin from a rock only slightly older than the host magma.

The other two volcanic rocks of intermediate composition (89302132 and 88502031) are considerably younger, despite being originally classified as of Devonian-Carboniferous age (Ewers & others, 1989). Even though these lithologically similar rocks are geographically well separated, their identical ages of 297.4±3.9 Ma and 297.3±4.8 Ma indicate that they represent part of a short-lived episode of intermediate volcanism. Pooling the two ages produces a mean age of 297.4±2.9 Ma for that episode.

The age consistency between those two samples of intermediate composition is mirrored by the consistency of ages derived for the Locharwood Rhyolite (304.7±6.2 Ma for 88502032) and its correlative (304.7±4.0 Ma for 88503170). Both these instances of age similarities within similar rock types would be difficult to explain if there was any bias in the ion-microprobe data, and there is no reason to suspect such bias. The latter ages pool to give a mean temporal estimate of 304.7±3.2 Ma for this episode of felsic volcanism. The mean age difference of 7.3 Ma between this episode and that which produced the 297.4±2.9 Ma intermediate volcanism is significant at greater than the 99.8% confidence level. Therefore, the conclusion to be reached from these data is that the intermediate igneous activity exemplified by samples 89302132 and 88502031 occurred after and not before (as proposed in Black & others, 1990) the more felsic volcanism which formed the Locharwood Rhyolite and its correlatives.

Southwest of the Burdekin Falls, rhyolite-dominated representatives of the Bulgonunna Volcanics unconformably overlie rocks assigned to a dacite-rhyolite association. There is thus unequivocal field evidence that some felsic volcanism postdates the intermediate volcanism. However, the unambiguously younger felsic unit is not the Locharwood Rhyolite but the Arundel Rhyolite. Although the Arundel Rhyoloite U-Pb zircon age of 293.5±5.6 Ma is totally consistent with that observation, it should be stressed that the 3.9 Ma mean age difference between this age and that of the intermediate volcanism (297.4±2.9 Ma - pooled age from two samples) is not quite significant at the 95% confidence level. Therefore, the isotopic data strictly do not independently confirm this aspect of the observed stratigraphic sequence, though they do support it. In contrast, the data indicate that the 11.2 Ma mean age difference between the Locharwood Rhyolite and the Arundel Rhyolite is highly significant (at greater than the 99.9% confidence level). This unequivocally indicates that the Bulgonunna Volcanics were formed by at least two separate episodes of felsic volcanism. Although it is generally referred to as being of Late Carboniferous age, this volcanism actually straddled the Carboniferous - Permian boundary, which is placed at about 298 Ma (Hess & Lippolt, 1986).

When combined, the indistinguishable ages obtained for the two granites yield a pooled age of 289.4±4.0 Ma (i.e., Early Permian) for their magmatic emplacement. This event was significantly younger than those which produced the intermediate volcanics (at greater than the 99.8% confidence level) and the Locharwood Rhyolite and its felsic correlatives (at greater than the 99.9% confidence level). Although its indicated mean age is younger, the granites are not proven to be significantly younger than the Arundel Rhyolite, though their mean age suggests that they might well be younger.

The Late Palaeozoic igneous activity which occurred at the northern end of the Drummond Basin was therefore of a more complex chronological nature than has hitherto been realised. Additional work might yet prove it to have been even more complex. However, the simplest model to fit the current geochronological data is that there was an initial episode of essentially intermediate Devonian - Carboniferous volcanism at about 356 Ma. This was followed by felsic volcanism at 304.7±3.2 Ma, and later by further intermediate volcanism at 297.4±2.9 Ma. Volcanism ceased with a second episode of felsic activity at 293.5±5.6 Ma. The entire spectrum of felsic plutonic rocks appears to have crystallised at about 289.4±4.0 Ma, perhaps shortly after the close of volcanic activity.

REGIONAL IMPLICATIONS

Igneous activity at the northern end of the Drummond Basin did not occur in temporal isolation; similar ages have been documented elsewhere in the Tasman Orogen. For example, Flood & Shaw (1977) and Hensel & others (1985) showed that substantial parts of the New England Batholith (NSW) were also formed at roughly that time. The similarity between the two regions is enhanced by their comparably low initial $^{87}Sr/^{86}Sr$ values. A Rb-Sr study (L.P. Black, unpublished analyses) has identified many comparably-aged units in the Featherbed Volcanics (which lie to the east of the Georgetown Inlier), although a documented younger event of about 280 Ma has not been detected in the Drummond Basin. Another difference is that the Featherbed Volcanics are characterised by markedly higher initial $^{87}Sr/^{86}Sr$. Granitic rocks in the more northerly Coen Inlier are of comparable age to the youngest component of the Featherbed Volcanics (Black & others, 1992).

Late Carboniferous - Early Permian igneous activity therefore played an important role in the evolution of the Tasman Orogen, presumably because a common tectonic process (subduction?) was simultaneously imposed on geographically well separated regions. It is possible that similar sources were involved in the production of the igneous rocks of the northern Drummond Basin and those of the New England Batholith.

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REFERENCES

BLACK L.P. & McCULLOCH M.T. 1990. Isotopic evidence for the dependence of recurrent felsic magmatism on new crust formation: an example from the Georgetown region of northeastern Australia. *Geochimica et Cosmochimica Acta* **54**, 183-196.

BLACK L.P. & WITHNALL I.W. 1993. The ages of Proterozoic granites in the Georgetown Inlier of northeastern Australia, and their relevance to the dating of tectonothermal events. *AGSO Journal of Australian Geology and Geophysics* **14**, 331-341.

BLACK L.P., BULTITUDE R.J., SUN S-S., KNUTSON J. & BLEWETT R.S. 1992. Emplacement ages of granitic rocks in the Coen Inlier (Cape York): implications for local geological evolution and regional correlation. *BMR Journal of Australian Geology and Geophysics* **13**, 191-200.

BLACK L.P., MACKENZIE D.E., OVERSBY B.S. & McPHIE J. 1990. Setting of epithermal gold mineralisation in the northern Drummond Basin further refined. *BMR Research Newsletter* **12**, 14-15.

CLAOUE-LONG J.C., JONES P.J., ROBERTS J & MAXWELL S. 1992. The numerical age of the Devonian-Carboniferous boundary. *Geological Magazine* **129**, 281-291.

COMPSTON W., WILLIAMS I.S. & MEYER C. 1984. U-Pb geochronology of zircons from lunar breccia 73217 using a sensitive high-resolution ion-microprobe. Proceedings of the 14th Lunar science Conference. *Journal of Geophysical Research* **89**, B525-534.

DAY R.W., MURRAY C.G. & WHITAKER W.G. 1978. The eastern part of the Tasman Orogenic Zone. *In* Scheibner E (Ed.). The Phanerozoic structure of Australia and variations in tectonic style. *Tectonophysics* **48**, 327-364.

EWERS G.R., MACKENZIE D.E., McPHIE J., OVERSBY B.O., WYBORN, D. & LAW, S.R. 1989. New mapping extends Drummond Basin gold potential. *BMR Research Newsletter* **10**, 1-4.

EWERS G.R., WOOD D.G., TEDDER I.J., WHITE N.C. & HOFFMANN C.F. 1990. Epithermal gold prospects in the Conway area, northern Drummond Basin, Queensland. *In* Pacific Rim Congress 90, *Australasian Institute of Mining and Metallurgy*, Melbourne, 2, 357-362.

FLOOD R.H. & SHAW, S.E. 1977. Two "S-type" granite suites with low initial $^{87}Sr/^{86}Sr$ ratios from the New England Batholith, Australia. *Contributions to Mineralogy and Petrology* **61**, 163-173.

HENSEL H-D., McCULLOCH M.T. & CHAPPELL B.W. 1985. The New England Batholith: constraints on its derivation from Nd and Sr isotopic studies of granitoids and country rocks. *Geochimica et Cosmochimica Acta* **49**, 369-384.

HESS J.C. & LIPPOLT H.J. 1986. $^{40}Ar/^{39}Ar$ age of tonstein and tuff sanidines: new calibration points for the improvement of the Upper Carboniferous time scale. *Chemical Geology: Isotope Science* **59**, 143-154.

HUTTON L.J., GRIMES K.G., LAW S.R. & McLENNAN T.P.T. 1991. Geology of the Mount Coolon 1:250 000 Sheet area. *Queensland Department of Resource Industries, Record,* 1991/19.

KLOOTWIJK C., GIDDINGS J.W. & PERCIVAL P. 1993. Palaeomagnetic reconnaissance of upper Palaeozoic volcanics, northeastern Queensland. *Australian Geological Survey Organisation. Record* 1993/36.

McPHIE J., BLACK L.P., LAW S.R., MACKENZIE D.E., OVERSBY B.S. & WYBORN D. 1990. Distribution, character and setting of mineralised Palaeozoic volcanic sequences, Burdekin Falls region, northeastern Queensland. *In* Pacific Rim Congress 90, *Australasian Institute of Mining and Metallurgy,* Melbourne 2, 465-471.

OVERSBY B.S., MACKENZIE D.E., McPHIE J., LAW S.R. & WYBORN. D. 1991. Catalogue of field compilation sheets of late Palaeozoic ignimbrites and associated rocks in the Burdekin Falls Dam - "Conway" area (Glendon and adjacent parts of Ravenswood, Strathalbyn, Harvest Home, and Collinsville 1=100 000 Sheet areas), northeastern Queensland. *Bureau of Mineral Resources, Australia, Record,* 1991/28.

PAGE R.W. 1983. Timing of superposed volcanism in the Proterozoic Mount Isa Inlier, Australia. *Precambrian Research* **21**, 223-245.

PAGE R.W., McCULLOCH M.T. & Black L.P. 1984. Isotopic record of major Precambrian events in Australia. *Precambrian Geology.* VNU Press. Proceedings of the 27th International Geological Congress **5**, 25-72.

WEBB A.W. 1969. Metallogenic epochs in eastern Queensland. *Proceedings of the Australasian Institute of Mining and Metallurgy* **230**, 29-37.

WEBB A.W. 1970. Appendix - Isotopic age determinations from the Townsville 1:250 000 Sheet area. *In* Wyatt D.H., Paine A.G.L., Clarke D.E. and Harding R.R., Geology of the Townsville 1: 250 000 Sheet area, Queensland. *Bureau of Mineral Resources, Australia, Geology and Geophysics, Report* **127**, 84-85.

WEBB A.W. 1971. Appendix 2 - Isotopic age determinations. *In* Wyatt D.H., Paine A.G.L., Clarke D.E., Gregory C.M. & Harding R.R. Geology of the Charters Towers 1:250 000 Sheet area, Queensland. *Bureau of Mineral Resources, Australia, Geology and Geophysics, Report* **137**, 79-81.

WEBB A.W. & McDOUGALL I. 1968. The geochronology of the igneous rocks of eastern Queensland. *Journal of the Geological Society of Australia* **15**, 313-346.

WILLIAMS I.S., COMPSTON W., BLACK L.P., IRELAND T.R. & FOSTER J.J. 1984. Unsupported radiogenic Pb in zircon: a cause of anomalously high Pb-Pb, U-Pb and Th-Pb ages. *Contributions to Mineralogy and Petrology* **88**, 322-327.

WILLIAMS I.S., COMPSTON W., CHAPPELL B.W. & SHIRAHASE T. 1976. Rubidium-strontium age determinations on micas from a geologically controlled, composite batholith. *Journal of the Geological Society of Australia* **22**, 497-506.

Table 1. Ion-microprobe U-Th-Pb data for zircons from the northern Drummond Basin.

Grain area	U (μg/g)	Th (μg/g)	Th/U	$^{206}Pb/^{204}Pb$	f_{206}	$^{206}Pb/^{238}U$ ±1σ error	$^{207}Pb/^{235}U$ ±1σ error	$^{207}Pb/^{206}Pb$ ±1σ error	*$^{206}Pb/^{238}U$ ±1σ error	*Age ±1σ error
					88503170					
1.1	215	220	1.025	739	0.0133	0.0462±.0009	0.365±.031	0.0572±.0046	0.0459±.0009	289±5
2.1	476	220	0.463	3234	0.0110	0.0474±.0009	0.337±.015	0.0517±.0020	0.0474±.0009	299±5
3.1	310	251	0.811	1469	0.0160	0.0470±.0009	0.310±.023	0.0477±.0033	0.0473±.0009	298±5
4.1	225	232	1.031	1762	0.0178	0.0456±.0009	0.321±.031	0.0511±.0047	0.0456±.0008	288±5
5.1	265	213	0.803	6131	0.0021	0.0484±.0009	0.363±.028	0.0544±.0040	0.0483±.0009	304±5
6.1	383	236	0.618	14198	0.0067	0.0467±.0009	0.337±.017	0.0524±.0023	0.0467±.0009	294±5
7.1	519	386	0.745	20786	0.0006	0.0499±.0009	0.367±.016	0.0534±.0020	0.0498±.0009	313±6
8.1	119	115	0.968	815	0.0023	0.0510±.0010	0.422±.038	0.0600±.0051	0.0505±.0009	318±6
9.1	228	134	0.591	2949	0.0018	0.0483±.0009	0.382±.021	0.0574±.0028	0.0480±.0009	302±5
10.1	637	783	1.230	1875	0.0073	0.0511±.0009	0.361±.020	0.0512±.0025	0.0512±.0009	322±6
11.1	490	385	0.786	4978	0.0044	0.0479±.0009	0.339±.016	0.0514±.0022	0.0480±.0009	302±5
12.1	169	174	1.026	2058	0.0109	0.0463±.0009	0.313±.028	0.0489±.0042	0.0465±.0009	293±5
13.1	303	196	0.645	5490	0.0022	0.0483±.0009	0.371±.019	0.0557±.0026	0.0481±.0009	303±5
14.1	338	468	1.386	644	0.0298	0.0467±.0009	0.387±.030	0.0600±.0043	0.0463±.0008	291±5
15.1	340	331	0.974	16236	0.0056	0.0482±.0009	0.362±.021	0.0545±.0028	0.0481±.0009	303±5
16.1	427	335	0.784	5802	-0.0037	0.0482±.0009	0.379±.017	0.0571±.0022	0.0479±.0009	301±5
16.2	606	193	0.318	21547	0.0008	0.0473±.0009	0.360±.012	0.0553±.0014	0.0471±.0009	297±5
17.1	189	203	1.074	907	0.0198	0.0458±.0009	0.310±.030	0.0490±.0045	0.0460±.0008	290±5
18.1	287	275	0.960	6030	0.0106	0.0475±.0009	0.310±.022	0.0474±.0032	0.0478±.0009	301±5
19.1	1581	6909	4.372	32	0.0202	0.0672±.0014	4.653±.150	0.5020±.0110	0.0295±.0006	188±4
20.1	271	172	0.634	5927	0.0063	0.0481±.0009	0.352±.019	0.0531±.0026	0.0480±.0009	303±5
21.1	464	283	0.608	1222	0.0105	0.0477±.0009	0.326±.015	0.0495±.0021	0.0479±.0009	301±5
					88502032					
1.1	572	514	0.898	427	0.0457	0.0441±.0011	0.294±.019	0.0482±.0028	0.0444±.0011	280±7
2.1	411	181	0.440	692	0.0238	0.0511±.0013	0.369±.017	0.0524±.0019	0.0511±.0013	321±8
3.1	396	244	0.615	9226	0.0138	0.0490±.0012	0.346±.018	0.0512±.0021	0.0490±.0012	309±8
4.1	525	340	0.648	5794	0.0100	0.0469±.0012	0.336±.016	0.0520±.0019	0.0469±.0012	296±7

5.1	94	62	0.660	370	0.0626	0.0503±.0013	0.399±.042	0.0575±.0057	0.0500±.0013	315±8
6.1	304	209	0.686	1358	0.0218	0.0476±.0012	0.361±.021	0.0550±.0027	0.0475±.0012	299±7
7.1	327	167	0.510	594	0.0220	0.0486±.0012	0.377±.018	0.0563±.0022	0.0484±.0012	305±7
8.1	379	293	0.775	383	0.0331	0.0506±.0013	0.404±.020	0.0579±.0024	0.0502±.0013	316±8
9.1	518	469	0.906	12294	0.0154	0.0478±.0012	0.331±.018	0.0502±.0023	0.0480±.0012	302±7
10.1	191	156	0.819	299	0.0382	0.0508±.0013	0.352±.026	0.0502±.0034	0.0509±.0013	320±8
11.1	210	171	0.817	253	0.0577	0.0482±.0012	0.373±.027	0.0561±.0037	0.0480±.0012	302±7
12.1	119	46	0.387	358	0.0778	0.0488±.0012	0.390±.033	0.0580±.0044	0.0485±.0012	305±8
13.1	670	470	0.702	936	0.0023	0.0474±.0012	0.411±.015	0.0629±.0015	0.0467±.0012	294±7
14.1	353	315	0.892	460	0.0391	0.0487±.0012	0.371±.022	0.0551±.0028	0.0485±.0012	306±7
15.1	270	179	0.663	120	0.1273	0.0510±.0013	0.390±.027	0.0554±.0034	0.0508±.0013	320±8
16.1	339	252	0.744	525	0.0372	0.0468±.0012	0.336±.019	0.0520±.0026	0.0468±.0012	295±7
17.1	517	548	1.060	2805	0.0026	0.0492±.0012	0.383±.019	0.0564±.0022	0.0490±.0012	308±8
18.1	298	228	0.766	446	0.0280	0.0462±.0012	0.442±.022	0.0695±.0027	0.0452±.0011	285±7
19.1	297	262	0.883	15689	0.0173	0.0472±.0012	0.317±.021	0.0487±.0028	0.0475±.0012	299±7

89503028

1.1	580	201	0.346	18657	0.0008	0.3238±.0065	5.106±.108	0.1144±.0005	0.3240±.0066	1809±32
2.1	342	250	0.731	1380	0.0059	0.0483±.0010	0.350±.016	0.0526±.0020	0.0483±.0010	304±6
7.1	223	99	0.443	1102	0.0077	0.0464±.0009	0.341±.016	0.0533±.0021	0.0464±.0009	292±6
8.1	323	243	0.751	388	0.0431	0.0473±.0010	0.323±.018	0.0495±.0024	0.0475±.0010	299±6
9.1	37	18	0.479	105	0.0463	0.0447±.0010	0.244±.042	0.0396±.0067	0.0454±.0010	286±6
10.1	390	319	0.818	4593	0.0098	0.0461±.0009	0.302±.015	0.0475±.0021	0.0464±.0009	292±6
11.1	293	206	0.702	2194	0.0028	0.0456±.0009	0.343±.016	0.0546±.0021	0.0455±.0009	287±6
12.1	424	376	0.886	1323	0.0054	0.0468±.0009	0.337±.015	0.0523±.0020	0.0468±.0009	295±6
13.1	339	308	0.911	697	0.0234	0.0462±.0009	0.331±.018	0.0520±.0026	0.0462±.0009	291±6
14.1	372	263	0.707	1282	0.0100	0.0463±.0009	0.324±.015	0.0507±.0020	0.0464±.0009	292±6
15.1	324	225	0.696	7138	0.0088	0.0457±.0009	0.307±.015	0.0488±.0021	0.0459±.0009	289±6
16.1	219	128	0.585	955	0.0053	0.0458±.0009	0.340±.017	0.0538±.0024	0.0457±.0009	288±6
17.1	1403	1122	0.800	5224	0.0051	0.0476±.0010	0.327±.010	0.0499±.0011	0.0477±.0010	301±6
18.1	244	103	0.422	859	0.0280	0.0462±.0009	0.341±.016	0.0534±.0022	0.0462±.0009	291±6
19.1	395	342	0.864	1329	0.0090	0.0480±.0010	0.337±.016	0.0509±.0021	0.0481±.0010	303±6

88502031

1.1	213	169	0.795	295	0.0076	0.0477±.0009	0.413±.025	0.0629±.0036	0.0470±.0009	296±5

2.1	179	100	0.560	997	0.0107	0.0447±.0008	0.328±.022	0.0532±.0032	0.0447±.0008	282±5
3.1	254	216	0.851	842	0.0138	0.0471±.0009	0.347±.022	0.0535±.0031	0.0470±.0009	296±5
4.1	165	115	0.698	434	0.0211	0.0475±.0009	0.356±.025	0.0543±.0036	0.0474±.0009	299±5
5.1	421	383	0.909	272	0.0529	0.0493±.0009	0.398±.022	0.0586±.0029	0.0490±.0009	308±5
5.2	399	419	1.048	379	0.0499	0.0496±.0009	0.422±.027	0.0618±.0037	0.0490±.0009	308±5
5.3	409	215	0.525	311	0.0430	0.0502±.0009	0.359±.019	0.0519±.0025	0.0502±.0009	316±6
6.1	285	256	0.896	477	0.0188	0.0467±.0009	0.331±.022	0.0514±.0032	0.0468±.0009	295±5
7.1	858	328	0.382	9193	0.0061	0.0480±.0009	0.340±.010	0.0514±.0011	0.0480±.0009	302±5
7.2	308	213	0.690	1039	0.0116	0.0457±.0008	0.331±.019	0.0525±.0027	0.0457±.0008	288±5
8.1	327	201	0.614	1208	0.0150	0.0467±.0009	0.348±.017	0.0540±.0024	0.0466±.0009	294±5
9.1	365	673	1.844	807	0.0145	0.0487±.0009	0.355±.035	0.0529±.0050	0.0486±.0009	306±5
10.1	279	351	1.262	275	0.0539	0.0454±.0009	0.281±.031	0.0449±.0049	0.0458±.0008	289±5
11.1	319	420	1.318	418	0.0249	0.0479±.0009	0.376±.031	0.0569±.0045	0.0476±.0009	300±5
12.1	351	579	1.649	891	0.0121	0.0470±.0009	0.375±.032	0.0578±.0047	0.0467±.0009	294±5
13.1	425	328	0.773	564	0.0385	0.0486±.0009	0.317±.018	0.0474±.0025	0.0489±.0009	308±5
14.1	571	443	0.777	703	0.0194	0.0467±.0009	0.313±.015	0.0486±.0021	0.0469±.0009	295±5
15.1	1263	1531	1.212	91	0.1405	0.0495±.0009	0.652±.025	0.0956±.0030	0.0468±.0009	295±5
15.2	185	159	0.860	1197	0.0304	0.0469±.0009	0.321±.027	0.0496±.0040	0.0471±.0009	297±5
16.1	178	142	0.800	169	0.1084	0.0477±.0009	0.345±.041	0.0525±.0060	0.0476±.0009	300±5
17.1	312	178	0.568	119	0.1323	0.0527±.0010	0.462±.032	0.0635±.0040	0.0520±.0010	327±6
18.1	320	357	1.115	400	0.0372	0.0452±.0008	0.319±.028	0.0512±.0043	0.0453±.0008	286±5

89302132

1.1	213	194	0.910	807	0.0001	0.0476±.0009	0.378±.021	0.0577±.0029	0.0472±.0009	298±5
2.1	243	183	0.755	14043	0.0015	0.0484±.0009	0.381±.019	0.0571±.0025	0.0481±.0009	303±5
3.1	198	156	0.787	1253	0.0030	0.0456±.0008	0.348±.022	0.0553±.0033	0.0454±.0008	286±5
5.1	110	44	0.403	5491	0.0030	0.1575±.0029	1.955±.057	0.0900±.0018	0.1453±.0033	875±19
6.1	185	204	1.104	1503	0.0068	0.0468±.0009	0.375±.026	0.0581±.0037	0.0465±.0008	293±5
7.1	404	490	1.213	2756	0.0021	0.0482±.0009	0.351±.019	0.0529±.0026	0.0481±.0009	303±5
8.1	391	348	0.891	7716	-0.0032	0.0471±.0009	0.375±.016	0.0578±.0022	0.0467±.0008	294±5
9.1	263	308	1.173	1602	0.0033	0.0479±.0009	0.362±.023	0.0547±.0032	0.0478±.0009	301±5
10.1	253	214	0.844	2022	0.0003	0.0492±.0009	0.367±.019	0.0542±.0025	0.0490±.0009	309±5
11.1	117	97	0.826	612	0.0100	0.0486±.0009	0.376±.028	0.0561±.0040	0.0483±.0009	304±5
13.1	257	119	0.463	8123	0.0019	0.2618±.0048	4.570±.103	0.1266±.0013	0.2947±.0058	1665±29
14.1	419	218	0.521	1986	-0.0015	0.0572±.0010	0.453±.016	0.0574±.0016	0.0568±.0010	356±6
15.1	86	63	0.735	712	0.0055	0.0476±.0009	0.366±.029	0.0558±.0042	0.0474±.0009	298±5

16.1	185	183	0.988	342	0.0267	0.0471±.0009	0.361±.024	0.0555±.0034	0.0470±.0009	296±5
17.1	311	147	0.473	12300	0.0013	0.3301±.0060	5.188±.104	0.1140±.0007	0.3271±.0062	1824±30
18.1	225	230	1.024	4600	-0.0049	0.0469±.0009	0.382±.021	0.0591±.0030	0.0465±.0008	293±5
19.1	259	338	1.305	672	0.0153	0.0494±.0009	0.385±.024	0.0565±.0032	0.0492±.0009	309±5
20.1	99	102	1.038	1492	0.0163	0.0455±.0009	0.286±.033	0.0456±.0050	0.0459±.0008	289±5
21.1	415	434	1.045	2615	-0.0016	0.0462±.0008	0.364±.017	0.0570±.0024	0.0460±.0008	290±5
22.1	65	33	0.518	252	0.0200	0.0449±.0008	0.303±.030	0.0490±.0046	0.0451±.0008	284±5
23.1	187	152	0.813	7156	-0.0081	0.0478±.0009	0.386±.020	0.0586±.0028	0.0474±.0009	299±5
24.1	129	129	0.998	4341	0.0067	0.0483±.0009	0.338±.027	0.0508±.0038	0.0484±.0009	305±5
25.1	247	214	0.867	989	0.0095	0.0475±.0009	0.352±.019	0.0538±.0026	0.0474±.0009	299±5
26.1	139	140	1.009	977	0.0050	0.0486±.0009	0.358±.031	0.0535±.0043	0.0485±.0009	305±5
27.1	381	304	0.798	2986	-0.0032	0.0479±.0009	0.376±.016	0.0569±.0021	0.0476±.0009	300±5
28.1	124	145	1.171	183	0.0906	0.0468±.0009	0.371±.044	0.0576±.0065	0.0465±.0009	293±5
29.1	358	337	0.941	2596	0.0048	0.0470±.0009	0.334±.018	0.0516±.0025	0.0471±.0009	297±5
30.1	110	96	0.875	5748	0.0059	0.0467±.0009	0.336±.029	0.0522±.0043	0.0467±.0009	294±5
32.1	107	89	0.833	6140	0.0100	0.0452±.0008	0.287±.027	0.0460±.0041	0.0456±.0008	287±5
33.1	111	110	0.995	1224	0.0119	0.0487±.0009	0.351±.036	0.0522±.0052	0.0487±.0009	307±5
34.1	172	119	0.694	1317	0.0041	0.0477±.0009	0.336±.023	0.0510±.0032	0.0478±.0009	301±5
						89503064				
3.1	124	59	0.478	426	0.0199	0.0578±.0012	0.425±.024	0.0533±.0027	0.0578±.0012	362±7
4.1	378	183	0.484	11395	0.0087	0.0558±.0011	0.401±.015	0.0522±.0015	0.0559±.0011	351±7
5.1	1403	83	0.059	4279	0.0037	0.2657±.0053	3.554±.074	0.0970±.0004	0.2655±.0053	1518±27
6.1	3463	378	0.109	70721	0.0002	0.2777±.0056	3.696±.075	0.0965±.0002	0.2776±.0056	1579±28
						88503023				
4.1	134	95	0.704	4934	0.0028	0.4583±.0087	10.651±.233	0.1685±.0012	0.4587±.0087	2434±38
12.1	140	97	0.692	982	0.0179	0.1130±.0021	0.989±.061	0.0635±.0036	0.1132±.0021	691±12
31.1	217	301	1.384	2709	0.0052	0.3620±.0067	7.979±.166	0.1599±.0012	0.3623±.0067	1993±32
31.2	179	161	0.901	1620	0.0086	0.3204±.0059	7.255±.159	0.1642±.0016	0.3203±.0059	1791±29
						88302095				
1.1	99	75	0.753	273	0.0162	0.0448±.0012	0.340±.028	0.0550±.0041	0.0447±.0012	282±7
2.1	54	23	0.420	154	0.0398	0.0468±.0012	0.384±.033	0.0596±.0047	0.0463±.0012	292±8

3.1	73	67	0.914	105	0.1169	0.0475±.0013	0.435±.048	0.0664±.0069	0.0467±.0012	294±8
4.1	192	144	0.748	413	0.0056	0.0468±.0012	0.347±.022	0.0538±.0029	0.0467±.0012	294±8
5.1	158	174	1.104	674	0.0084	0.0453±.0012	0.350±.027	0.0561±.0038	0.0451±.0012	284±7
6.1	108	110	1.018	543	-0.0252	0.0483±.0013	0.590±.033	0.0886±.0040	0.0461±.0012	290±7
7.1	177	145	0.818	850	0.0052	0.0473±.0012	0.355±.026	0.0544±.0035	0.0472±.0012	297±8
8.1	81	52	0.644	425	0.0086	0.0457±.0012	0.368±.030	0.0584±.0043	0.0454±.0012	286±7
9.1	315	496	1.574	2121	-0.0103	0.0456±.0012	0.406±.027	0.0646±.0037	0.0449±.0012	283±7
10.1	135	95	0.706	648	0.0071	0.0464±.0012	0.332±.023	0.0519±.0031	0.0465±.0012	293±7
11.1	126	89	0.704	501	0.0057	0.0471±.0012	0.347±.024	0.0535±.0033	0.0471±.0012	296±8
12.1	101	111	1.097	319	0.0112	0.0447±.0012	0.319±.031	0.0518±.0046	0.0447±.0012	282±7
13.1	154	110	0.714	2680	0.0022	0.0464±.0012	0.364±.021	0.0570±.0028	0.0461±.0012	291±7
14.1	154	118	0.767	9533	0.0016	0.0466±.0012	0.374±.023	0.0582±.0030	0.0463±.0012	292±7
15.1	158	114	0.725	1142	0.0007	0.0462±.0012	0.379±.023	0.0595±.0030	0.0458±.0012	289±7
35.1	176	150	0.852	953	0.0019	0.0463±.0012	0.358±.023	0.0560±.0032	0.0461±.0012	290±7
36.1	165	133	0.806	3049	-0.0018	0.0464±.0012	0.367±.023	0.0573±.0031	0.0461±.0012	291±7

89302108

16.1	112	109	0.970	375	0.0106	0.0432±.0011	0.358±.029	0.0602±.0044	0.0427±.0011	270±7
17.1	200	281	1.402	13996	-0.0027	0.0458±.0012	0.363±.027	0.0574±.0037	0.0455±.0012	287±7
18.1	297	469	1.583	2440	-0.0098	0.0455±.0012	0.396±.025	0.0632±.0035	0.0449±.0012	283±7
19.1	245	373	1.523	1156	-0.0132	0.0471±.0012	0.452±.030	0.0696±.0040	0.0461±.0012	290±7
20.1	509	692	1.358	2377	-0.0069	0.0465±.0012	0.380±.019	0.0592±.0024	0.0461±.0012	291±7
21.1	264	337	1.276	20764	-0.0009	0.0485±.0013	0.369±.023	0.0551±.0029	0.0483±.0013	304±8
22.1	424	615	1.449	2582	-0.0074	0.0468±.0012	0.393±.022	0.0609±.0028	0.0463±.0012	292±7
23.1	194	196	1.008	1111	-0.0007	0.0474±.0012	0.374±.025	0.0573±.0033	0.0471±.0012	296±8
24.1	231	315	1.363	3423	0.0024	0.0463±.0012	0.350±.027	0.0549±.0038	0.0462±.0012	291±7
25.1	164	131	0.801	2432	0.0002	0.0458±.0012	0.372±.023	0.0589±.0031	0.0455±.0012	287±7
26.1	113	101	0.898	6044	0.0014	0.0475±.0013	0.383±.030	0.0585±.0042	0.0471±.0012	297±8
27.1	117	149	1.270	453	0.0021	0.0447±.0012	0.385±.034	0.0625±.0051	0.0442±.0012	279±7
28.1	98	120	1.221	7036	0.0150	0.0467±.0013	0.328±.035	0.0509±.0051	0.0468±.0012	295±8
29.1	90	107	1.188	434	-0.0041	0.0483±.0013	0.417±.038	0.0626±.0052	0.0477±.0013	300±8
30.1	117	142	1.206	640	0.0030	0.0472±.0013	0.359±.033	0.0551±.0046	0.0470±.0012	296±8
31.1	185	248	1.344	1336	-0.0005	0.0460±.0012	0.378±.030	0.0597±.0042	0.0455±.0012	287±7
32.1	120	116	0.962	714	0.0161	0.0454±.0012	0.366±.032	0.0585±.0046	0.0450±.0012	284±7
33.1	109	113	1.043	681	-0.0005	0.0476±.0013	0.398±.034	0.0607±.0047	0.0471±.0012	297±8
34.1	137	171	1.242	483	0.0078	0.0444±.0012	0.324±.034	0.0530±.0052	0.0443±.0012	280±7

f_{206} is the ratio of common Pb to total Pb in terms of mass 206. The analytical procedures used for the SHRIMP ion-microprobe are described by Compston et al. (1984) and Williams et al. (1984). Operation at a mass resolution of more than 6500 eliminated significant spectral interferences. Minor changes in inter-element fractionation were monitored by repeated analyses of a zircon standard (SL3 P1). Absolute values for Pb/U and Pb/Th are referenced to a $^{206}Pb/^{238}U$ ratio in that standard of 0.0928, which is equivalent to an age of 572 Ma. Systematic inter-element fractionation was compensated by the use of a quadratic relationship obtained between Pb+/U+ and UO+/U+ on the standard zircon. In order to obtain optimal analytical precision, correction for common Pb for all Palaeozoic zircons is based on the ^{208}Pb isotope. ^{204}Pb correction was used for all of the Precambrian zircon grains because some of these showed evidence of disturbance to U-Th-Pb systematics. The last two columns, $*^{206}Pb/^{238}U$ and *Age, represent ^{207}Pb-corrected parameters. This correction procedure, which assumes isotopic concordance, eliminates minor aberrations arising from quantitatively imprecise common Pb correction. Even though the uncertainties given in the above table are 1 σ, ages in diagrams and in the text are reported at the 95% confidence level.

Table 2. Rb-Sr isotopic data for igneous rocks of the northern Drummond Basin.

Sample No.	Rock unit	Rb (μg/g)	Sr (μg/g)	$^{87}Sr/^{86}Sr$	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$ (initial)
89503028	Arundel Rhyolite	167	119	0.72180	4.044	0.7049
88302095	Easter Granodiorite	93	303	0.70824	0.8837	0.7046
89302108	Nostone Creek Granodiorite	59	359	0.70640	0.4781	0.7044

Analytical techniques are described in Williams et al. (1976). The initial $^{87}Sr/^{86}Sr$ values are calculated from the U-Pb zircon ages.

Table 3. Summary of U-Pb zircon crystallisation ages for igneous rocks at the northern end of the Drummond Basin.

SAMPLE NUMBER	ROCK TYPE	UNIT	AGE
88503170	Welded rhyolitic ignimbrite	correlative of Locharwood Rhyolite	300±5 Ma
88502032	Welded rhyolitic ignimbrite	"type" Locharwood Rhyolite	305±6 Ma
88502031	Welded dacitic ignimbrite	Smedley Dacite	298±4 Ma
89302132	Dacitic andesite	"Smedley" association?	297±4 Ma
89503028	Welded ignimbrite	Arundel Rhyolite	294±5 Ma
89302108	Quartz monzodiorite	Nostone Creek Granodiorite	291±6 Ma
88302095	Hornblende-biotite granodiorite	Easter Granodiorite	291±6 Ma