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REPLY

Timing of magmatism and metamorphism in the Gruinard Bay area of the Lewisian Gneiss Complex: comparison with the Assynt Terrane and implications for terrane accretion—reply

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Corfu urges us to keep discussions more firmly rooted in ‘‘the reality’’. Unfortunately, no individual has a monopoly on ‘‘the reality’’. We all emphasize different aspects of a complex reality according to our experience and prejudices. Whereas Corfu et al. (1998) concluded that their age data were consistent with longstanding conventional concepts envisaging ‘‘major crustal accretion of the entire Lewisian complex during plate convergence, tectonism and widespread magmatism in the period 2850–2700 Ma ...’’, we have concluded from our age data (e.g. Friend and Kinny 2001) that the complex represents a collage of accreted terranes of differing age and early history. In order to resolve these two alternative realities, we need to examine the origins of the different data sets further.

The strengths and weaknesses of TIMS and SIMS approaches to zircon U–Pb geochronology have been discussed at length elsewhere, and in simple geological scenarios both methods yield ages that agree to within error. When results disagree and neither analyst nor equipment is technically at fault (neither is at issue here), the complexity of the geological scenario is to blame, manifest in the isotopic complexity of the zircon populations sampled at the different analytical scales. A technically perfect analysis of a mixed age domain is likely to result in ambiguity regardless of the analytical method employed. TIMS age data comes with spectacular analytical precision which tends to lull the non-specialist into a false sense of security when ages are quoted. Nevertheless, interpretations of TIMS age data are based on comparatively few data points, which in complex populations have a high likelihood of representing average compositions of multiple domains. Extrapolation errors can be large. SIMS age data come with comparatively low analytical precision for individual data points which can mask fine age structure and slight discordance. This is well illustrated in Corfu’s Fig. 1a which highlights the size of SIMS error boxes for extremely low U domains. However, with many more points analysed of much smaller volumes, SIMS can yield a more complete picture of the range of isotopic subdomains in the population and, through cathodoluminescence (CL) imaging, comes with detailed documentation of the analysed sites. As Corfu has reiterated, our understanding of what the isotopic domains in complex zircon crystals really mean, and our ability to link age dates to specific geological events and structures, are imperfect. The zircon populations from the high-grade rocks of the Assynt and Gruinard terranes of the Lewisian Gneiss Complex are as complex as any we have dealt with. It is not surprising that their interpretation has proven contentious.

The Corfu et al. (1994) data set for the trondhjemite sheet at Badcall Bay in which outer shells of grains

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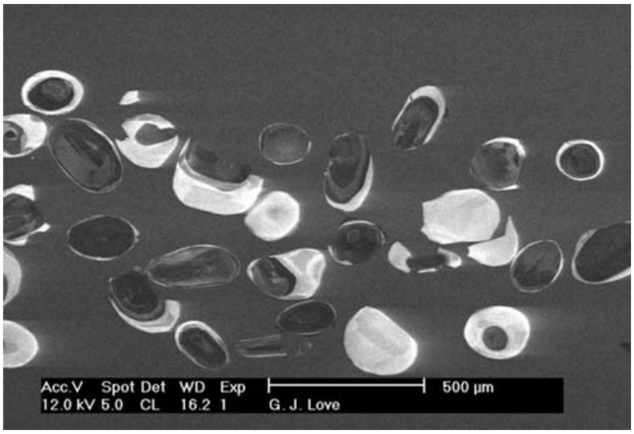

Fig. 1 Cathodoluminescence image of sectioned zircons from Badcall Bay trondhjemite sheet sample S98/1. Note the faint zonation present within the brightly luminescent (low-U) rims and whole-grains whose origin we interpret as due to recrystallisation

yielded ages older than core fractions, is a clear demonstration of the fact that internal isotopic variations do not occur in simple, concentric core—rim patterns only, and that even domains that appear simple and uniform in CL images can contain unexpected variations in isotopic composition. Figure 1 is a CL image of zircons from the trondhjemite sheet (sample S98/1, see also Fig. 3c of Love et al. 2004), illustrating the brightly luminescent low-U zircon domains that occur both as rims and as whole grains. It is the SIMS data from these low-U domains that Corfu has replotted on his Fig. 1a, not our whole data set (c.f. Fig. 5a with b, Love et al. 2004). Whereas one might expect the bright rims to yield a consistent age that one might associate with a metamorphic event, they do not. Some give ages as old as the oldest cores. This immediately corroborates the age variations Corfu et al. (1994) found among their shell fragments, without having to consider them as mixed core-rim fractions, i.e. there are real age variations present among the rim domains themselves, as indeed among the cores. We interpret these data as indicating that the bright low-U domains were derived by *recrystallization* of magmatic zircon rather than by growth during later metamorphism, whereby the affected domains lost U, Th, and radiogenic Pb incompletely and unevenly across the grains. Supporting evidence for this can be seen in Fig. 1 where faint zonation is visible in some low-U domains. This may represent remnants of magmatic oscillatory growth zonation. Furthermore, unpublished laser ablation Hf isotope data for the zircons (Love 2003) show that the Hf isotopic composition of the core and rim domains are identical to within error (average ^{176}Hf/^{177}Hf ratio 0.280941), which strongly supports the recrystallization model, as one would otherwise expect there to be a difference in composition between an original grain and a younger, metamorphically grown rim, as indeed one would expect between a magmatic population and older inherited cores (Kinny et al. 2006).

The problem is that Corfu regards all our oldest zircon ages as representing inherited material (as an explanation of why the original TIMS data set neither included any data points nor indicated an upper intercept age significantly over 2700 Ma). If we are dealing with inheritance, the low-U rims and grains that gave ages up to c. 2900 Ma must be inherited also, which would make their geochemical similarity with other rims that developed on younger grains in the sample an extremely unlikely coincidence. In general, trondhjemites are undersaturated with respect to Zr (e.g. Watson 1996) and it would be presumed the case here. Therefore, any entrained zircons are likely to dissolve in the melt and so inheritance of early zircon is not a common occurrence. Moreover, if the oldest grains are inherited, where is the main magmatic population? Corfu would argue that the age of the rock is c. 2700 Ma. So even if we allow for a few inherited cores, why is there not an accompanying main population of SIMS core analyses clustering at 2700 Ma? In fact, the majority of core analyses yielded ages ranging from 2700 to 2900 Ma with no significant clustering discernable by us, hence our interpretation of them as a disturbed older population (Love et al. 2004). But if you accept that the true magmatic age of the sheet is c. 2700 Ma, this would imply that nearly every zircon core we analysed was inherited material and that either there is no significant magmatic population or that we just missed it every time. Neither alternative seems likely to us. Nor did we find any grain whose CL image showed the likely presence of an inherited component in the form of a discrete inner core with its internal zonation truncated by an irregular boundary to an outer core. Nor did we date any 2900 Ma inner cores mantled by domains that yielded 2700 Ma. The areas which yielded the oldest ages were morphologically unremarkable in the context of the overall population, and we could not predict the age we would obtain from any area in advance. The Badcall Bay trondhjemite sheet is not an isolated example. We have now dated seven rocks from the Assynt Terrane by SIMS and all have yielded protolith ages over 2900 Ma (Friend and Kinny 1995; Kinny and Friend 1997; Love et al. 2004). Following our 1997 publication, Corfu et al. (1998) remarked "*It is possible that the five gneiss samples investigated by Friend and Kinny ... are genetically* *distinct from the units sampled by Corfu et al.* (1994). *Alternatively, the oldest apparent ages ... may reflect the presence of xenocrystic zircon components*''. We do not believe that either is true, particularly as two of the samples come from the localities used by Pidgeon and Bowes (1972) for their study. Even allowing for the occasional presence of xenocrystic components (e.g. a 3115 Ma structural core in sample GST 10, Kinny and Friend 1997), the older protolith ages together with the dominant c. 2490 Ma metamorphic disturbance first identified by Corfu et al. (1994), are consistent features of the gneisses of the Assynt Terrane as defined by our work, and constitute the main criteria for distinction from the Gruinard Terrane, where protolith ages are younger, granulite facies metamorphism is recorded at c. 2730 Ma, and the c. 2490 Ma event is absent.

Corfu is right to point out that the TIMS data lie above a 2490–2900 Ma mixing line and so cannot be explained by a simple two-stage evolution model, i.e. zircons formed at c. 2900 Ma and losing Pb or growing new rims at 2490 Ma. One possible explanation is that a substantial amount of the Pb loss from the older zircons occurred prior to 2490 Ma, i.e. during earlier disturbances. This is not a suggestion made purely for convenience. There is compelling evidence for multiple high-grade events, as we have explicitly stated: ''*Instead, it appears likely that the area has been subjected to two high-grade events, the first generated localised partial melting and the trondhjemite magmas. ...The second metamorphic episode is considered to be the Badcallian granulite facies event, imparting the high grade assemblages noted in the area, and causing high degrees of resetting of the U–Pb system*'' (Love et al. 2004, p 623). One of the prime motivations for the Love et al. (2004) study was to attempt to date earlier high-grade events, hence the dating of Badcall Bay sample GL00-14, a gneissic trondhjemitic melt that disrupts isoclinal folds. The severity of the 2490 Ma Badcallian event defeated us.

As to why the TIMS data have so far failed to record ages significantly older than 2700 Ma we can only offer the following two suggestions: firstly that the earlier high-grade event (most likely between 2750 and 2700 Ma in age) was as severe as the 2490 Ma event in depleting the zircons of radiogenic Pb (hence the data not lining up on a 2900–2490 Ma mixing line), and secondly that the subdomains within the grain cores which are the least disturbed and which therefore give the oldest ages in the SIMS data, are comparatively small and hence form only a minor component of, or are absent from the grain fragments used for TIMS analysis. Ultimately, whether or not this hypothesis turns out to be ''the reality'' remains to be seen. We rather suspect that future TIMS work will confirm the older protolith ages.

Lastly, regarding the dating of the Gruinard Bay samples it is worth noting that, unlike previous workers, we chose specifically to study unretrogressed granulite facies rocks at Gruinard Bay, in an attempt to avoid the extra complications that may arise from later hydrous retrogressive events. Our interpretation of the ages obtained from the brightly luminescent zircon rims as dating high-grade metamorphism is based on consistent results from three samples. One was an unretrogressed granulite facies rock (GL00/09) and another a granulite facies dehydration partial melt (GL01/10). These rims resemble those from the Assynt Terrane discussed above. They have Th/U ratios which are atypical of igneous suites and the presence within them of partial zoning again may be ascribed to recrystallisation of pre-exisiting zircon rather than to igneous growth. Given the fact that tonalitic granulite sample GL00/09 was taken from a different locality to trondhjemitic sample GL00/07 that did not share the same history of retrogression, and given the geological complexity of the latter locality, we are unconcerned that GL009's interpreted protolith age is the slightly younger of the two, as it is neither clear that the tonalitic phases at the two localities are equivalent, nor that there is only one generation of trondhjemitic material at the latter.

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References

Corfu F, Heaman LM, Rogers G (1994) Polymetamorphic evolution of the Lewisian Complex, NW Scotland, as recorded by U–Pb isotopic compositions of zircon, titanite and rutile. Contrib Mineral Petrol 117:215–228

Corfu F, Crane A, Moser D, Rogers G (1998) U–Pb zircon systematics at Gruinard Bay, northwest Scotland: implications for the early orogenic evolution of the Lewisian Complex. Contrib Mineral Petrol 133:329–345

Friend CRL, Kinny PD (1995) New evidence for protolith ages of Lewisian granulites, NW Scotland. Geology 23:1027–1030

Friend CRL, Kinny PD (2001) A reappraisal of the Lewisian Gneiss Complex: geochronological evidence for tectonic assembly of disparate terranes in the Proterozoic. Contrib Mineral Petrol 142:198–218

Kinny PD, Friend CRL (1997) U–Pb isotopic evidence for the accretion of different crustal blocks to form the Lewisian Complex of Northwest Scotland. Contrib Mineral Petrol 129:326–340

Kinny PD, Love GJ, Pearson NJ (2006) Hf isotopes and zircon recrystallization: a case study. Abstract, 16th V. M. Goldschmidt Conference, Melbourne

Love GJ (2003) The origins and accretionary development of the Lewisian Gneiss Complex of NW Scotland: constraints from in situ U–Pb and Hf isotopic analysis of accessory minerals. Unpublished Ph.D Thesis, Curtin University of Technology

Love GJ, Kinny PD, Friend CRL (2004) Timing of magmatism and metamorphism in the Gruinard Bay area of the Lewisian Complex: comparisons with the Assynt Terrane and implications for terrane accretion. Contrib Mineral Petrol 146:620–636

Pidgeon RT, Bowes DR (1972) Zircon U–Pb ages of granulites from the Central Region of the Lewisian, northwestern Scotland. Geol Mag 109:247–258

Watson EB (1996) Dissolution, growth and survival of zircons during crustal fusion: kinetic principles, geological models and implications for isotopic inheritance. Trans R Soc Edinb Earth Sci 87:43–56