CORRESPONDENCE

Comments on the letter 'In defence of the external detector method of fission track dating' by P. F. Green

SIR – The recent assessment by Gale & Beckinsale (1983) of the work of Ross *et al.* (1982) on 'Fission track dating of British Ordovician and Silurian stratotypes' made one essential point: the errors for the fission track dates presented by Ross *et al.* (1982) are so large that these dates do not significantly constrain the numerical calibration of the Phanerozoic timescale. In his letter Green (1984) agrees that at present a reasonable estimate for the precision of a fission track age is $\pm 10\%$ (2σ) for a single determination; it should be noted that 8 out of the 13 reliable dates quoted by Ross *et al.* rely on but a single determination. Using the conventional statistical approach (Green, 1981*a*) to compute the 2σ error of a fission track date even the *best* of the 5 duplicate fission track dates published by Ross *et al.* (1982) has a *precision* of only about $\pm 5\%$. Moreover it seems possible that even these errors may be underestimated if we compare them with the 2σ errors quoted by Hurford & Green (1983) for no less than 45 repeat fission track dates for the Fish Canyon Tuff, which range from $\pm 4.3\%$ to $\pm 7.7\%$ depending on the neutron dosimeter glass used, and for which the overall variation in individual determinations is $\pm 18\%$.

These large errors of precision for fission track dates compare very unfavourably with the 2σ errors of about $\pm 1\%$ to $\pm 1.5\%$ associated with many K–Ar, Rb–Sr, or U–Pb ages available for calibrating the time scale (Gale, 1985). It is chiefly in that sense that Gale & Beckinsale (1983) suggested that the data of Ross *et al.* (1982) did not provide a considerable advance in the numerical calibration of the Phanerozoic time scale. It is Green's (1984) privilege now to dissociate himself from that view, perhaps somewhat inconsistently in the light of his agreement with our assessment of the errors associated with the data published by Ross *et al.* (1982). The reader must judge for himself in the light of the following passage from Hurford & Green, whether Gale & Beckinsale (1983) were wrong to associate these authors with some reservations about the contribution made by Ross *et al.* (1982) to the numerical calibration of the time scale. Hurford & Green (1982, p. 349) state (the italics are mine):

'The work by Ross *et al.* has demonstrated the *potential* contribution which fission track dating *could make* to geological and stratigraphical studies: the presence of residual zircons, sphenes and apatites permits the dating of often otherwise undatable, volcanically derived marker horizons. Stratigraphic ages and the ages of the contained palaeofauna or flora are not infrequently contentious and *safeguards must be taken against the further addition of misleading data resulting from the related problems of* λ_f *and neutron dosimetry*.'

That said I should like to stress that nowhere in their letter do Gale & Beckinsale (1983) themselves attack the external detector method of fission track dating (EDM) and it is simply not the case, as Green (1984) avers, that 'Gale & Beckinsale...assert that Ross *et al.* are unaware of the problems associated with the EDM'. Recognizing that they are not experts in the field of fission track dating Gale & Beckinsale (1983), except for their comments on the statistical assessment of errors, were careful to confine themselves to quotations from correspondence with, or the publications of, those who have established reputations in this field; in this case Hurford & Green (1982) and Storzer & Wagner (1982). They assumed, with Harland (1983), that the review of fission track dating by Storzer & Wagner (1982), being both the most recent and one written specifically for inclusion in a book devoted to the numerical calibration of the time scale, would represent an authoritative statement of the current state of the art. Subsequent written comments from Naeser, and perusal of papers by Gleadow & Lovering (1977), Green & Durrani (1978) and Hurford & Green (1983) have weakened my confidence in some parts of the review by Storzer & Wagner (1982) to the point where I have recently written (Gale, 1985) 'We believe that the errors to be attached to these fission track ages have been properly assessed by Gale & Beckinsale (1983). However, in that paper we relied too much on criticisms made by Storzer & Wagner (1982) of certain technical features of the fission track measurements reported by Ross *et al.* (1982). We are now convinced that the technical quality of these measurements was of a very high standard, that possible track annealing was properly considered and that the zircons, dated by the external detector method, were oriented in such a way that the geometry factor was known with certainty.' It is, nevertheless, disconcerting to find so much disarray amongst the fission track experts.

Proceeding with the comments by Green (1984) on the letter by Gale & Beckinsale (1983), I come to the question of the calibration of the external detector method of fission track determination and the avoidance of the gross errors in neutron dosimetry which can arise even when NBS standard uranium glasses are used. These matters were discussed in detail by Hurford & Green (1982), who pointed out that in fission track dating the neutron fluence calibration and the decay constant λ_f (together referred to as the calibration ratio B/λ_f) constitute a combined unknown factor in the age equation whose evaluation, for all practical purposes, requires the irradiation of standards of known age, determined by other geochronological methods. The statement about this in Gale & Beckinsale (1982), quoted by Green (1984), was not intended to specify precisely how the calibration in terms of age standards is to be effected. Hurford & Green (1982, p. 351) specifically state that 'Hurford and Green (1981) have advocated the inclusion of an age standard in every reactor run, which should be used subsequently either to check an established calibration ratio (B/λ_f)...or to calculate the age of unknown samples by direct comparison of the track densities of standard and sample.' In their abstract Hurford & Green (1982) state 'An alternative approach is presented, formally relating unknown ages of samples to known ages of standards, either by direct comparison of standard and sample track densities, or by the repeated calibration of a glass against age standards.'

At no point in their 1982 paper do Hurford & Green recommend either of these alternative procedures in preference to the other. It is indeed unfair for Green (1984) to attempt to use results from a later paper (Hurford & Green, 1983) to criticize an earlier statement by Gale & Beckinsale (1983) which is in fact entirely in accord with the

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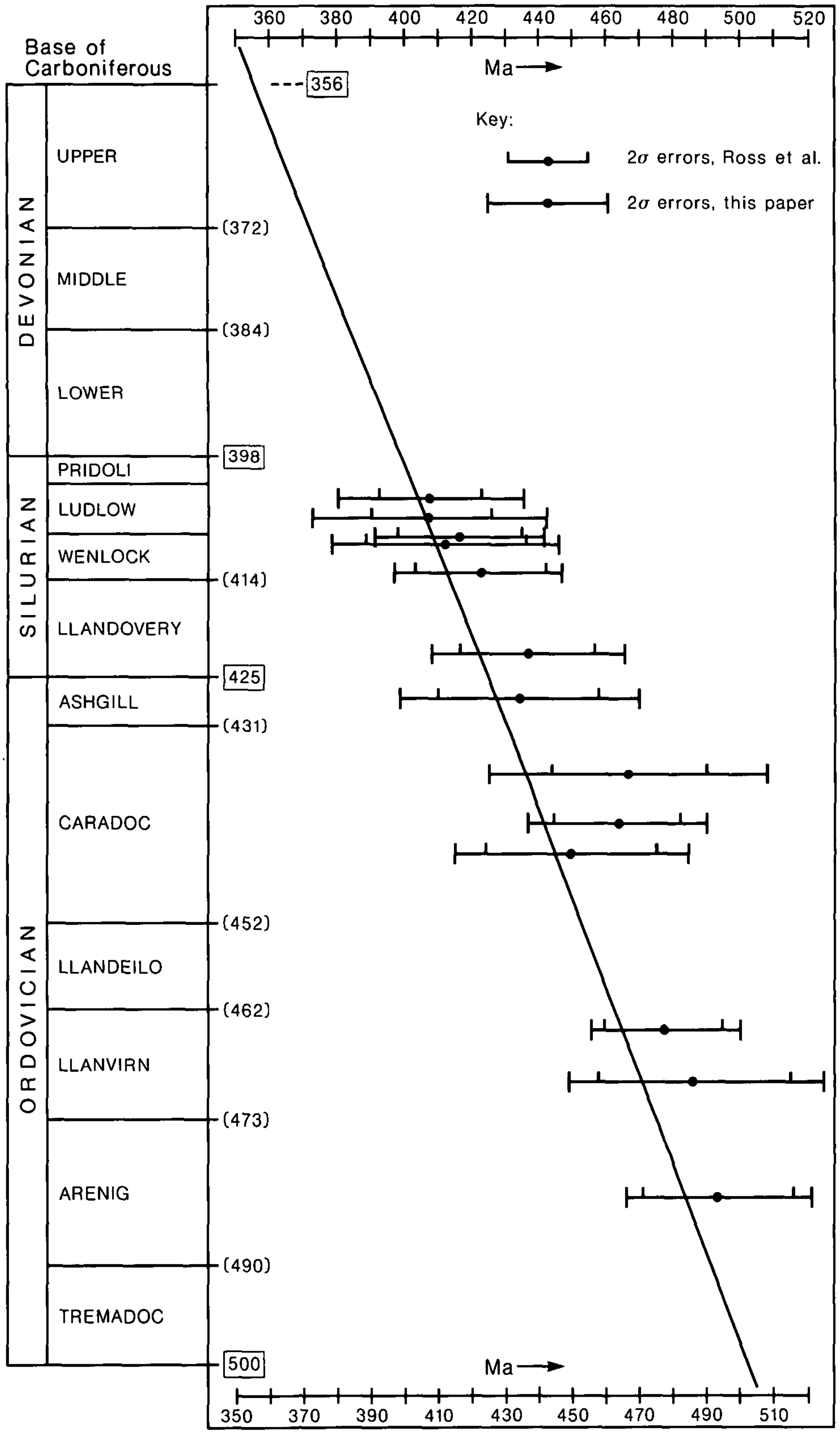

Figure 1. Plot of the fission track ages of Ross *et al.* (1982) against a stratigraphic axis where the relative lengths of the series have been chosen to be consistent with estimates made by palaeontologists and stratigraphers. The line through the data is the numerical calibration of this part of the time scale suggested by Gale & Beckinsale (1983); it is not the best fit line through the fission track data, but is entirely consistent with this data. The errors shown are both the erroneously too small errors calculated by Ross *et al.* and the errors computed using the conventional statistical treatment. The plot shows clearly that the fission track ages do not constrain very exactly the numerical calibration of this part of the time scale.

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recommendations contained in Hurford & Green (1982). Of course a moment's reflection is sufficient to decide that superior precision should result from repeated fission track measurements of a series of age standards so as to yield a calibration baseline for a uranium bearing glass neutron dosimeter, rather than direct comparison of an unknown FTD age with a single simultaneous run on a FTD age standard. Hurford & Green (1983) are to be congratulated on their careful work establishing empirically the truth of this conclusion, and for their proof that this is at present the best available approach to the determination of fission track ages. I accept that this superior method is effectively the procedure which was followed by Ross *et al.* Since Ross *et al.* apparently evaluated their quoted neutron fluence values by reference to the Cu calibration of the NBS fission track standard glasses SRM 962 and SRM 963, then for comparison with ages established by other geochronological methods '...the uncertainty of the NBS activation monitor measurement ($\sim \pm 3\%$) must be propagated to the experimental fluence measurement *and* the age', as Hurford wrote to me on 21 April 1982.

One does not need to be a fission track expert to decide that the statistical treatment by Johnson, McGee & Naeser (1979) of the errors in a fission track age is incorrect, and that the conventional error assignment in EDM advocated by Green (1981*a*) is correct. However Green (1984) is mistaken when he states that in their discussion of this topic Gale & Beckinsale (1983) '...seem to have missed the point somewhat. This is that while there is indeed a correlation between variation in ρ_s and ρ_i caused by variation of uranium content from grain to grain, this is not what is assessed by the conventional error assignment in the EDM. Instead, as explained in more detail in Green (1981) [*a*], this error assignment estimates how well the age (or ρ_s/ρ_i) can be constrained from the numbers of tracks counted, as a result of Poisson variation, and the Poisson distributions (virtual, not real) of ρ_s and ρ_i can never be correlated.'

Contrary to Green's (1984) implication, Gale & Beckinsale (1983) were well aware, and explicitly stated, that the correlation between ρ_s and ρ_i arising from the functional relationship between them does not in any way affect the correct assessment of the statistical error $\sigma(\rho_s/\rho_i)$. Green (1984) prefers to state this fact by saying that the Poisson distributions of measurements of ρ_s and ρ_i can never be correlated; we prefer a more general statement since, as shown by Burchart (1981), Green (1981*a*) and Galbraith (1981), it is possible for certain experimental factors to introduce extra, non-Poissonian, variation to the measured values of ρ_s and ρ_i. We repeat that, whatever statistical probability distribution functions properly describe the fluctuations in the measured values of ρ_s and ρ_i, a functional relationship between ρ_s and ρ_i does not necessarily imply that measurements of ρ_s and ρ_i are *statistically* dependent, as is lucidly explained by Mandel (1964, pp. 52–7). In the present case, although there is a functional relationship between ρ_s and ρ_i for a particular crystal, the measurement of ρ_s and ρ_i (as track densities) are made quite independently of each other in two separate observations so that $\sigma(\rho_s)$ and $\sigma(\rho_i)$, the errors associated with these two separate observations, are necessarily statistically independent, with zero correlation coefficient, even though the expected values of ρ_s and ρ_i themselves are correlated through the uranium concentration. It should not have needed a series of papers dealing with the elementary statistics involved (Johnson, McGee & Naeser, 1979, 1982; Green 1981*a*, 1981*b*, 1982) to demonstrate this fact, which follows in an obvious way from the physics of the experimental situation in EDM. For those who believe in nothing until it has been proven experimentally, the incorrectness of the error estimates given by the treatment of Johnson, McGee & Naeser (1979) and used by Ross *et al.* (1982) has now been nicely demonstrated by the painstaking series of measurements reported by Hurford & Green (1983, fig. 5).

Those fission track ages selected as reliable by Ross *et al.* (1982) are plotted in Figure 1, where both the erroneously small errors computed by Ross *et al.* are indicated together with the 2σ errors computed from the conventional statistical approach (Green, 1981*a*). The solid line represents the best fit line through the 33 critical radiometric ages discussed by Gale & Beckinsale (1983, table 1 and fig. 1). It is clear that the fission track ages are consistent within errors with the numerical calibration suggested by Gale & Beckinsale (1983), but the errors associated with the fission track ages are so large that they agree also with the different calibration proposed by McKerrow, Lambert & Chamberlain (1980). Figure 1 demonstrates forcibly that the fission track ages of Ross *et al.* (1982) provide no useful constraint on the numerical calibration of the time scale. For example, extreme lines can be drawn through the fission track ages of Figure 1 which fix the base of the Devonian no better than between 375 and 430 Ma and the base of the Silurian between 415 and 455 Ma.

Nevertheless, as Gale & Beckinsale (1983) wrote, the work of Ross *et al.* '...has demonstrated the potential contribution which fission track dating could make to stratigraphical studies in the future', *provided that the errors can be reduced.* Green (1984) holds out the hope that this may be achieved by multiple determinations, but certain other improvements also remain to be made before fission track ages can reliably be incorporated with other types of radiometric ages in the calibration of the time scale. First there is the possibility that the errors of fission track ages may be even larger than those calculated by the conventional statistics if non-Poisson experimental errors are present (Green, 1981*a*; Hurford & Green, 1983, pp. 310–11). Though the presence of such extra sources of error can be detected by a χ^2 test (Galbraith, 1981) it seems that at present there exists no generally accepted alternative analysis to estimate the magnitude of the overall errors for such fission track data.

Careful consideration of possible systematic errors is also necessary. Green (1984) has reiterated that, for lack of suitable age standards, it has yet to be demonstrated that EDM gives a consistent calibration scale for ages much in excess of 100 Ma, as was indeed acknowledged by Ross *et al.* (1982).

A considerable extrapolation is required to use the EDM method to measure fission track ages of $\sim$ 400 Ma based on age standards of less than 100 Ma, and the errors for the ages of the standards must be propagated into the fission track ages of the unknowns. Further, Green (1984) is not satisfied that Ross *et al.* (1982) have demonstrated adequately that their preferred fission track ages are thermally unaffected, depositional ages; in other words, some of their accepted ages may only be minimum ages. An effect in the other direction could result from the presence of detrital zircon grains amongst those counted. Although detrital zircon crystals of grossly higher age can easily be distinguished from those properly associated with the bentonites, a problem occurs when the contaminating zircons are only a littler older than the zircons one wishes to date (Naeser, Hurford & Gleadow, 1977). The large statistical error associated with the number of fission tracks observed in a single grain makes

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this a difficult problem to overcome, and it seems that it should receive more discussion for any fission track date put forward as a serious candidate for a calibration point for the time scale. In conclusion the fission track dating method is indeed developing rapidly, but seems still to have some way to go before it can compare in precision with conventional radiometric dating methods.

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