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GEOTRACK
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FISSION TRACK ANALYSIS OF SAMPLES FROM ORANGE-2, AMADEUS BASIN

ONSHORE

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SAMPLES AND SUITABILITY

Two samples of washed cuttings were submitted for fission track analysis from Orange-2 in the Amadeus Basin. Sample details provided with this material is shown in Table 1 together with their respective yields of detrital apatite.

Table 1: Sample details and apatite yields

Sample number	Depth	Formation	Age	Apatite yield
8422-81	1130-1185m	Pacoota Sst.	Late Cambrian -early Ordovician	satisfactory
8422-82	2850-2880m	Arumbera Sst.	Late Proteroz. -early Cambrian	excellent

The samples were crushed to disaggregate detrital grains using a rotating disc mill, washed and dried prior to mineral separation. The crushed and sized material (<250 μm) was then processed by conventional heavy-liquid and magnetic techniques to recover any uranium-bearing accessory minerals. Both samples proved to contain suitable yields of detrital apatite in their heavy mineral populations, as indicated in Table 1.

Apatites of distinctively different petrographic character were found in the two samples and these are illustrated by the photomicrographs in Figure 1. In the Pacoota Sandstone sample (8422-81) from Orange-2 the apatites were not abundant, making up only about 10 % of the final concentrate. However there were quite sufficient grains for analysis and they were of exceptionally high quality. These apatites were typically large (100-250 μm), subhedral to euhedral in form and containing high, uniform fission track densities. The grains were also free of interfering dislocation etch pits. The remainder of the concentrate was made up largely of organic phosphate in the form of conodont fragments. The apatites in this sample are shown in Figure 1a.

In contrast the apatites from the Arumbera Sandstone (8422- 82) were abundant and a nearly pure concentrate was obtained. Two distinct groups of detrital apatite grains could be seen in the mounted concentrate (Figure 1b). The first (8422-82 A) were rare (about 5%) and essentially identical in character to those described from the Pacoota Sandstone. The second and far more abundant group (8422-82B) are mostly of medium size (50-150 μm), very well rounded, and conspicuously stained with iron oxide coatings. Track densities were mostly fairly low but these grains also proved to be highly suitable materials for fission track analysis. The first group is so different from the second, especially in the lack of any ferruginous coatings, that it is thought that they are probably cavings from other formations, such as the Pacoota, higher in the well sequence.

TECHNIQUES

Fission track age and length measurements were made using techniques outlined by Gleadow et al. (1983). Apatites were mounted in epoxy resin on glass slides, polished and etched for 20 sec in 5M HNO_3 at 20 °C to reveal the fossil fission tracks. The apatite mounts were processed by the external detector method (Gleadow, 1981) which, apart from its greater inherent precision, has the advantage of allowing single grain ages to be determined. Tracks were counted over mostly 20 grains in each mount the actual number depending on the availability of suitably etched and oriented apatites. The numbers of tracks used for each track density and length determination are also shown in Table 2.

Track lengths were measured using the full length of 'confined' fission tracks i.e. those which do not intersect the polished surface but have been etched from other tracks or fractures. Lengths were measured on 50 to 100 horizontal confined tracks. The uncertainty quoted for the length measurements in Table 2 is the standard deviation of the distribution, which gives a measure of the breadth of the distribution. The precision of the length measurements is indicated by the standard error of the mean which would be one tenth the standard deviation where 100 tracks were measured.

Ages were calculated using the standard fission track age equation (Hurford and Green, 1982) and errors are quoted at the level of one standard deviation throughout. Errors were calculated using the 'conventional' technique outlined by Green (1981) based on the total number of tracks counted for each track density measurement. All constants used in derivation of the results are shown at the bottom of Table 2 using the nomenclature of Hurford and Green (1982). The Zeta calibration factor has been determined empirically by direct comparison with K-Ar ages for a set of carefully chosen age standards.

Neutron irradiations were carried out in a well thermalised flux (X-7 facility) in the Australian Atomic Energy Commission's HIFAR research reactor. Total neutron fluence was monitored by counting tracks in mica external detectors attached to two pieces of the NBS standard glass SRM612 included in the irradiation cannister at each end of the sample stack. No flux gradient is usually found in the irradiation facility used over the length of the sample package and this was confirmed by the track counts over the two dosimeter glasses.

RESULTS

Full analytical data for the fission track ages are given in Table 2 together with the mean track lengths for both the samples from Orange-2. The maximum probability age is determined from the ratio of track densities obtained from the pooled data for all grains counted. The variation in both apparent apatite age and mean track length is also shown in Figure 2 as a function of increasing sample depth for Orange-2.

Two statistical parameters are also summarised in Table 2, which are used to test the variability of apparent ages between single apatite grains. The correlation coefficient indicates how well correlated the fossil and induced track densities are for all the grains counted. For a population of apatites having a uniform age and a significant spread in uranium concentrations, the correlation coefficient should be close to 1. However, if the uranium concentration is relatively uniform, a low correlation coefficient may be obtained, even where the apatite grain ages are identical. A more useful parameter is the Chi squared statistic which indicates the probability that all the grains counted belong to a single age population. A probability of less than 5% is taken as evidence that the grains represent a mixed age population with real differences between the apparent ages of individual grains.

A spread in grain ages can result either from inheritance of detrital grains from mixed source areas, or from partial annealing by heating to above about 90°C. It can be seen in Table 2 that none of the samples analysed from Orange-2 pass the Chi squared test at the 95% confidence level and most have relatively low (<0.85) correlation coefficients. The usual measurement of combined fission track age, the maximum probability age, is not strictly valid for grains of mixed age, being biased towards the grains with higher track counts. In such cases the mean grain age is probably the more useful estimate and this parameter has been used as the apparent apatite age where appropriate.

Track length distributions are shown as histograms in Figure 3 for the samples from Orange-2, the dashed line indicating the mean in each case. The results have been normalised to 100 tracks for each sample to facilitate comparison. Variation in the apparent ages of single apatite grains is illustrated by a histogram and a smoothed probability distribution for each sample in Figure 4. Single grain ages are also given with the primary counting results and statistical data in the Appendix.

PRINCIPLES OF INTERPRETATION

Table 3 contains an analysis of the apatite length and age data which is given as an aid to interpretation of the thermal history. Also included in Table 3 are the depth, estimated stratigraphic age and present-day temperature, T, for each sample. Temperatures were crudely estimated from the sample depths using an assumed thermal gradient of 25 °C and a mean surface temperature of 25 °C.

An estimated temperature (T_l) and a 'corrected' fission track age (t_l) can be derived for each sample for comparison with the downhole temperature (T) and measured apatite age (t) respectively. These estimates, shown in Table 3, give an indication of whether the tracks are in equilibrium with their present thermal environment or not, and what the apatite ages might have been prior to annealing in a particular well. The estimates are made on the basis of the observed reduction in apparent fission track age and mean track length with increasing downhole temperature in Otway Basin wells, as described by Gleadow and Duddy (1981) and Gleadow et al. (1983). The wells on which the calibration is based are considered to be in equilibrium with their present thermal environment.

T_l in Table 3 is the temperature which would be calculated to give the observed length reduction. These can be compared with the estimated present-day temperature, T, in the well. The length reduction is determined by comparing the mean length, l, with that of fresh induced fission tracks in apatite ($l_o = 16.3 \pm 0.9$ µm). The estimate T_l assumes that temperatures close to the maximum experienced have been maintained for times of the order of 10^8 years.

The length-corrected age (t_l) is calculated from the measured age using the observed track length reduction l/l_o. This calculation uses the relationship between age reduction and length reduction observed in Otway Basin wells (Gleadow et al. 1983). The corrected age would be the original age expected if the sample had remained at the temperature T_l for times of the order of 10^8 years.

It should be noted that if the assumptions on which the correction is made are violated then the resulting 'age' will have no geological significance. These assumptions are that the apatites all have similar annealing properties to those Otway Basin apatites upon which the calibration is based, that the observed annealing has occurred since burial, and that no tracks have been shortened to the point of complete erasure. Although it not possible to correct for complete loss of some tracks, the apparent age pattern can give evidence that this has occurred.

The degree to which the fission tracks are in equilibrium with their present thermal environment can be judged by comparing the estimated and observed temperatures, T_l and T respectively in Table 3 and from various other fission track parameters. If significant differences are observed then the fission tracks are preserving a record of annealing at temperatures other than those which prevail today. Further information can be obtained by comparing the fission track ages with the stratigraphic age of the sediment. This difference is expressed as Δt (= corrected age - stratigraphic age) in Table 3.

DISCUSSION AND THERMAL HISTORY

It can be seen in Figure 2 and Table 2 that both the apparent apatite age and the mean track length show a decrease from the shallower Pacoota Sandstone to the deeper Arumbera Sandstone. Two samples are insufficient to define the shape of the apatite age profile with depth, from which important thermal history information can be derived, but they do nonetheless give clear evidence of significant downhole fission track annealing. This suggests that the section sampled has been at least hot enough to produce hydrocarbon maturity. Various aspects of the evidence for track annealing and the temperatures at which this may have occurred are given below.

The fission track results for the anomalous apatite grains in the Arumbera Sandstone sample (8422-82A) strongly support their suggested origin as cavings from higher up the well sequence. The apparent ages, mean lengths and standard deviations (Table 1) for these apatites are all essentially identical to those for the Pacoota Sandstone sample 8422-81. This is also true for the shape of the track length distributions (Figure 3) although there is significantly more variation in single grain ages in 8422-82A than 8422-81 (Figure 4). This latter observation is probably indicative of derivation of some of the grains from a greater part of the well section than sampled by 8422-81.

The very low Chi squared probabilities indicated in Table 1 are indicative of real variation in apparent ages between individual apatite grains. This is a characteristic of apatite populations which have experienced temperatures in the hotest region (>90 °C) of the apatite annealing zone due to small differences in the annealing properties of individual grains.

The apatite ages for both samples (8422-81 and 8422-82B) are much younger than the stratigraphic ages of the sediments in which they occur. Originally the apatites must have had ages at least as old, and probably much greater than, the stratigraphic age so that this relationship gives a measure of the amount of post-depositional track annealing. The length- corrected ages for the two samples (t_l in Table 3) are almost coincident at about 290 Myr, and a similar value was also obtained for the anomalous grains in the deeper sample. The large negative values of t for apatites from the two samples (Table 3) show that even the corrected ages are very much younger than the stratigraphic ages. Even allowing for possibly large errors in the corrected ages (possibly 50 Myr) these results show that the apatites have been sufficiently hot since deposition to have lost all pre-existing tracks. This degree of annealing would require temperatures of at least 105 °C maintained for times of the order of hundreds of Myr.

The similarity of the corrected ages to each other suggests that the apatites cooled around this time after an earlier thermal maximum about which no information is preserved in these two samples. Very similar fission track results have been obtained for outcrop samples around the northern part of the Amadeus Basin and from other wells in the area such as Orange-1 (P.R. Tingate, unpublished results). The most likely explanation for this pattern is that the cooling around 250 - 300 Myr represents a period of erosion following the Alice Springs Orogeny when a considerable thickness of covering section was removed.

The differences in apparent apatite age and mean track length between the two samples in Orange-2 are consistent with annealing in the present thermal environment. The deeper Arumbera Sandstone sample shows an age and length reduction (Table 3) consistent with a present temperature of about 96 °C, essentially the same as that estimated for this depth in the well, suggesting a present thermal gradient of about 25 °C/km. The shallower Pacoota Sandstone sample has a temperature value (T_l) estimated from the mean lengths which is significantly greater than its estimated present temperature. This is interpreted as preserving a record of exposure to higher temperatures during the earlier period of cooling.

In summary, all the fission track parameters indicate that the two samples studied have been subjected to temperatures sufficient to erase all tracks formed prior to about 250 -350 Myr. A possible explanation for this would have been cooling due to erosion after a thermal maximum during the Alice Springs Orogeny. The implications of this model are that the section studied is mature to over-mature for hydrocarbon generation.

REFERENCES

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Gleadow A.J.W. and Duddy I.R. 1981, A natural long-term track annealing experiment for apatite. Nuclear Tracks 5, 169- 174.

Gleadow A.J.W., Duddy I.R. and Lovering J.F. 1983, Fission track analysis: a new tool for the evaluation of thermal histories and hydrocarbon potential. APEA J. 23, 93-102.

Green P.F. 1981, A new look at statistics in fission track dating. Nuclear Tracks 5, 77-86.

Hurford A.J. and Green P.F. 1982, A user's guide to fission track dating calibration. Ear. Plan. Sci Lett. 59, 343-354.

Table 2: Fission track analytical results - Orange-2, Amadeus Basin:

Sample number	Depth m	Number of grains	Standard track density x10^{6}cm^{-2}	Fossil track density x10^{6}cm^{-2}	Induced track density x10^{6}cm^{-2}	Correlation coefficient	Chi square prob.	Age Myr	Uranium ppm	Mean track length µm
8422-81 Pacoota Sandstone	1130-1185	20	1.215 (3858)	3.228 (2209)	3.078 (2106)	0.831	4%	225 ± 8 *231 ± 10	33	12.16 ± 1.48 (50)
8422-82A (probable cavings)	(2850-2880)	9	1.215 (3858)	3.260 (873)	3.264 (874)	0.774	<1%	214 ± 11 *217 ± 19	36	12.26 ± 1.18 (100)
8422-82B Arumbera Sandstone	2850-2880	21	1.215 (3858)	0.828 (647)	2.933 (2291)	0.828	<<1%	61 ± 3 *75 ± 11	32	10.25 ± 2.08 (100)

Brackets show number of tracks counted. Standard and induced track densities measured on mica external detector surfaces (g=0.5), and fossil track densities on internal mineral surfaces. Ages calculated using Zeta = 359 for dosimeter glass SRM612 (Hurford and Green, 1983). * Mean age, used where pooled data fail Chi square test at 5%.

Table 3: Analysis of apatite results:

Sample Number	Depth	Statigraphic Age (Myr)	I/I_0	*T_1 (°C)	Temp T (°C)	*t/t_0	FT Age t (Myr)	Corr. age *t_1 (Myr)	Δt (Myr)
8422-81	1130-1185	480 - 520	0.75	79	54	0.80	231 ± 10	289	-210
8422-82A	(2850-2880)	550 - 600	0.75	79	(97)	0.83	217 ± 19	261	-315
8422-82B	2850-2880	550 - 600	0.63	96	97	0.26	75 ± 11	288	-285

* Estimated - see text for explanation.

FIGURE 1(a): Apatites in the Pacoota Sandstone (8422-81). The apatites are the two transparent, colourless, euhedral grains. Etched fission tracks can be seen in these apatites and all the other apatite grains shown in this series of photomicrographs. Mid to dark brown grains are conodont fragments.

Scale bar is 30 μm in all photomicrographs.

FIGURE 1(b): A single euhedral apatite grain from the Pacoota Sandstone (8422-81).

FIGURE 1(c): Apatites from the Arumbera Sandstone showing normal rounded, Fe oxide-stained grains (8422-82B) and one of the 'anomalous' euhedral grains (8422-82A, right).

FIGURE 1(d): Rounded, Fe oxide-stained grain in the Arumbera Sandstone (8422-82B).

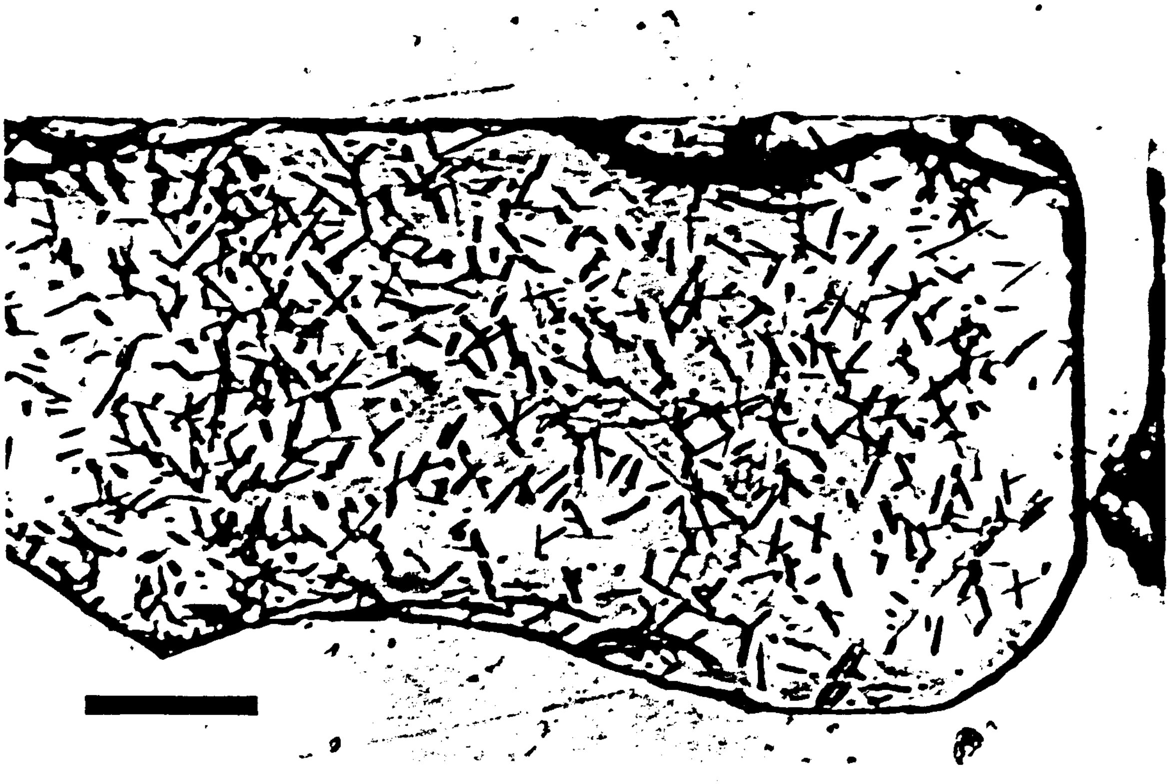

FIGURE 1(e): Anomalous euhedral apatite from the Arumbera Sandstone (8422-82A) showing the similarity to those from the Pacoota Sandstone.

ØRANGE-2

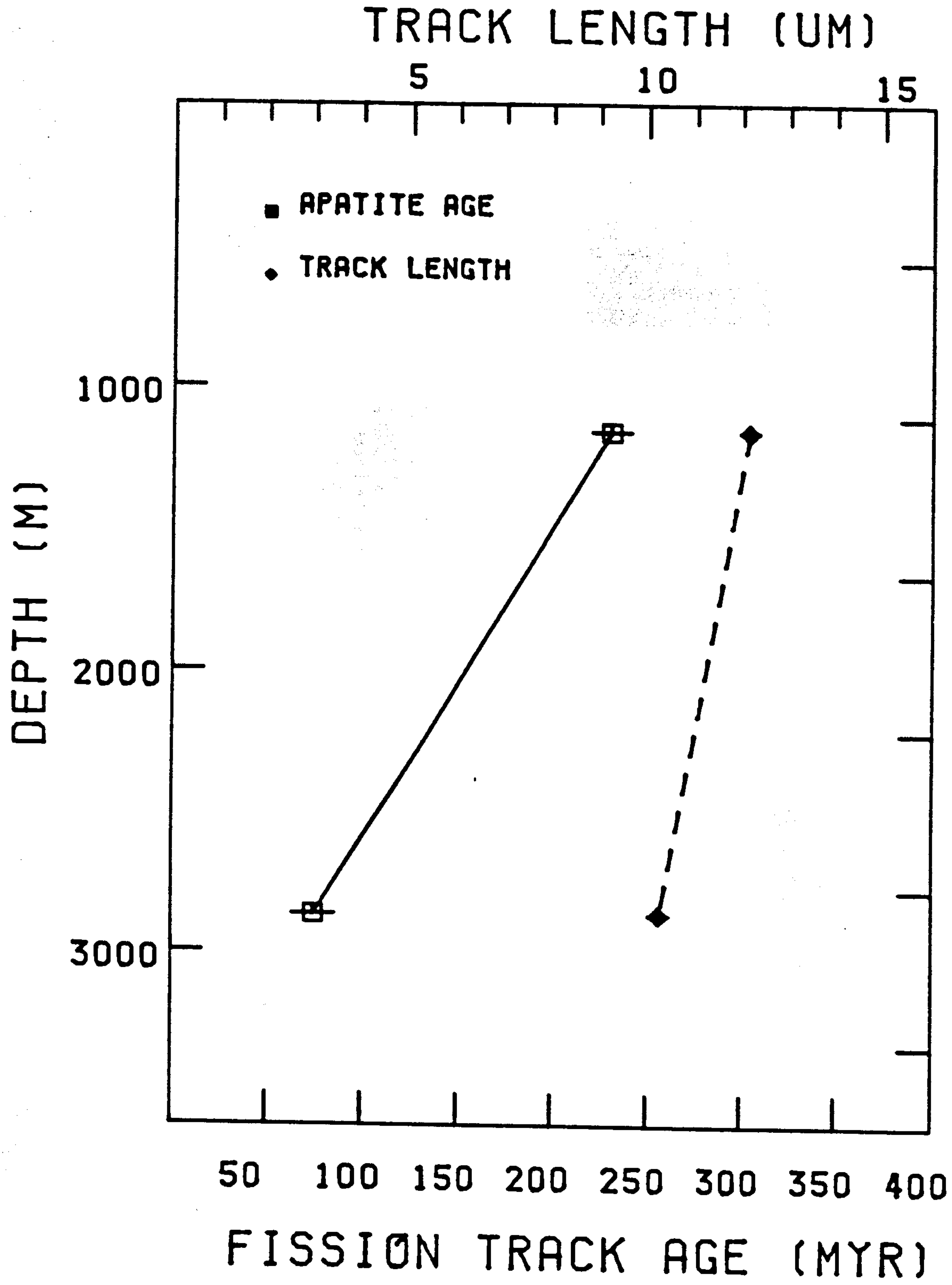

FIGURE 2: Variation of apparent fission track age ad mean track length with depth for apatites from Orange-2:

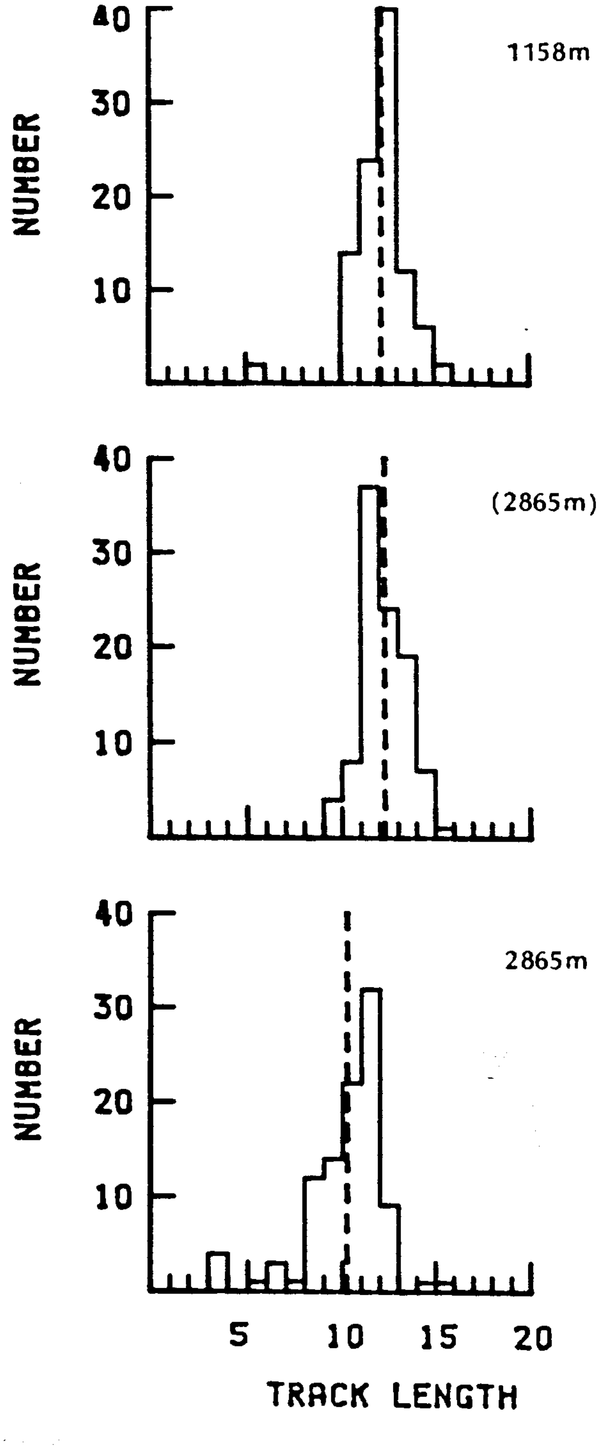

FIGURE 3: Fission track length distributions for Orange-2

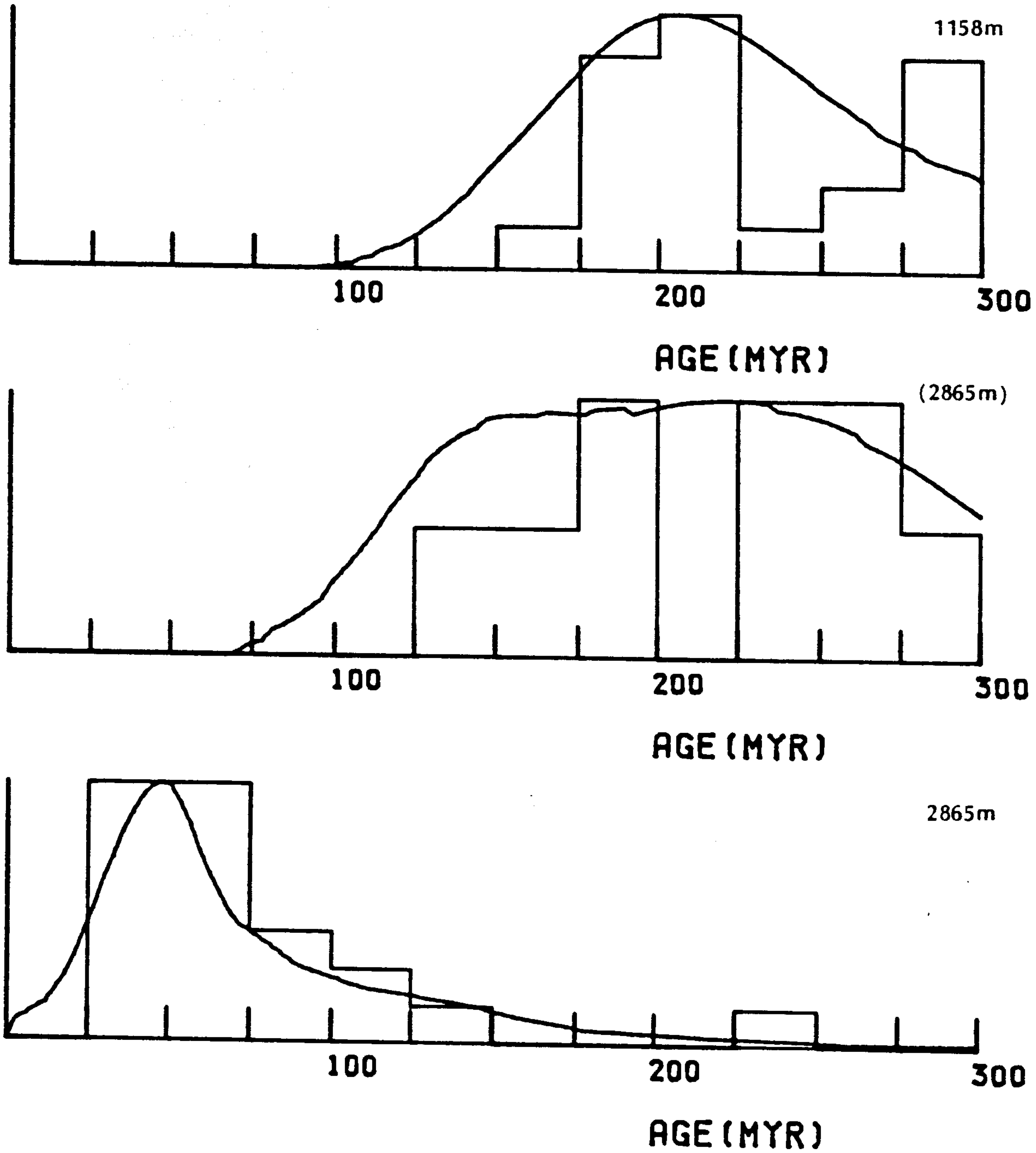

FIGURE 4: Single-grain apatite fission track age distributions for Orange-2.

APATITE 8422-81 ORANGE-2

IRRADIATION: PT676-4
ANALYSIS BY AJWG

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                                   AREA
CRYSTAL     NS          NI         UNITS        RATIO      RHO S        RHO I          AGE(MYR)

 1          126         140         80          0.900      4.24E+06     4.71E+06     193.4 +-  23.7
 2          115         116         100         0.991      3.09E+06     3.12E+06     212.7 +-  28.0
 3          132         95          80          1.389      4.44E+06     3.19E+06     296.1 +-  39.8
 4          92          88          60          1.045      4.12E+06     3.94E+06     224.1 +-  33.4
 5          85          89          100         0.955      2.29E+06     2.39E+06     205.0 +-  31.1
 6          148         143         100         1.035      3.98E+06     3.85E+06     221.9 +-  26.0
 7          109         97          100         1.124      2.93E+06     2.61E+06     240.5 +-  33.6
 8          95          75          100         1.267      2.55E+06     2.02E+06     270.5 +-  41.8
 9          177         179         80          0.989      5.95E+06     6.02E+06     212.1 +-  22.5
 10         163         175         100         0.931      4.38E+06     4.71E+06     200.0 +-  21.8
 11         152         114         100         1.333      4.09E+06     3.07E+06     284.4 +-  35.2
 12         76          59          100         1.288      2.04E+06     1.59E+06     275.0 +-  47.7
 13         88          101         60          0.871      3.94E+06     4.53E+06     187.3 +-  27.3
 14         95          71          100         1.338      2.55E+06     1.91E+06     285.4 +-  44.8
 15         112         80          100         1.400      3.01E+06     2.15E+06     298.3 +-  43.7
 16         89          98          100         0.908      2.39E+06     2.64E+06     195.1 +-  28.6
 17         77          87          100         0.885      2.07E+06     2.34E+06     190.2 +-  29.8
 18         84          106         100         0.792      2.26E+06     2.85E+06     170.6 +-  24.9
 19         86          68          80          1.265      2.89E+06     2.29E+06     270.1 +-  43.8
 20         108         125         100         0.864      2.90E+06     3.36E+06     185.7 +-  24.4

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            2209        2106                                3.228E+06    3.078E+06

AREA OF BASIC UNIT =  3.719E-07  CM²
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VARIANCE OF SQR(NS) = 1.8951
VARIANCE OF SQR(NI) = 2.43273 CORRELATION COEFFICIENT = 0.831

CHI SQUARED = 32.289 WITH 19 DEGREES OF FREEDOM FAIL

NS/NI = 1.049 +- 0.032 MEAN RATIO = 1.079 +- 0.045

AGE CALCULATED USING A ZETA OF 359 FOR SRM612 GLASS
RHO D = 1.215E+06 ND = 3858

POOLED AGE = 224.8 +- 7.7 MYR

MEAN AGE = 231.0 +- 10.4 MYR

ANOMALOUS GRAINS (?CAVINGS)

APATITE 8422-82A ORANGE-2

IRRADIATION: PT676-3
ANALYSIS BY AJWG

CRYSTAL	NS	NI	AREA UNITS	RATIO	RHO S	RHO I	AGE(MYR)
1	92	147	100	0.626	2.47E+06	3.95E+06	135.1 +- 18.0
2	83	99	80	0.838	2.79E+06	3.33E+06	180.3 +- 26.8
3	64	50	60	1.280	2.87E+06	2.24E+06	273.3 +- 51.6
4	88	80	60	1.100	3.94E+06	3.59E+06	235.5 +- 36.4
5	117	87	100	1.345	3.15E+06	2.34E+06	286.8 +- 40.6
6	54	76	80	0.711	1.82E+06	2.55E+06	153.1 +- 27.3
7	46	52	80	0.885	1.55E+06	1.75E+06	190.1 +- 38.5
8	148	140	60	1.057	6.63E+06	6.27E+06	226.5 +- 26.7
9	181	143	100	1.266	4.87E+06	3.85E+06	270.3 +- 30.2
	873	874			3.260E+06	3.264E+06	

AREA OF BASIC UNIT = 3.719E-07 CM^2

VARIANCE OF SQR(NS) = 4.84525
VARIANCE OF SQR(NI) = 3.79541 CORRELATION COEFFICIENT = 0.774

CHI SQUARED = 29.3444 WITH 8 DEGREES OF FREEDOM FAIL

NS/NI = 0.999 +- 0.048 MEAN RATIO = 1.012 +- 0.087

AGE CALCULATED USING A ZETA OF 359 FOR SRM612 GLASS
RHO D = 1.215E+06 ND = 3858

POOLED AGE = 214.2 +- 10.8 MYR

MEAN AGE = 217.0 +- 18.9 MYR

Fe OXIDE COATED GRAINS

APATITE 8422-828 ORANGE-2 2865M

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IRRADIATION: PT676-3
ANALYSIS BY AJWG

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                                   AREA
CRYSTAL     NS          NI         UNITS        RATIO     RHO S        RHO I         AGE(MYR)

  1         82          370         100         0.222    2.20E+06     9.95E+06     48.2 +-   5.9
  2         22          76          100         0.289    5.92E+05     2.04E+06     62.8 +-  15.2
  3         64          156         100         0.410    1.72E+06     4.19E+06     88.9 +-  13.2
  4         2           6           100         0.333    5.38E+04     1.61E+05     72.3 +-  59.0
  5         2           7           100         0.286    5.38E+04     1.88E+05     62.0 +-  49.7
  6         28          115         100         0.243    7.53E+05     3.09E+06     52.9 +-  11.1
  7         22          97          100         0.227    5.92E+05     2.61E+06     49.3 +-  11.6
  8         9           17          100         0.529    2.42E+05     4.57E+05    114.4 +-  47.2
  9         16          14          100         1.143    4.30E+05     3.76E+05    244.6 +-  89.5
 10         33          215         100         0.153    8.87E+05     5.78E+06     33.4 +-   6.2
 11         126         207         100         0.609    3.39E+06     5.57E+06    131.4 +-  14.8
 12         14          40          100         0.350    3.76E+05     1.08E+06     75.9 +-  23.6
 13         9           17          100         0.529    2.42E+05     4.57E+05    114.4 +-  47.2
 14         13          61          100         0.213    3.50E+05     1.64E+06     46.3 +-  14.1
 15         20          131         100         0.153    5.38E+05     3.52E+06     33.2 +-   8.0
 16         37          122         100         0.303    9.95E+05     3.28E+06     65.8 +-  12.4
 17         3           8           100         0.375    8.07E+04     2.15E+05     81.3 +-  55.0
 18         6           35          100         0.171    1.61E+05     9.41E+05     37.3 +-  16.5
 19         88          358         100         0.246    2.37E+06     9.63E+06     53.4 +-   6.4
 20         5           16          100         0.313    1.34E+05     4.30E+05     67.8 +-  34.7
 21         46          223         100         0.206    1.24E+06     6.00E+06     44.8 +-   7.3

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           647         2291                                8.284E+05    2.933E+06

AREA OF BASIC UNIT =  3.719E-07  CM²


VARIANCE OF SQR(NS) =  7.57441
VARIANCE OF SQR(NI) =  28.2593        CORRELATION COEFFICIENT = 0.828

CHI SQUARED =  108.116  WITH  20  DEGREES OF FREEDOM    FAIL

NS/NI = 0.282 +- 0.013       MEAN RATIO = 0.348 +- 0.048


 AGE CALCULATED USING A ZETA OF  359  FOR SRM612 GLASS
            RHO D =  1.215E+06    ND =  3858

            POOLED AGE =  61.3 +-   2.9 MYR

            MEAN AGE =  75.4 +-  10.5 MYR
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