

Supporting Information for

M6, a monazite reference material for fission-track thermochronology

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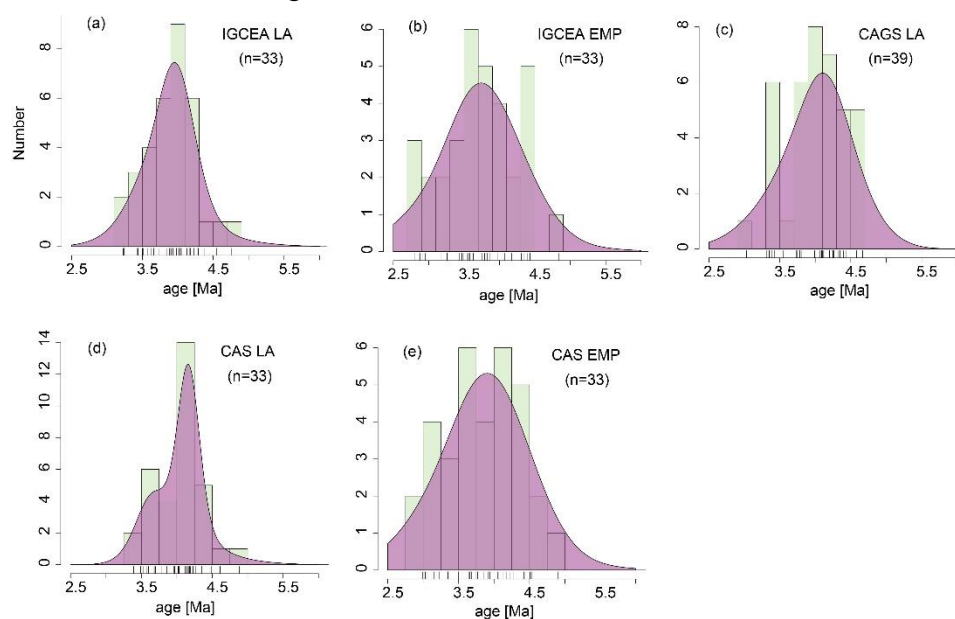


Fig S1. Spot FT ages distribution of monazite M6.

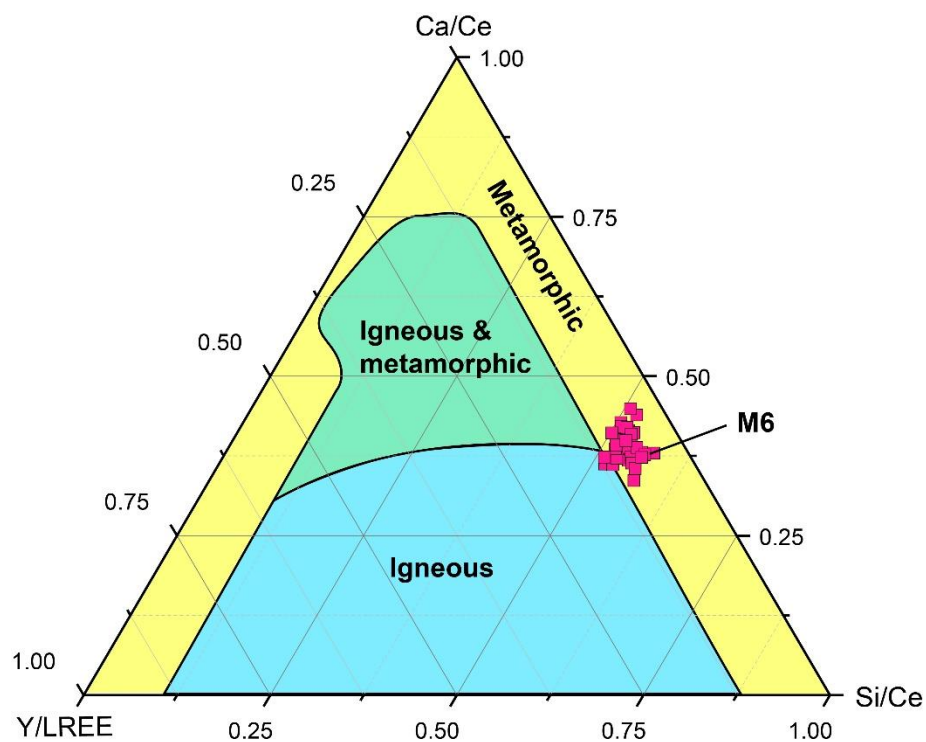


Fig S2. Ternary diagram of monazite end-members: cheralite, huttonite, and monazite (modified after Foster and Harlov., 1999; Wu et al., 2019). The integrated data are from the literature (Supplementary Table S1).

Reference

- Förster, H., and D. E. Harlov (1999), Monazite-(Ce)-huttonite solid solutions in granulite-facies metabasites from the Ivrea-Verbano Zone, Italy, *Mineralogical Magazine*, 63, 587 - 594.
- Wu, L.-G., X.-H. Li, X.-X. Ling, Y.-H. Yang, C.-F. Li, Y.-L. Li, Q. Mao, Q.-L. Li, and B. Putlitz (2019), Further Characterization of the RW-1 Monazite: A New Working Reference Material for Oxygen and Neodymium Isotopic Microanalysis, *Minerals*, 9(10), 583.

Table S2. U and Th concentrations of monazite M6 analyzed by LA-ICP-MS

| IGCEA-FT lab | | | | | CAGS-FT lab | | | | |
|--------------|------------------------------|------------|--|------------|-------------|------------------------------|------------|--|------------|
| Sample No | [²³² Th] wt % | 2 σ | [²³⁸ U] $\mu\text{g/g}$ | 2 σ | Sample No | [²³² Th] wt % | 2 σ | [²³⁸ U] $\mu\text{g/g}$ | 2 σ |
| M6-3-1 | 10.51 | 0.24 | 3709 | 59 | M6-11-1 | 11.51 | 0.22 | 3864 | 61 |
| M6-3-2 | 10.52 | 0.22 | 3709 | 49 | M6-11-2 | 11.39 | 0.17 | 3812 | 59 |
| M6-3-3 | 10.68 | 0.26 | 3781 | 54 | M6-11-3 | 11.34 | 0.21 | 3862 | 64 |
| M6-3-4 | 10.7 | 0.24 | 3751 | 56 | M6-11-4 | 11.46 | 0.17 | 3890 | 68 |
| M6-3-5 | 10.56 | 0.23 | 3715 | 50 | M6-11-5 | 11.34 | 0.22 | 3828 | 57 |
| M6-4-1 | 10.53 | 0.21 | 3406 | 49 | M6-11-6 | 11.38 | 0.17 | 3891 | 64 |
| M6-4-2 | 10.57 | 0.24 | 3440 | 51 | M6-11-7 | 11.54 | 0.22 | 3886 | 63 |
| M6-4-3 | 10.73 | 0.25 | 3410 | 50 | M6-11-8 | 11.49 | 0.17 | 3899 | 58 |
| M6-4-4 | 10.44 | 0.24 | 3398 | 50 | M6-11-9 | 11.58 | 0.22 | 3894 | 73 |
| M6-4-5 | 10.61 | 0.23 | 3394 | 43 | M6-11-10 | 11.39 | 0.18 | 3818 | 59 |
| M6-5-1 | 9.87 | 0.25 | 3549 | 52 | M6-11-11 | 11.46 | 0.2 | 3889 | 61 |
| M6-5-2 | 10.04 | 0.23 | 3590 | 57 | M6-11-12 | 11.66 | 0.19 | 3911 | 55 |
| M6-5-3 | 10.16 | 0.23 | 3568 | 52 | M6-11-13 | 11.48 | 0.2 | 3923 | 57 |
| M6-5-4 | 10.15 | 0.21 | 3495 | 55 | M6-11-14 | 11.75 | 0.2 | 3906 | 69 |
| M6-5-5 | 10.21 | 0.23 | 3520 | 48 | M6-11-15 | 11.63 | 0.21 | 3909 | 67 |
| M6-6-1 | 11.72 | 0.23 | 4340 | 59 | M6-11-16 | 11.47 | 0.27 | 3827 | 70 |
| M6-6-2 | 11.59 | 0.22 | 4278 | 58 | M6-11-17 | 11.39 | 0.28 | 3802 | 72 |
| M6-6-3 | 11.1 | 0.24 | 3939 | 51 | M6-11-18 | 11.33 | 0.19 | 3865 | 71 |
| M6-6-4 | 10.83 | 0.24 | 3859 | 59 | M6-11-19 | 11.72 | 0.22 | 3856 | 69 |
| M6-6-5 | 11.33 | 0.27 | 4111 | 65 | M6-11-20 | 11.33 | 0.24 | 3791 | 65 |
| M6-6-6 | 11.32 | 0.24 | 4050 | 54 | M6-12-1 | 9.49 | 0.31 | 3460 | 110 |
| M6-7-1 | 11.66 | 0.25 | 4312 | 59 | M6-12-2 | 9.85 | 0.15 | 3680 | 69 |
| M6-7-2 | 11.2 | 0.23 | 4266 | 64 | M6-12-3 | 10.05 | 0.21 | 3760 | 74 |
| M6-7-3 | 11.55 | 0.23 | 4357 | 56 | M6-12-4 | 10.27 | 0.24 | 3683 | 87 |
| M6-7-4 | 11.49 | 0.2 | 4332 | 56 | M6-12-5 | 10.23 | 0.18 | 3644 | 62 |
| M6-8-1 | 11.22 | 0.22 | 3697 | 40 | M6-12-6 | 9.96 | 0.17 | 3656 | 58 |
| M6-8-2 | 11.74 | 0.29 | 3805 | 48 | M6-12-7 | 9.92 | 0.26 | 3562 | 86 |
| M6-8-3 | 11.57 | 0.27 | 3732 | 55 | M6-12-8 | 10.26 | 0.22 | 3800 | 100 |
| M6-8-4 | 11.23 | 0.27 | 3663 | 46 | M6-12-9 | 10.71 | 0.52 | 3840 | 120 |
| M6-9-1 | 11.49 | 0.28 | 4183 | 66 | M6-12-10 | 10.42 | 0.65 | 3650 | 170 |
| M6-9-2 | 11.73 | 0.3 | 4244 | 78 | M6-12-11 | 10.22 | 0.18 | 3822 | 66 |
| M6-10-1 | 11.5 | 0.22 | 4154 | 55 | M6-12-12 | 10.13 | 0.2 | 3620 | 91 |
| M6-10-2 | 11.3 | 0.3 | 3976 | 68 | M6-12-13 | 10.42 | 0.3 | 3700 | 110 |
| | | | | | M6-12-14 | 10.57 | 0.23 | 3841 | 75 |
| | | | | | M6-12-15 | 10.64 | 0.29 | 3820 | 100 |
| | | | | | M6-12-16 | 10.64 | 0.17 | 3771 | 55 |
| | | | | | M6-12-17 | 10.41 | 0.29 | 3570 | 110 |
| | | | | | M6-12-18 | 10.46 | 0.2 | 3822 | 85 |
| | | | | | M6-12-19 | 10.57 | 0.19 | 3775 | 78 |
| Average | 10.97 | 0.24 | 3840.39 | 54.91 | | 10.89 | 0.23 | 3789.72 | 76.62 |

Table S3-1. Fission-track ages for monazite M6 from IGCEA-FT lab

| Sample No. | Ns | Area (10 ⁵ cm ²) | ρ_s (10 ⁶ cm ⁻²) | Dpc/Dpb μm | LA ICP MS | | | | EMP | | | |
|------------|-----|--|---|--------------------------|-----------------------|------------|-------------------|------------|-----------------------|------------|------|------------|
| | | | | | C _U (μg/g) | σ_U | Ages [#] | 1 σ | C _U (μg/g) | σ_U | Ages | 1 σ |
| M6-3-1 | 379 | 4.71 | 8.05 | 0.86 | 3709 | 59 | 3.88 | 0.36 | 3737 | 98 | 3.86 | 0.37 |
| M6-3-2 | 635 | 7.81 | 8.13 | 0.87 | 3709 | 49 | 3.93 | 0.34 | 4249 | 98 | 3.43 | 0.31 |
| M6-3-3 | 745 | 8.87 | 8.4 | 0.89 | 3781 | 54 | 3.98 | 0.34 | 3967 | 99 | 3.79 | 0.34 |
| M6-3-4 | 526 | 6.73 | 7.82 | 0.89 | 3751 | 56 | 3.73 | 0.33 | 3473 | 97 | 4.03 | 0.37 |
| M6-3-5 | 828 | 10.18 | 8.13 | 0.91 | 3715 | 50 | 3.91 | 0.33 | 3006 | 96 | 4.84 | 0.44 |
| M6-4-1 | 565 | 8.32 | 6.79 | - | 3406 | 49 | 3.57 | 0.32 | 4125 | 98 | 2.95 | 0.27 |
| M6-4-2 | 375 | 5.67 | 6.61 | - | 3440 | 51 | 3.44 | 0.32 | 3632 | 97 | 3.26 | 0.31 |
| M6-4-3 | 392 | 6.36 | 6.17 | - | 3410 | 50 | 3.24 | 0.3 | 3861 | 97 | 2.86 | 0.27 |
| M6-4-4 | 267 | 4.36 | 6.12 | - | 3398 | 50 | 3.23 | 0.32 | 3914 | 98 | 2.8 | 0.28 |
| M6-4-5 | 406 | 5.85 | 6.93 | - | 3394 | 43 | 3.66 | 0.34 | 3579 | 97 | 3.47 | 0.33 |
| M6-5-1 | 514 | 7.4 | 6.94 | 0.82 | 3549 | 52 | 3.5 | 0.31 | 3314 | 98 | 3.75 | 0.35 |
| M6-5-2 | 489 | 7.11 | 6.87 | 0.86 | 3590 | 57 | 3.43 | 0.31 | 4284 | 99 | 2.88 | 0.26 |
| M6-5-3 | 587 | 7.78 | 7.55 | 0.9 | 3568 | 52 | 3.79 | 0.33 | 3808 | 98 | 3.55 | 0.32 |
| M6-5-4 | 734 | 9.66 | 7.59 | 0.83 | 3495 | 55 | 3.89 | 0.34 | 3834 | 98 | 3.55 | 0.32 |
| M6-5-5 | 490 | 5.98 | 8.19 | 0.86 | 3520 | 48 | 4.17 | 0.38 | 4099 | 99 | 3.58 | 0.33 |
| M6-6-1 | 608 | 6.54 | 9.29 | 0.96 | 4340 | 59 | 3.84 | 0.34 | 3975 | 98 | 4.19 | 0.38 |
| M6-6-2 | 827 | 8.77 | 9.43 | 0.92 | 4278 | 58 | 3.95 | 0.34 | 4407 | 99 | 3.83 | 0.33 |
| M6-6-3 | 562 | 6.36 | 8.83 | 0.94 | 3939 | 51 | 4.02 | 0.36 | 4451 | 99 | 3.56 | 0.32 |
| M6-6-4 | 340 | 4.5 | 7.55 | 0.86 | 3859 | 59 | 3.51 | 0.33 | 4637 | 100 | 2.92 | 0.28 |
| M6-6-5 | 816 | 8.8 | 9.27 | 0.81 | 4111 | 65 | 4.04 | 0.35 | 4178 | 99 | 3.97 | 0.35 |
| M6-6-6 | 885 | 9.38 | 9.43 | 0.81 | 4050 | 54 | 4.17 | 0.35 | 4839 | 101 | 3.49 | 0.3 |
| M6-7-1 | 685 | 7 | 9.78 | 0.81 | 4312 | 59 | 4.06 | 0.35 | 4593 | 96 | 3.82 | 0.34 |
| M6-7-2 | 592 | 6.01 | 9.85 | 0.83 | 4266 | 64 | 4.13 | 0.36 | 4020 | 84 | 4.39 | 0.39 |
| M6-7-3 | 772 | 7.59 | 10.2 | 0.89 | 4357 | 56 | 4.18 | 0.36 | 4196 | 88 | 4.34 | 0.38 |
| M6-7-4 | 960 | 9.26 | 10.4 | 0.82 | 4332 | 56 | 4.29 | 0.36 | 4187 | 88 | 4.43 | 0.38 |
| M6-8-1 | 509 | 5.18 | 9.82 | 0.89 | 3697 | 40 | 4.76 | 0.42 | 4081 | 85 | 4.31 | 0.39 |
| M6-8-2 | 679 | 7.56 | 8.98 | 0.89 | 3805 | 48 | 4.23 | 0.37 | 3658 | 99 | 4.4 | 0.4 |
| M6-8-3 | 571 | 6.26 | 9.13 | 0.91 | 3732 | 55 | 4.38 | 0.39 | 4011 | 99 | 4.07 | 0.37 |
| M6-8-4 | 571 | 6.13 | 9.32 | 0.91 | 3663 | 46 | 4.55 | 0.4 | 4002 | 100 | 4.17 | 0.38 |
| M6-9-1 | 367 | 4.34 | 8.45 | 0.94 | 4183 | 66 | 3.62 | 0.34 | 4760 | 100 | 3.18 | 0.3 |
| M6-9-2 | 503 | 5.31 | 9.47 | 0.92 | 4244 | 78 | 4 | 0.36 | 4786 | 100 | 3.54 | 0.32 |
| M6-10-1 | 429 | 4.6 | 9.32 | 0.9 | 4154 | 55 | 4.02 | 0.37 | 4099 | 99 | 4.07 | 0.38 |
| M6-10-2 | 498 | 5.84 | 8.53 | 0.93 | 3976 | 68 | 3.84 | 0.35 | 4205 | 101 | 3.63 | 0.33 |

Table S3-2. Fission-track ages for monazite M6 from CAGS-FT lab

| Sample No. | Ns | Area (10 ⁵ cm ²) | ρ_s (10 ⁶ cm ⁻²) | LA ICP MS | | | |
|------------|-----|--|---|-----------------------|------------|-------------------|------------|
| | | | | C _U (μg/g) | σ_U | Ages [#] | 1 σ |
| M6-1-1 | 282 | 2.85 | 9.9 | 3864 | 61 | 4.59 | 0.45 |
| M6-1-2 | 324 | 3.32 | 9.76 | 3812 | 59 | 4.59 | 0.44 |
| M6-1-3 | 351 | 3.48 | 10.1 | 3862 | 64 | 4.67 | 0.44 |
| M6-1-4 | 335 | 3.36 | 9.96 | 3890 | 68 | 4.59 | 0.44 |
| M6-1-5 | 412 | 4.21 | 9.79 | 3828 | 57 | 4.58 | 0.42 |
| M6-1-6 | 280 | 3.06 | 9.14 | 3891 | 64 | 4.2 | 0.41 |
| M6-1-7 | 298 | 3.16 | 9.44 | 3886 | 63 | 4.35 | 0.42 |
| M6-1-8 | 332 | 3.7 | 8.98 | 3899 | 58 | 4.12 | 0.39 |
| M6-1-9 | 309 | 3.46 | 8.93 | 3894 | 73 | 4.11 | 0.4 |
| M6-1-10 | 276 | 3.08 | 8.96 | 3818 | 59 | 4.2 | 0.41 |
| M6-1-11 | 339 | 3.52 | 9.63 | 3889 | 61 | 4.43 | 0.42 |
| M6-1-12 | 288 | 3.03 | 9.51 | 3911 | 55 | 4.35 | 0.43 |
| M6-1-13 | 290 | 3.01 | 9.64 | 3923 | 57 | 4.4 | 0.43 |
| M6-1-14 | 290 | 3.13 | 9.27 | 3906 | 69 | 4.25 | 0.42 |
| M6-1-15 | 300 | 3.38 | 8.88 | 3909 | 67 | 4.07 | 0.4 |
| M6-1-16 | 270 | 2.92 | 9.23 | 3827 | 70 | 4.32 | 0.43 |
| M6-1-17 | 260 | 3.01 | 8.64 | 3802 | 72 | 4.07 | 0.41 |
| M6-1-18 | 244 | 2.99 | 8.15 | 3865 | 71 | 3.78 | 0.38 |
| M6-1-19 | 270 | 2.94 | 9.17 | 3856 | 69 | 4.26 | 0.42 |
| M6-1-20 | 261 | 3.09 | 8.44 | 3791 | 65 | 3.99 | 0.4 |
| M6-2-1 | 256 | 3.73 | 6.86 | 3460 | 110 | 3.55 | 0.37 |
| M6-2-2 | 227 | 2.95 | 7.69 | 3680 | 69 | 3.74 | 0.39 |
| M6-2-3 | 238 | 2.97 | 8.01 | 3760 | 74 | 3.81 | 0.39 |
| M6-2-4 | 233 | 2.99 | 7.78 | 3683 | 87 | 3.78 | 0.39 |
| M6-2-5 | 205 | 2.97 | 6.9 | 3644 | 62 | 3.39 | 0.36 |
| M6-2-6 | 209 | 2.99 | 6.98 | 3656 | 58 | 3.42 | 0.36 |
| M6-2-7 | 231 | 2.83 | 8.17 | 3562 | 86 | 4.11 | 0.43 |
| M6-2-8 | 214 | 2.48 | 8.62 | 3800 | 100 | 4.06 | 0.43 |
| M6-2-9 | 251 | 2.86 | 8.77 | 3840 | 120 | 4.09 | 0.43 |
| M6-2-10 | 164 | 2.35 | 6.98 | 3650 | 170 | 3.42 | 0.41 |
| M6-2-11 | 191 | 2.95 | 6.47 | 3822 | 66 | 3.03 | 0.32 |
| M6-2-12 | 227 | 3.35 | 6.78 | 3620 | 91 | 3.35 | 0.35 |
| M6-2-13 | 207 | 3.03 | 6.83 | 3700 | 110 | 3.31 | 0.36 |
| M6-2-14 | 240 | 2.73 | 8.8 | 3841 | 75 | 4.1 | 0.42 |
| M6-2-15 | 239 | 3 | 7.96 | 3820 | 100 | 3.73 | 0.39 |
| M6-2-16 | 243 | 2.84 | 8.55 | 3771 | 55 | 4.06 | 0.41 |
| M6-2-17 | 215 | 2.88 | 7.46 | 3570 | 110 | 3.74 | 0.4 |
| M6-2-18 | 218 | 2.99 | 7.3 | 3822 | 85 | 3.42 | 0.36 |
| M6-2-19 | 248 | 2.88 | 8.62 | 3775 | 78 | 4.09 | 0.42 |

Table S3-3. Fission-track dating results for monazite M6 from CAS-FT lab

| No. | Ns | Area (10 ⁻⁸ cm ²) | ρ_s (10 ⁶ cm ⁻²) | LA ICP MS | | EPM | | | | | |
|---------|-----|---|---|--------------|------------|-------------------|------------|--------------|------------|------|------------|
| | | | | C_U (µg/g) | σ_U | Ages [#] | 1 σ | C_U (µg/g) | σ_U | Ages | 1 σ |
| M6-3-1 | 405 | 4.71 | 8.6 | 3709 | 59 | 4.15 | 0.38 | 3737 | 98 | 4.12 | 0.39 |
| M6-3-2 | 681 | 7.81 | 8.72 | 3709 | 49 | 4.21 | 0.37 | 4249 | 98 | 3.68 | 0.33 |
| M6-3-3 | 770 | 8.87 | 8.68 | 3781 | 54 | 4.11 | 0.35 | 3967 | 99 | 3.92 | 0.35 |
| M6-3-4 | 544 | 6.73 | 8.09 | 3751 | 56 | 3.86 | 0.34 | 3473 | 97 | 4.17 | 0.38 |
| M6-3-5 | 838 | 10.2 | 8.23 | 3715 | 50 | 3.97 | 0.34 | 3006 | 96 | 4.9 | 0.44 |
| M6-4-1 | 586 | 8.32 | 7.04 | 3406 | 49 | 3.7 | 0.33 | 4125 | 98 | 3.06 | 0.28 |
| M6-4-2 | 385 | 5.67 | 6.79 | 3440 | 51 | 3.53 | 0.33 | 3632 | 97 | 3.35 | 0.32 |
| M6-4-3 | 410 | 6.36 | 6.45 | 3410 | 50 | 3.39 | 0.31 | 3861 | 97 | 2.99 | 0.28 |
| M6-4-4 | 289 | 4.36 | 6.62 | 3398 | 50 | 3.49 | 0.34 | 3914 | 98 | 3.03 | 0.3 |
| M6-4-5 | 410 | 5.85 | 7 | 3394 | 43 | 3.69 | 0.34 | 3579 | 97 | 3.5 | 0.33 |
| M6-5-1 | 540 | 7.57 | 7.14 | 3549 | 52 | 3.6 | 0.32 | 3314 | 98 | 3.86 | 0.36 |
| M6-5-2 | 510 | 7.11 | 7.17 | 3590 | 57 | 3.58 | 0.32 | 4284 | 99 | 3 | 0.27 |
| M6-5-3 | 624 | 7.78 | 8.02 | 3568 | 52 | 4.03 | 0.35 | 3808 | 98 | 3.77 | 0.34 |
| M6-5-4 | 775 | 9.66 | 8.02 | 3495 | 55 | 4.11 | 0.35 | 3834 | 98 | 3.75 | 0.33 |
| M6-5-5 | 502 | 5.98 | 8.39 | 3520 | 48 | 4.27 | 0.38 | 4099 | 99 | 3.66 | 0.34 |
| M6-6-1 | 637 | 6.54 | 9.74 | 4340 | 59 | 4.02 | 0.35 | 3975 | 98 | 4.39 | 0.39 |
| M6-6-2 | 875 | 8.77 | 9.97 | 4278 | 58 | 4.17 | 0.35 | 4407 | 99 | 4.05 | 0.35 |
| M6-6-3 | 581 | 6.42 | 9.05 | 3939 | 51 | 4.11 | 0.36 | 4451 | 99 | 3.64 | 0.33 |
| M6-6-4 | 450 | 5.52 | 8.16 | 3859 | 59 | 3.78 | 0.35 | 4637 | 100 | 3.15 | 0.29 |
| M6-6-5 | 836 | 8.8 | 9.5 | 4111 | 65 | 4.14 | 0.35 | 4178 | 99 | 4.07 | 0.36 |
| M6-6-6 | 888 | 9.38 | 9.46 | 4050 | 54 | 4.18 | 0.35 | 4839 | 101 | 3.5 | 0.3 |
| MZ6-7-1 | 707 | 7 | 10.1 | 4312 | 59 | 4.19 | 0.36 | 4593 | 96 | 3.94 | 0.35 |
| MZ6-7-2 | 606 | 6.01 | 10.1 | 4266 | 64 | 4.23 | 0.37 | 4020 | 84 | 4.49 | 0.4 |
| MZ6-7-3 | 789 | 7.59 | 10.4 | 4357 | 56 | 4.27 | 0.37 | 4196 | 88 | 4.44 | 0.39 |
| MZ6-7-4 | 975 | 9.26 | 10.5 | 4332 | 56 | 4.35 | 0.37 | 4187 | 88 | 4.51 | 0.39 |
| M6-8-1 | 522 | 5.18 | 10.1 | 3697 | 40 | 4.88 | 0.43 | 4081 | 85 | 4.42 | 0.4 |
| M6-8-2 | 699 | 7.56 | 9.25 | 3805 | 48 | 4.35 | 0.38 | 3658 | 99 | 4.53 | 0.41 |
| M6-8-3 | 586 | 6.26 | 9.37 | 3732 | 55 | 4.49 | 0.4 | 4011 | 99 | 4.18 | 0.38 |
| M6-8-4 | 578 | 6.13 | 9.43 | 3663 | 46 | 4.61 | 0.41 | 4002 | 100 | 4.22 | 0.38 |
| M6-9-1 | 373 | 4.34 | 8.59 | 4183 | 66 | 3.68 | 0.35 | 4760 | 100 | 3.23 | 0.31 |
| M6-9-2 | 518 | 5.31 | 9.75 | 4244 | 78 | 4.12 | 0.37 | 4786 | 100 | 3.65 | 0.33 |
| M6-10-1 | 461 | 4.7 | 9.8 | 4154 | 55 | 4.23 | 0.38 | 4099 | 99 | 4.28 | 0.4 |
| M6-10-2 | 514 | 5.84 | 8.8 | 3976 | 68 | 3.96 | 0.36 | 4205 | 101 | 3.75 | 0.34 |

[#]Ages were calculated by using the absolute dating approach of HeFTy 2.1.7 (contact Richard A. Ketcham).