**表1小东山火山岩不同岩性锆石的U-Th-Pb同位素分析结果**

**Table 1 U-Th-Pb isotopic analyses for zircon from the Xiaodongshan volcanic rocks**

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 点号 | ωB/10-6 | | Th/U | 同位素比值 | | | | | | 年龄/Ma | | | | | |
| Th232 | U238 | 207Pb/206Pb | 1σ | 207Pb/235U | 1σ | 206Pb/238U | 1σ | 207Pb/206Pb | 1σ | 207Pb/235U | 1σ | 206Pb/238U | 1σ |
| 英安斑岩（AQS02） | | | | | | | | | | | | | | | |
| 1 | 47 | 83 | 0.56 | 0.0485 | 0.0023 | 0.3300 | 0.0142 | 0.0494 | 0.0007 | 124.2 | 109.2 | 289.5 | 10.9 | 310.6 | 4.3 |
| 2 | 99 | 162 | 0.61 | 0.0489 | 0.0018 | 0.3257 | 0.0111 | 0.0483 | 0.0006 | 146.4 | 85.2 | 286.3 | 8.5 | 303.8 | 3.4 |
| 3 | 102 | 166 | 0.62 | 0.0550 | 0.0019 | 0.3652 | 0.0121 | 0.0481 | 0.0006 | 413.0 | 84.3 | 316.1 | 9.0 | 303.0 | 3.8 |
| 4 | 92 | 156 | 0.59 | 0.0555 | 0.0019 | 0.3752 | 0.0133 | 0.0490 | 0.0006 | 431.5 | 75.9 | 323.5 | 9.8 | 308.6 | 3.9 |
| 5 | 50 | 95 | 0.52 | 0.0554 | 0.0021 | 0.3796 | 0.0132 | 0.0497 | 0.0007 | 427.8 | 89.8 | 326.7 | 9.8 | 312.5 | 4.1 |
| 6 | 96 | 138 | 0.70 | 0.0552 | 0.0018 | 0.3812 | 0.0123 | 0.0501 | 0.0006 | 420.4 | 70.4 | 327.9 | 9.1 | 315.2 | 3.6 |
| 7 | 110 | 141 | 0.78 | 0.0511 | 0.0018 | 0.3394 | 0.0112 | 0.0481 | 0.0006 | 255.6 | 81.5 | 296.7 | 8.5 | 303.1 | 3.8 |
| 8 | 112 | 136 | 0.83 | 0.0510 | 0.0019 | 0.3407 | 0.0126 | 0.0484 | 0.0006 | 242.7 | 85.2 | 297.7 | 9.5 | 304.7 | 3.7 |
| 9 | 54 | 112 | 0.48 | 0.0537 | 0.0022 | 0.3552 | 0.0126 | 0.0480 | 0.0006 | 366.7 | 97.2 | 308.6 | 9.5 | 302.1 | 3.9 |
| 10 | 93 | 141 | 0.66 | 0.0533 | 0.0018 | 0.3702 | 0.0119 | 0.0503 | 0.0006 | 342.7 | 75.9 | 319.8 | 8.8 | 316.4 | 3.6 |
| 11 | 67 | 125 | 0.54 | 0.0519 | 0.0020 | 0.3553 | 0.0125 | 0.0497 | 0.0007 | 279.7 | 88.9 | 308.7 | 9.4 | 312.6 | 4.0 |
| 12 | 82 | 154 | 0.53 | 0.0522 | 0.0021 | 0.3527 | 0.0125 | 0.0490 | 0.0006 | 294.5 | 92.6 | 306.7 | 9.4 | 308.4 | 3.9 |
| 13 | 97 | 141 | 0.69 | 0.0519 | 0.0019 | 0.3463 | 0.0129 | 0.0484 | 0.0006 | 283.4 | 85.2 | 301.9 | 9.8 | 304.5 | 3.9 |
| 14 | 51 | 98 | 0.52 | 0.0531 | 0.0023 | 0.3651 | 0.0153 | 0.0498 | 0.0007 | 344.5 | 100.0 | 316.0 | 11.4 | 313.6 | 4.3 |
| 15 | 107 | 158 | 0.68 | 0.0524 | 0.0021 | 0.3591 | 0.0145 | 0.0497 | 0.0007 | 301.9 | 90.7 | 311.5 | 10.8 | 312.6 | 4.4 |
| 花岗斑岩（AQS07） | | | | | | | | | | | | | | | |
| 1 | 207 | 245 | 0.85 | 0.0531 | 0.0008 | 0.3701 | 0.0057 | 0.0505 | 0.0004 | 331.5 | 33.3 | 319.8 | 4.2 | 317.8 | 2.2 |
| 2 | 148 | 267 | 0.56 | 0.0522 | 0.0007 | 0.3697 | 0.0055 | 0.0512 | 0.0004 | 300.1 | 31.5 | 319.4 | 4.1 | 322.0 | 2.3 |
| 3 | 116 | 195 | 0.60 | 0.0539 | 0.0009 | 0.3760 | 0.0061 | 0.0506 | 0.0004 | 368.6 | 37.0 | 324.1 | 4.5 | 318.2 | 2.3 |
| 4 | 153 | 245 | 0.62 | 0.0529 | 0.0009 | 0.3648 | 0.0059 | 0.0500 | 0.0004 | 324.1 | 37.0 | 315.8 | 4.4 | 314.3 | 2.2 |
| 5 | 131 | 245 | 0.54 | 0.0549 | 0.0009 | 0.3762 | 0.0058 | 0.0495 | 0.0004 | 409.3 | 39.8 | 324.2 | 4.3 | 311.7 | 2.2 |
| 6 | 248 | 340 | 0.73 | 0.0524 | 0.0007 | 0.3686 | 0.0048 | 0.0510 | 0.0003 | 301.9 | 29.6 | 318.6 | 3.6 | 320.7 | 2.1 |
| 7 | 182 | 227 | 0.80 | 0.0532 | 0.0007 | 0.3735 | 0.0053 | 0.0510 | 0.0004 | 344.5 | 31.5 | 322.2 | 3.9 | 320.8 | 2.6 |
| 8 | 304 | 329 | 0.92 | 0.0529 | 0.0007 | 0.3625 | 0.0048 | 0.0496 | 0.0003 | 324.1 | 29.6 | 314.1 | 3.6 | 311.9 | 2.0 |
| 9 | 140 | 189 | 0.74 | 0.0550 | 0.0009 | 0.3801 | 0.0067 | 0.0500 | 0.0004 | 413.0 | 37.0 | 327.1 | 4.9 | 314.6 | 2.4 |
| 10 | 144 | 158 | 0.91 | 0.0538 | 0.0010 | 0.3807 | 0.0073 | 0.0512 | 0.0004 | 364.9 | 42.6 | 327.5 | 5.3 | 322.0 | 2.5 |
| 11 | 150 | 199 | 0.76 | 0.0553 | 0.0009 | 0.3858 | 0.0063 | 0.0505 | 0.0003 | 433.4 | 35.2 | 331.3 | 4.6 | 317.4 | 2.1 |
| 12 | 258 | 409 | 0.63 | 0.0526 | 0.0006 | 0.3729 | 0.0049 | 0.0512 | 0.0004 | 322.3 | 27.8 | 321.8 | 3.6 | 322.2 | 2.3 |
| 13 | 142 | 272 | 0.52 | 0.0524 | 0.0007 | 0.3640 | 0.0053 | 0.0503 | 0.0004 | 301.9 | 5.6 | 315.2 | 4.0 | 316.7 | 2.3 |
| 14 | 245 | 330 | 0.74 | 0.0526 | 0.0006 | 0.3704 | 0.0046 | 0.0511 | 0.0004 | 322.3 | 27.8 | 320.0 | 3.4 | 321.2 | 2.3 |
| 15 | 257 | 285 | 0.90 | 0.0529 | 0.0007 | 0.3743 | 0.0052 | 0.0514 | 0.0004 | 324.1 | 26.9 | 322.8 | 3.8 | 323.2 | 2.3 |
| 16 | 70 | 173 | 0.41 | 0.0540 | 0.0009 | 0.3816 | 0.0065 | 0.0514 | 0.0004 | 368.6 | 37.0 | 328.2 | 4.8 | 323.3 | 2.4 |
| 花岗斑岩（AQS08） | | | | | | | | | | | | | | | |
| 1 | 102 | 159 | 0.64 | 0.0534 | 0.0011 | 0.3686 | 0.0078 | 0.0504 | 0.0004 | 346.4 | 46.3 | 318.6 | 5.8 | 316.8 | 2.7 |
| 2 | 74 | 117 | 0.63 | 0.0525 | 0.0010 | 0.3681 | 0.0075 | 0.0511 | 0.0005 | 309.3 | 46.3 | 318.2 | 5.5 | 321.0 | 2.8 |
| 3 | 105 | 190 | 0.56 | 0.0521 | 0.0009 | 0.3630 | 0.0063 | 0.0506 | 0.0004 | 300.1 | 38.9 | 314.4 | 4.7 | 318.0 | 2.3 |
| 4 | 323 | 432 | 0.75 | 0.0527 | 0.0006 | 0.3639 | 0.0045 | 0.0503 | 0.0004 | 322.3 | 27.8 | 315.2 | 3.3 | 316.2 | 2.6 |
| 5 | 201 | 320 | 0.63 | 0.0535 | 0.0007 | 0.3701 | 0.0051 | 0.0501 | 0.0003 | 350.1 | 34.3 | 319.7 | 3.8 | 315.3 | 2.1 |
| 6 | 188 | 201 | 0.93 | 0.0533 | 0.0009 | 0.3669 | 0.0061 | 0.0499 | 0.0004 | 338.9 | 37.0 | 317.4 | 4.6 | 314.0 | 2.2 |
| 7 | 309 | 352 | 0.88 | 0.0554 | 0.0007 | 0.3821 | 0.0051 | 0.0501 | 0.0004 | 431.5 | 31.5 | 328.6 | 3.8 | 315.3 | 2.3 |
| 8 | 185 | 221 | 0.84 | 0.0518 | 0.0008 | 0.3568 | 0.0057 | 0.0499 | 0.0004 | 276.0 | 33.3 | 309.8 | 4.3 | 313.7 | 2.3 |
| 9 | 115 | 218 | 0.53 | 0.0540 | 0.0009 | 0.3757 | 0.0064 | 0.0506 | 0.0004 | 368.6 | 38.9 | 323.9 | 4.8 | 318.1 | 2.3 |
| 10 | 98 | 176 | 0.56 | 0.0554 | 0.0009 | 0.3851 | 0.0063 | 0.0503 | 0.0004 | 431.5 | 35.2 | 330.8 | 4.6 | 316.5 | 2.2 |
| 11 | 159 | 222 | 0.72 | 0.0525 | 0.0008 | 0.3676 | 0.0056 | 0.0508 | 0.0004 | 305.6 | 33.3 | 317.9 | 4.1 | 319.5 | 2.3 |
| 12 | 91 | 143 | 0.64 | 0.0541 | 0.0012 | 0.3756 | 0.0074 | 0.0507 | 0.0004 | 376.0 | 52.8 | 323.8 | 5.5 | 318.7 | 2.5 |
| 橄榄玄武岩（AQS21） | | | | | | | | | | | | | | | |
| 1 | 204 | 272 | 0.75 | 0.0525 | 0.0007 | 0.3667 | 0.0053 | 0.0508 | 0.0004 | 305.6 | 36.1 | 317.2 | 3.9 | 319.2 | 2.5 |
| 2 | 233 | 270 | 0.86 | 0.0525 | 0.0008 | 0.3717 | 0.0060 | 0.0512 | 0.0004 | 309.3 | 35.2 | 320.9 | 4.5 | 322.1 | 2.3 |
| 3 | 131 | 321 | 0.41 | 0.0533 | 0.0008 | 0.3741 | 0.0056 | 0.0508 | 0.0004 | 338.9 | 31.5 | 322.7 | 4.1 | 319.7 | 2.2 |
| 4 | 156 | 237 | 0.66 | 0.0537 | 0.0008 | 0.3721 | 0.0059 | 0.0500 | 0.0004 | 366.7 | 31.5 | 321.2 | 4.4 | 314.7 | 2.2 |
| 5 | 148 | 324 | 0.46 | 0.0519 | 0.0007 | 0.3586 | 0.0052 | 0.0499 | 0.0003 | 283.4 | 36.1 | 311.2 | 3.9 | 314.0 | 2.1 |
| 6 | 328 | 607 | 0.54 | 0.0525 | 0.0006 | 0.3666 | 0.0042 | 0.0505 | 0.0003 | 309.3 | 24.1 | 317.2 | 3.2 | 317.7 | 2.1 |
| 7 | 150 | 289 | 0.52 | 0.0551 | 0.0008 | 0.3815 | 0.0055 | 0.0502 | 0.0003 | 416.7 | 36.1 | 328.2 | 4.0 | 315.8 | 2.0 |
| 8 | 341 | 389 | 0.88 | 0.0537 | 0.0007 | 0.3775 | 0.0051 | 0.0510 | 0.0004 | 366.7 | 29.6 | 325.2 | 3.7 | 320.8 | 2.3 |

**表2小东山火山岩锆石的Lu-Hf同位素分析结果**

**Table 2 Lu-Hf isotopic analyses for zircon from the Xiaodongshan volcanic rocks**

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 样号 | 176Yb/177Hf | 1σ | 176Lu/177Hf | 1σ | 176Hf/177Hf | 1σ | 176Hf/177Hfi | εHf(T) | εHf(present) | tDM 1(Ma) | tDMC (Ma) | fLu/Hf |
| 花岗斑岩（AQS07） | | | | | | | | | | | | |
| 1 | 0.055671 | 0.000628 | 0.002016 | 0.000019 | 0.282895 | 0.000016 | 0.282883 | 10.54 | 3.89 | 520 | 632 | -0.94 |
| 2 | 0.058272 | 0.000397 | 0.002227 | 0.000018 | 0.282884 | 0.000015 | 0.282871 | 10.11 | 3.50 | 539 | 660 | -0.93 |
| 3 | 0.054030 | 0.000699 | 0.001931 | 0.000020 | 0.282882 | 0.000010 | 0.282870 | 10.10 | 3.42 | 538 | 661 | -0.94 |
| 4 | 0.039379 | 0.000622 | 0.001391 | 0.000015 | 0.282907 | 0.000008 | 0.282898 | 11.09 | 4.30 | 495 | 597 | -0.96 |
| 5 | 0.064955 | 0.000692 | 0.002365 | 0.000028 | 0.282878 | 0.000011 | 0.282864 | 9.86 | 3.27 | 551 | 676 | -0.93 |
| 6 | 0.073132 | 0.000668 | 0.002622 | 0.000016 | 0.282880 | 0.000013 | 0.282864 | 9.88 | 3.35 | 552 | 675 | -0.92 |
| 7 | 0.064496 | 0.001280 | 0.002262 | 0.000047 | 0.282872 | 0.000011 | 0.282858 | 9.66 | 3.06 | 558 | 689 | -0.93 |
| 8 | 0.079974 | 0.000830 | 0.002813 | 0.000034 | 0.282852 | 0.000011 | 0.282835 | 8.86 | 2.37 | 596 | 740 | -0.92 |
| 9 | 0.074037 | 0.000613 | 0.002801 | 0.000015 | 0.282870 | 0.000019 | 0.282853 | 9.50 | 3.01 | 569 | 699 | -0.92 |
| 10 | 0.067660 | 0.001260 | 0.002388 | 0.000039 | 0.282854 | 0.000013 | 0.282839 | 9.00 | 2.43 | 586 | 731 | -0.93 |
| 11 | 0.059167 | 0.000275 | 0.002278 | 0.000018 | 0.282878 | 0.000013 | 0.282864 | 9.88 | 3.27 | 549 | 675 | -0.93 |
| 12 | 0.086608 | 0.000964 | 0.003044 | 0.000021 | 0.282861 | 0.000013 | 0.282842 | 9.11 | 2.67 | 587 | 724 | -0.91 |
| 13 | 0.064694 | 0.000584 | 0.002242 | 0.000013 | 0.282860 | 0.000009 | 0.282847 | 9.28 | 2.67 | 574 | 714 | -0.93 |
| 14 | 0.085041 | 0.001980 | 0.003007 | 0.000059 | 0.282875 | 0.000012 | 0.282857 | 9.62 | 3.17 | 565 | 692 | -0.91 |
| 15 | 0.052609 | 0.000354 | 0.001877 | 0.000012 | 0.282888 | 0.000010 | 0.282877 | 10.33 | 3.64 | 528 | 646 | -0.94 |
| 16 | 0.051096 | 0.000385 | 0.001936 | 0.000013 | 0.282889 | 0.000016 | 0.282877 | 10.35 | 3.67 | 528 | 645 | -0.94 |
| 花岗斑岩(AQS08) | | | | | | | | | | | | |
| 1 | 0.050282 | 0.000721 | 0.001907 | 0.000028 | 0.282888 | 0.000017 | 0.282876 | 10.31 | 3.62 | 529 | 648 | -0.94 |
| 2 | 0.033363 | 0.000390 | 0.001185 | 0.000013 | 0.282927 | 0.000013 | 0.282920 | 11.86 | 5.02 | 463 | 548 | -0.96 |
| 3 | 0.064076 | 0.000547 | 0.002156 | 0.000016 | 0.282904 | 0.000015 | 0.282891 | 10.83 | 4.20 | 509 | 614 | -0.94 |
| 4 | 0.091591 | 0.000398 | 0.002908 | 0.000013 | 0.282906 | 0.000010 | 0.282889 | 10.75 | 4.28 | 517 | 620 | -0.91 |
| 5 | 0.081377 | 0.000989 | 0.002540 | 0.000033 | 0.282888 | 0.000008 | 0.282873 | 10.19 | 3.64 | 538 | 655 | -0.92 |
| 6 | 0.090139 | 0.001620 | 0.002858 | 0.000037 | 0.282905 | 0.000011 | 0.282888 | 10.71 | 4.23 | 518 | 622 | -0.91 |
| 7 | 0.081273 | 0.002130 | 0.002515 | 0.000059 | 0.282896 | 0.000011 | 0.282881 | 10.49 | 3.94 | 525 | 636 | -0.93 |
| 8 | 0.070634 | 0.000310 | 0.002395 | 0.000025 | 0.282943 | 0.000014 | 0.282929 | 12.18 | 5.60 | 454 | 528 | -0.93 |
| 9 | 0.058434 | 0.000673 | 0.001999 | 0.000025 | 0.282908 | 0.000015 | 0.282896 | 11.02 | 4.35 | 501 | 602 | -0.94 |
| 10 | 0.088150 | 0.000422 | 0.002781 | 0.000013 | 0.282891 | 0.000009 | 0.282875 | 10.26 | 3.76 | 537 | 651 | -0.92 |
| 11 | 0.067503 | 0.000266 | 0.002150 | 0.000006 | 0.282912 | 0.000009 | 0.282900 | 11.14 | 4.51 | 497 | 595 | -0.94 |
| 12 | 0.070490 | 0.001210 | 0.002342 | 0.000049 | 0.282914 | 0.000011 | 0.282900 | 11.15 | 4.56 | 497 | 594 | -0.93 |
| 橄榄玄武岩(AQS21) | | | | | | | | | | | | |
| 1 | 0.090575 | 0.000541 | 0.002987 | 0.000020 | 0.282906 | 0.000010 | 0.282888 | 10.72 | 4.26 | 518 | 621 | -0.91 |
| 2 | 0.069729 | 0.001070 | 0.002425 | 0.000021 | 0.282916 | 0.000013 | 0.282902 | 11.22 | 4.65 | 494 | 589 | -0.93 |
| 3 | 0.081259 | 0.000740 | 0.002541 | 0.000018 | 0.282886 | 0.000009 | 0.282870 | 10.10 | 3.56 | 542 | 661 | -0.92 |
| 4 | 0.116341 | 0.001720 | 0.003489 | 0.000054 | 0.282905 | 0.000011 | 0.282884 | 10.57 | 4.23 | 527 | 631 | -0.90 |
| 5 | 0.058187 | 0.000599 | 0.001909 | 0.000031 | 0.282908 | 0.000008 | 0.282896 | 11.01 | 4.33 | 500 | 602 | -0.94 |
| 6 | 0.072253 | 0.000223 | 0.002410 | 0.000008 | 0.282753 | 0.000011 | 0.282739 | 5.45 | -1.12 | 734 | 958 | -0.93 |
| 7 | 0.091412 | 0.000247 | 0.002863 | 0.000012 | 0.282905 | 0.000009 | 0.282888 | 10.73 | 4.25 | 517 | 620 | -0.91 |
| 8 | 0.083076 | 0.000546 | 0.002894 | 0.000016 | 0.282900 | 0.000012 | 0.282883 | 10.55 | 4.07 | 525 | 632 | -0.91 |

**表3 小东山火山岩的主量元素和微量元素组成分析结果  
Table 3 Major and trace element contents of the Xiaodongshan volcanic rocks**

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 组分 | 19AQS-01 | 19AQS-02 | 19AQS-03 | 19AQS-04 | 19AQS-05 | 19AQS-11 | 19AQS-12 | 19AQS-13 | 19AQS-06 | | 19AQS-07 | 19AQS-08 |
| 岩石类型 | 英安斑岩 | | | | | | | | 花岗斑岩 | | | |
| 主量元素 (%) | | | | | | | | | | | | |
| SiO2 | 60.81 | 61.83 | 73.56 | 63.41 | 60.63 | 62.61 | 63.37 | 60.81 | 75.27 | | 76.82 | 76.54 |
| TiO2 | 0.89 | 0.69 | 0.25 | 0.60 | 0.80 | 0.71 | 0.71 | 0.89 | 0.21 | | 0.16 | 0.30 |
| A12O3 | 15.52 | 15.96 | 13.41 | 14.61 | 15.53 | 16.84 | 16.71 | 15.52 | 13.04 | | 11.68 | 12.29 |
| TFe2O3 | 8.36 | 6.17 | 1.06 | 6.96 | 8.15 | 3.94 | 3.60 | 8.36 | 0.61 | | 0.97 | 0.99 |
| MnO | 0.45 | 0.28 | 0.04 | 0.16 | 0.22 | 0.11 | 0.10 | 0.45 | 0.02 | | 0.03 | 0.02 |
| MgO | 2.88 | 2.43 | 0.74 | 2.07 | 3.26 | 2.97 | 2.59 | 2.88 | 0.40 | | 0.45 | 0.37 |
| CaO | 1.23 | 2.47 | 0.87 | 4.79 | 1.92 | 1.89 | 1.99 | 1.23 | 0.76 | | 0.90 | 0.63 |
| Na2O | 6.38 | 5.52 | 4.57 | 3.93 | 5.32 | 4.94 | 5.04 | 6.38 | 4.84 | | 3.25 | 5.33 |
| K2O | 1.17 | 2.08 | 3.98 | 0.96 | 1.87 | 3.03 | 3.00 | 1.17 | 3.87 | | 4.46 | 2.05 |
| P2O5 | 0.16 | 0.17 | 0.05 | 0.08 | 0.11 | 0.16 | 0.18 | 0.16 | 0.05 | | 0.05 | 0.08 |
| LOI | 1.89 | 2.15 | 1.16 | 2.12 | 2.01 | 2.35 | 2.26 | 1.89 | 0.67 | | 0.96 | 0.91 |
| 总和 | 99.75 | 99.74 | 99.69 | 99.70 | 99.82 | 99.52 | 99.54 | 99.75 | 99.74 | | 99.72 | 99.49 |
| FeOT | 4.51 | 7.53 | 5.55 | 6.26 | 7.33 | 4.40 | 3.54 | 3.24 | 0.96 | | 0.55 | 0.87 |
| Mg# | 45 | 41 | 44 | 37 | 44 | 60 | 60 | 59 | 58 | | 56 | 48 |
| FeOT/MgO | 2.22 | 2.61 | 2.28 | 3.02 | 2.25 | 1.19 | 1.20 | 1.25 | 1.29 | | 1.39 | 1.93 |
| 组分 | 19AQS-09 | 19AQS-10 | 19AQS-14 | 19AQS-15 | 19AQS-16 | 19AQS-17 | 19AQS-18 | 19AQS-19 | 19AQS-20 | | 19AQS-21 | |
| 岩石类型 | 花岗斑岩 | | | | | 安山岩 | | 玄武岩 | | 橄榄玄武岩 | | |
| 主量元素 (%) | | | | | | | | | | | | |
| SiO2 | 71.56 | 71.07 | 67.94 | 61.61 | 72.47 | 54.97 | 54.08 | 48.49 | 48.10 | | 52.32 | |
| TiO2 | 0.48 | 0.48 | 0.42 | 0.71 | 0.32 | 0.75 | 0.66 | 1.12 | 1.18 | | 1.17 | |
| A12O3 | 14.07 | 14.14 | 15.30 | 16.64 | 13.37 | 18.99 | 15.98 | 19.24 | 19.35 | | 18.72 | |
| TFe2O3 | 1.99 | 1.99 | 1.16 | 4.89 | 1.89 | 7.16 | 8.95 | 10.10 | 10.41 | | 9.20 | |
| MnO | 0.22 | 0.22 | 0.04 | 0.13 | 0.18 | 0.36 | 0.23 | 0.30 | 0.29 | | 0.23 | |
| MgO | 1.19 | 1.33 | 0.87 | 3.70 | 1.02 | 2.17 | 1.70 | 3.12 | 3.35 | | 2.98 | |
| CaO | 1.49 | 1.64 | 2.39 | 1.73 | 1.46 | 6.37 | 11.23 | 6.22 | 7.64 | | 4.50 | |
| Na2O | 7.13 | 7.21 | 5.97 | 4.15 | 6.63 | 3.37 | 1.91 | 5.01 | 4.30 | | 6.19 | |
| K2O | 0.09 | 0.08 | 3.22 | 3.21 | 0.85 | 2.33 | 0.82 | 1.34 | 0.89 | | 0.71 | |
| P2O5 | 0.13 | 0.13 | 0.10 | 0.15 | 0.05 | 0.14 | 0.10 | 0.16 | 0.18 | | 0.17 | |
| LOI | 1.56 | 1.56 | 2.28 | 2.75 | 1.64 | 2.82 | 3.97 | 4.62 | 4.01 | | 3.64 | |
| 总和 | 99.89 | 99.87 | 99.69 | 99.67 | 99.88 | 99.42 | 99.64 | 99.70 | 99.70 | | 99.83 | |
| FeOT | 1.79 | 1.79 | 0.89 | 1.05 | 1.70 | 6.44 | 8.05 | 9.08 | 9.37 | | 8.28 | |
| Mg# | 54 | 57 | 42 | 60 | 52 | 38 | 27 | 38 | 39 | | 39 | |
| FeOT/MgO | 1.51 | 1.35 | 2.43 | 1.20 | 1.67 | 2.96 | 4.75 | 2.91 | 2.80 | | 2.78 | |
| 组分 | 19AQS-01 | 19AQS-02 | 19AQS-03 | 19AQS-04 | 19AQS-05 | 19AQS-11 | 19AQS-12 | 19AQS-13 | 19AQS-06 | | 19AQS-07 | 19AQS-08 |
| 稀土和微量元素 (×10-6) | | | | | | | | | | | | |
| Li | 28.28 | 33.10 | 28.91 | 11.81 | 19.79 | 35.42 | 28.34 | 24.15 | 12.34 | | 7.59 | 7.55 |
| Sc | 14.51 | 19.28 | 21.64 | 19.29 | 16.49 | 16.13 | 16.41 | 15.93 | 4.81 | | 3.86 | 4.30 |
| V | 98.76 | 130.24 | 114.64 | 150.81 | 144.02 | 60.08 | 56.30 | 56.05 | 19.01 | | 13.38 | 15.64 |
| Ni | 2.66 | 8.86 | 7.17 | 9.70 | 14.56 | 6.23 | 5.37 | 5.36 | 1.21 | | 0.50 | 0.73 |
| Co | 2.49 | 3.58 | 3.95 | 12.88 | 10.21 | 8.12 | 6.34 | 5.57 | 1.72 | | 0.71 | 3.23 |
| Cu | 9.40 | 1.00 | 202.56 | 1.49 | 0.95 | 0.62 | 0.77 | 0.66 | 1.75 | | 28.33 | 2.66 |
| Ga | 15.38 | 14.32 | 15.80 | 14.16 | 13.91 | 18.07 | 16.76 | 16.86 | 12.20 | | 11.51 | 11.63 |
| Rb | 49.38 | 37.24 | 68.22 | 23.95 | 63.25 | 145.88 | 134.66 | 134.37 | 98.92 | | 90.20 | 104.91 |
| Sr | 241.79 | 139.63 | 296.88 | 388.33 | 250.11 | 552.27 | 509.28 | 567.71 | 219.66 | | 194.77 | 169.12 |
| Y | 21.24 | 24.86 | 25.73 | 20.74 | 22.04 | 34.94 | 34.06 | 34.77 | 19.43 | | 17.60 | 18.79 |
| Zr | 74.35 | 117.01 | 104.87 | 89.99 | 93.22 | 219.12 | 213.02 | 216.13 | 164.86 | | 165.01 | 136.46 |
| Nb | 2.43 | 3.97 | 4.01 | 3.09 | 3.60 | 8.78 | 8.88 | 9.20 | 5.98 | | 6.60 | 6.09 |
| Cs | 3.48 | 1.45 | 0.62 | 0.57 | 0.95 | 4.72 | 4.45 | 4.57 | 0.92 | | 0.90 | 1.07 |
| Ba | 265.70 | 229.59 | 271.54 | 135.32 | 311.99 | 883.02 | 857.55 | 836.30 | 1136.58 | | 1070.34 | 1207.26 |
| La | 7.57 | 8.22 | 14.43 | 9.99 | 3.72 | 22.75 | 23.72 | 22.97 | 12.82 | | 15.95 | 21.58 |
| Ce | 18.11 | 20.41 | 30.22 | 21.50 | 9.82 | 51.75 | 52.99 | 51.02 | 26.28 | | 30.38 | 40.04 |
| Pr | 2.54 | 2.72 | 3.51 | 2.65 | 1.29 | 5.97 | 6.05 | 5.96 | 2.96 | | 3.29 | 4.36 |
| Nd | 11.92 | 12.89 | 15.18 | 11.71 | 6.17 | 24.70 | 24.74 | 23.88 | 11.34 | | 12.40 | 15.86 |
| Sm | 3.16 | 3.50 | 3.73 | 3.01 | 1.80 | 5.29 | 5.32 | 5.27 | 2.57 | | 2.43 | 3.02 |
| Eu | 1.20 | 1.08 | 1.32 | 0.89 | 0.54 | 1.17 | 1.11 | 1.13 | 0.83 | | 0.72 | 1.02 |
| Gd | 3.33 | 3.81 | 3.95 | 3.16 | 2.08 | 5.18 | 5.13 | 5.11 | 2.47 | | 2.18 | 2.77 |
| Tb | 0.55 | 0.63 | 0.66 | 0.54 | 0.38 | 0.83 | 0.83 | 0.85 | 0.44 | | 0.37 | 0.43 |
| Dy | 3.59 | 4.13 | 4.30 | 3.50 | 2.99 | 5.36 | 5.28 | 5.46 | 2.93 | | 2.50 | 2.76 |
| Ho | 0.77 | 0.90 | 0.90 | 0.73 | 0.73 | 1.15 | 1.13 | 1.13 | 0.64 | | 0.57 | 0.62 |
| Er | 2.17 | 2.59 | 2.48 | 2.16 | 2.34 | 3.40 | 3.33 | 3.42 | 1.96 | | 1.84 | 1.94 |
| Tm | 0.33 | 0.39 | 0.37 | 0.34 | 0.37 | 0.53 | 0.53 | 0.56 | 0.32 | | 0.32 | 0.32 |
| Yb | 2.10 | 2.52 | 2.31 | 2.32 | 2.46 | 3.57 | 3.51 | 3.74 | 2.23 | | 2.19 | 2.19 |
| Lu | 0.31 | 0.39 | 0.36 | 0.35 | 0.35 | 0.57 | 0.57 | 0.58 | 0.37 | | 0.36 | 0.36 |
| Hf | 1.85 | 3.02 | 2.79 | 2.51 | 2.59 | 5.50 | 5.43 | 5.40 | 4.14 | | 4.33 | 3.68 |
| Ta | 0.14 | 0.27 | 0.29 | 0.50 | 0.26 | 0.65 | 0.65 | 0.69 | 0.42 | | 0.51 | 0.49 |
| Pb | 3.69 | 1.84 | 1.74 | 5.95 | 1.48 | 4.81 | 4.48 | 4.78 | 1.58 | | 0.97 | 1.08 |
| Th | 1.20 | 2.29 | 3.63 | 2.47 | 3.21 | 9.33 | 9.45 | 9.43 | 6.52 | | 7.68 | 7.53 |
| U | 0.48 | 0.61 | 0.91 | 0.74 | 0.81 | 2.03 | 1.99 | 2.06 | 1.36 | | 1.21 | 1.43 |
| ∑REE | 57.66 | 64.19 | 83.72 | 62.85 | 35.04 | 132.22 | 134.21 | 131.09 | 68.15 | | 75.51 | 97.26 |
| LREE | 44.50 | 48.82 | 68.39 | 49.75 | 23.35 | 111.64 | 113.91 | 110.24 | 56.80 | | 65.18 | 85.88 |
| HREE | 13.15 | 15.37 | 15.33 | 13.10 | 11.69 | 20.58 | 20.29 | 20.84 | 11.35 | | 10.33 | 11.38 |
| (La/Yb)N | 2.43 | 2.19 | 4.21 | 2.90 | 1.02 | 4.30 | 4.55 | 4.14 | 3.88 | | 4.90 | 6.64 |
| (La/Sm)N | 1.50 | 1.48 | 2.43 | 2.09 | 1.30 | 2.70 | 2.81 | 2.74 | 3.14 | | 4.12 | 4.50 |
| (Gd/Yb)N | 1.28 | 1.22 | 1.38 | 1.10 | 0.68 | 1.17 | 1.18 | 1.10 | 0.89 | | 0.80 | 1.02 |
| Zr/Hf | 40.19 | 38.75 | 37.59 | 35.85 | 35.99 | 39.84 | 39.23 | 40.02 | 39.82 | | 38.11 | 37.08 |
| Eu/Eu\* | 1.13 | 0.90 | 1.05 | 0.88 | 0.86 | 0.67 | 0.64 | 0.66 | 0.99 | | 0.94 | 1.06 |
| δCe | 0.99 | 1.04 | 0.99 | 0.99 | 1.08 | 1.05 | 1.04 | 1.03 | 0.99 | | 0.96 | 0.94 |
| 组分 | 19AQS-09 | 19AQS-10 | 19AQS-14 | 19AQS-15 | 19AQS-16 | 19AQS-17 | 19AQS-18 | 19AQS-19 | 19AQS-20 | | 19AQS-21 | |
| 稀土和微量元素 (×10-6) | | | | | | | | | | | | |
| Li | 9.53 | 0.54 | 6.66 | 10.96 | 18.15 | 12.94 | 19.02 | 14.26 | 20.43 | | 5.72 | |
| Sc | 8.70 | 5.57 | 5.65 | 8.38 | 7.88 | 18.54 | 23.54 | 23.92 | 24.09 | | 18.26 | |
| V | 59.73 | 58.54 | 28.05 | 44.07 | 27.08 | 185.96 | 198.51 | 373.36 | 475.53 | | 325.02 | |
| Ni | 1.91 | 1.89 | 3.11 | 1.80 | 2.38 | 5.77 | 4.73 | 13.30 | 15.57 | | 13.58 | |
| Co | 4.64 | 5.66 | 1.35 | 2.49 | 7.27 | 15.91 | 12.64 | 24.47 | 27.41 | | 24.17 | |
| Cu | 1.13 | 0.78 | 1.77 | 1.14 | 0.72 | 2.70 | 0.62 | 0.56 | 0.70 | | 0.85 | |
| Ga | 12.36 | 10.62 | 11.12 | 15.36 | 12.39 | 17.52 | 18.54 | 17.39 | 17.22 | | 12.79 | |
| Rb | 3.75 | 3.31 | 44.14 | 70.57 | 22.77 | 98.62 | 39.46 | 68.66 | 44.79 | | 37.75 | |
| Sr | 121.68 | 89.16 | 126.02 | 201.48 | 63.48 | 369.77 | 661.44 | 439.00 | 434.81 | | 283.35 | |
| Y | 28.25 | 23.85 | 18.65 | 30.11 | 24.87 | 22.19 | 24.94 | 27.19 | 27.00 | | 24.44 | |
| Zr | 192.49 | 180.86 | 193.16 | 222.75 | 176.79 | 81.80 | 86.52 | 69.33 | 75.01 | | 74.71 | |
| Nb | 4.96 | 4.86 | 5.39 | 6.63 | 6.18 | 2.89 | 2.82 | 2.10 | 2.15 | | 2.14 | |
| Cs | 0.23 | 0.20 | 0.58 | 1.57 | 0.26 | 1.98 | 1.09 | 3.98 | 2.90 | | 3.51 | |
| Ba | 16.38 | 15.80 | 472.62 | 970.29 | 76.24 | 522.83 | 109.54 | 190.74 | 123.52 | | 92.99 | |
| La | 8.35 | 3.90 | 21.19 | 16.74 | 8.06 | 8.30 | 10.07 | 6.35 | 7.55 | | 3.93 | |
| Ce | 19.54 | 12.01 | 29.53 | 34.26 | 18.38 | 19.13 | 21.40 | 16.06 | 18.15 | | 10.86 | |
| Pr | 2.56 | 1.38 | 4.53 | 3.91 | 2.43 | 2.47 | 2.78 | 2.21 | 2.53 | | 1.64 | |
| Nd | 11.97 | 6.94 | 16.67 | 15.85 | 10.88 | 11.52 | 12.62 | 11.10 | 12.61 | | 8.80 | |
| Sm | 3.38 | 2.30 | 3.39 | 3.83 | 2.95 | 3.11 | 3.26 | 3.29 | 3.57 | | 2.94 | |
| Eu | 0.70 | 0.54 | 0.85 | 0.86 | 0.61 | 0.97 | 1.00 | 1.05 | 1.11 | | 0.86 | |
| Gd | 3.77 | 2.80 | 2.99 | 4.00 | 3.18 | 3.39 | 3.62 | 3.88 | 4.16 | | 3.58 | |
| Tb | 0.64 | 0.52 | 0.49 | 0.67 | 0.55 | 0.58 | 0.62 | 0.67 | 0.69 | | 0.63 | |
| Dy | 4.40 | 3.64 | 3.18 | 4.45 | 3.68 | 3.80 | 4.06 | 4.48 | 4.60 | | 4.24 | |
| Ho | 0.94 | 0.79 | 0.67 | 0.97 | 0.79 | 0.78 | 0.85 | 0.93 | 0.95 | | 0.89 | |
| Er | 2.84 | 2.41 | 2.02 | 2.86 | 2.39 | 2.27 | 2.50 | 2.71 | 2.74 | | 2.52 | |
| Tm | 0.46 | 0.40 | 0.32 | 0.45 | 0.40 | 0.34 | 0.39 | 0.41 | 0.42 | | 0.39 | |
| Yb | 3.07 | 2.68 | 2.07 | 3.00 | 2.75 | 2.27 | 2.55 | 2.58 | 2.64 | | 2.47 | |
| Lu | 0.46 | 0.41 | 0.33 | 0.48 | 0.44 | 0.33 | 0.39 | 0.39 | 0.40 | | 0.37 | |
| Hf | 4.77 | 4.52 | 4.61 | 5.25 | 4.36 | 2.25 | 2.34 | 1.98 | 2.13 | | 2.13 | |
| Ta | 0.35 | 0.34 | 0.38 | 0.47 | 0.53 | 0.21 | 0.24 | 0.17 | 0.15 | | 0.20 | |
| Pb | 10.03 | 13.60 | 1.33 | 1.32 | 1.15 | 6.08 | 5.92 | 6.06 | 5.63 | | 8.34 | |
| Th | 4.04 | 2.89 | 5.39 | 6.01 | 7.41 | 2.13 | 2.63 | 0.93 | 0.95 | | 0.93 | |
| U | 1.20 | 1.18 | 1.17 | 0.97 | 2.07 | 0.62 | 1.08 | 0.42 | 0.60 | | 0.40 | |
| ∑REE | 63.09 | 40.73 | 88.24 | 92.32 | 57.48 | 59.26 | 66.10 | 56.12 | 62.12 | | 44.09 | |
| LREE | 46.50 | 27.08 | 76.17 | 75.45 | 43.31 | 45.50 | 51.12 | 40.07 | 45.52 | | 29.02 | |
| HREE | 16.59 | 13.65 | 12.07 | 16.87 | 14.17 | 13.76 | 14.98 | 16.05 | 16.59 | | 15.07 | |
| (La/Yb)N | 1.83 | 0.98 | 6.89 | 3.76 | 1.98 | 2.47 | 2.66 | 1.66 | 1.93 | | 1.07 | |
| (La/Sm)N | 1.55 | 1.07 | 3.93 | 2.75 | 1.72 | 1.68 | 1.95 | 1.21 | 1.33 | | 0.84 | |
| (Gd/Yb)N | 0.99 | 0.84 | 1.16 | 1.07 | 0.93 | 1.21 | 1.14 | 1.21 | 1.27 | | 1.17 | |
| Zr/Hf | 40.35 | 40.01 | 41.90 | 42.43 | 40.55 | 36.36 | 36.97 | 35.02 | 35.22 | | 35.08 | |
| Eu/Eu\* | 0.60 | 0.65 | 0.80 | 0.67 | 0.60 | 0.91 | 0.89 | 0.89 | 0.88 | | 0.81 | |
| δCe | 1.01 | 1.24 | 0.69 | 0.99 | 0.99 | 1.01 | 0.96 | 1.03 | 1.00 | | 1.03 | |

注：Mg#= MgO/(MgO+FeOT),为分子比。

**表4 小东山火山岩全岩Rb-Sr、Sm-Nd 同位素组成**

**Table 4 Rb-Sr and Sm-Nd isotopic analyses for zircon from the Xiaodongshan volcanic rocks**

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **样品编号** | **岩石类型** | **年龄 (Ma)** | **Rb(ppm)** | **Sr(ppm)** | **87Rb/86Sr** | **87Sr/86Sr** | **2σ** | **(87Sr/86Sr)i** | **Sm(ppm)** | **Nd(ppm)** | **147Sm144Nd** | **143Nd/144Nd** | **2σ** | **(143Nd/144Nd)i** | **εNd(t)** | ***T*DM(Ga)** |
| 19AQS-01 | 英安斑岩 | 308 | 49.4 | 242 | 0.591324 | 0.708406 | 0.000008 | 0.705814 | 3.16 | 11.9 | 0.161457 | 0.512852 | 0.000004 | 0.512527 | 5.57 | 0.87 |
| 19AQS-02 | 308 | 37.2 | 140 | 0.772300 | 0.709179 | 0.000011 | 0.705794 | 3.50 | 12.9 | 0.165048 | 0.512750 | 0.000004 | 0.512417 | 3.43 | 1.25 |
| 19AQS-03 | 308 | 68.2 | 297 | 0.665374 | 0.709264 | 0.000007 | 0.706347 | 3.73 | 15.2 | 0.149537 | 0.512705 | 0.000004 | 0.512403 | 3.16 | 1.06 |
| 19AQS-04 | 308 | 24.0 | 388 | 0.178598 | 0.706419 | 0.000009 | 0.705636 | 3.01 | 11.7 | 0.156284 | 0.512745 | 0.000004 | 0.512430 | 3.68 | 1.07 |
| 19AQS-05 | 308 | 63.2 | 250 | 0.732245 | 0.708793 | 0.000008 | 0.705584 | 1.80 | 6.17 | 0.177485 | 0.512815 | 0.000004 | 0.512457 | 4.20 | 1.41 |
| 19AQS-11 | 308 | 146 | 552 | 0.764873 | 0.709267 | 0.000009 | 0.705914 | 5.29 | 24.7 | 0.130465 | 0.512686 | 0.000004 | 0.512423 | 3.55 | 0.85 |
| 19AQS-12 | 308 | 135 | 509 | 0.765605 | 0.708932 | 0.000008 | 0.705576 | 5.32 | 24.7 | 0.130823 | 0.512695 | 0.000004 | 0.512431 | 3.70 | 0.84 |
| 19AQS-13 | 308 | 134 | 568 | 0.685346 | 0.708702 | 0.000009 | 0.705698 | 5.27 | 23.9 | 0.134424 | 0.512690 | 0.000004 | 0.512419 | 3.47 | 0.88 |
| 19AQS-06 | 花岗斑岩 | 316 | 98.9 | 220 | 1.303975 | 0.712200 | 0.000006 | 0.706335 | 2.57 | 11.3 | 0.138039 | 0.512755 | 0.000004 | 0.512470 | 4.66 | 0.80 |
| 19AQS-07 | 316 | 90.2 | 195 | 1.340998 | 0.711966 | 0.000011 | 0.705935 | 2.43 | 12.4 | 0.119477 | 0.512714 | 0.000005 | 0.512467 | 4.60 | 0.71 |
| 19AQS-08 | 316 | 105 | 169 | 1.796215 | 0.713575 | 0.000008 | 0.705497 | 3.02 | 15.9 | 0.115843 | 0.512718 | 0.000004 | 0.512478 | 4.83 | 0.67 |
| 19AQS-09 | 316 | 44.1 | 126 | 1.014336 | 0.710958 | 0.000009 | 0.706397 | 3.39 | 16.7 | 0.123758 | 0.512743 | 0.000005 | 0.512487 | 5.00 | 0.69 |
| 19AQS-10 | 318 | 70.6 | 201 | 1.014162 | 0.710730 | 0.000008 | 0.706140 | 3.83 | 15.9 | 0.146895 | 0.512771 | 0.000004 | 0.512465 | 4.62 | 0.87 |
| 19AQS-14 | 318 | 3.75 | 122 | 0.089243 | 0.707545 | 0.000007 | 0.707141 | 3.38 | 12.0 | 0.172043 | 0.512879 | 0.000004 | 0.512521 | 5.71 | 0.99 |
| 19AQS-15 | 318 | 3.31 | 89.2 | 0.107572 | 0.706903 | 0.000007 | 0.706416 | 2.30 | 6.94 | 0.201657 | 0.512915 | 0.000004 | 0.512495 | 5.20 | 2.96 |
| 19AQS-16 | 318 | 22.8 | 63.5 | 1.038888 | 0.710807 | 0.000006 | 0.706106 | 2.95 | 10.9 | 0.164774 | 0.512830 | 0.000004 | 0.512487 | 5.05 | 1.00 |
| 19AQS-17 | 安山岩 | 318 | 98.6 | 370 | 0.772283 | 0.707994 | 0.000008 | 0.704499 | 3.11 | 11.5 | 0.164594 | 0.512755 | 0.000005 | 0.512413 | 3.59 | 1.22 |
| 19AQS-18 | 318 | 39.5 | 661 | 0.172737 | 0.706544 | 0.000009 | 0.705762 | 3.26 | 12.6 | 0.157104 | 0.512763 | 0.000004 | 0.512436 | 4.05 | 1.04 |
| 19AQS-21 | 橄榄玄武岩 | 318 | 25.8 | 389 | 0.192103 | 0.707403 | 0.000007 | 0.706534 | 3.22 | 13.4 | 0.146250 | 0.512703 | 0.000004 | 0.512399 | 3.32 | 1.01 |