Supplementary material for

RESOLVING THE TIMING OF OROGENESIS IN THE WESTERN BLUE RIDGE, SOUTHERN APPALACHIANS VIA *IN SITU* ID-TIMS MONAZITE GEOCHRONOLOGY

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GEOLOGIC BACKGROUND (see also Kohn and Malloy, 2004)

Within the study area, Great Smoky Mountains National Park (Figure 1), the Western Blue Ridge thrust sheet consists of a Grenvillian (~1.0 – 1.2 Ga) basement overlain by the Ocoee Supergroup, a 12-15 km thick package of rift-related, clastic metasedimentary rocks (King et al., 1958; Rast and Kohles, 1986). Collectively, in ascending stratigraphic order, the Precambrian(?) Ocoee Supergroup consists of the Snowbird, Great Smoky, and Walden Creek Groups. The Snowbird Group nonconformably overlies the crystalline basement, and the Great Smoky Group both conformably rests on the Snowbird, as well as locally overlies the basement (Hadley and Goldsmith, 1963). In some areas, the Walden Creek group conformably overlies the Great Smoky Group (Costello and Hatcher, 1991).

This study focused on the Thunderhead Sandstone and the Anakeesta Formation of the Great Smoky Group. The Thunderhead Sandstone was deposited on the continental margin between ~670 and ~990 Ma (Aleinikoff et al., 2004), and is predominantly arkosic in composition. Its dominant quartzites are interbedded at a decimeter to meter scale with thin (cm- to dm-thick) bands of aluminous schist. Up section, the pelitic layers of the Thunderhead become progressively more graphitic, grading into the Anakeesta Formation, a graphitic and sulfidic schist with interbedded quartzite.

METHODS

Samples were collected from the Great Smoky Mountains National Park and surrounding region via agreement with the National Park Service. The majority of the samples were collected from road cuts, but some were also collected from outcrops near park trails. Polished thin sections were cut for each sample. Semi-quantitative X-ray maps of monazite were collected by using a Cameca SX50 electron microprobe housed in the Electron Microscopy Center at the University of South Carolina. Operating conditions for the X-ray maps consisted of an accelerating voltage of 15 kV, current of 200 nA, pixel time of 30 msec, step size of 0.5 μm/pixel, and map size of 256 × 256 to 512 × 512 pixels. Monazite X-ray maps were collected for the elements U, Th, Y, and Ce. These maps were used to characterize zoning, identify different generations of monazite growth (if more than one), and define core vs. rim regions to be microsampled for subsequent TIMS analysis. Samples selected for monazite analysis are identified in Figure DR1.

U-Pb ID-TIMS ages from monazite were collected using the facilities in the Geochronology and Isotope Geochemistry Laboratory at the University of North Carolina at Chapel Hill. NBS 981 was used as the standard. Raw data reduction, concordia plots, age estimates and age errors were generated with the PB MacDat-2 program (D. Coleman, 2003, personal communication) using data-reduction and error-propagation algorithms of Ludwig (1989, 1990). Common Pb corrections were made using Stacey and Kramers (1975) initial Pb ratio appropriate to the age of the sample. Measured Pb isotopes from biotite and/or plagioclase from four samples revealed ratios that were within about 0.5% of Stacey and Kramers (1975).

For those monazites that were suitable for microanalysis, 40-50 μm diameter pits were drilled *in situ* using a micromill, and the resulting powder from each pit was collected into a 3 mL Teflon beaker (i.e., one pit and U-Pb age per monazite grain). Sample preparation and column chemistry follow the same protocol as that of zircon (Ratajeski et al., 2001) with minor modifications to the dissolution procedure, as follows: Before dissolving the monazite powder, ~50 μg of a mixed ^{205}Pb-^{233}U-^{236}U spike was added to the beaker. Next, 100 μL of 10 M ultrapure HCl was pipetted into each beaker. The beakers were then placed on a hotplate in an evaporation box overnight. The next morning, the beakers were opened and dried down on the hotplate to ~ 5 μL drops. 100 μL of the 10 M HCl and 30 μL of 13 M HNO_3 were added. Beakers were capped and set on the hotplate overnight. The following morning, the beakers were once again opened and dried down to approximately a 5 μL drop. To convert the sample to bromides for loading, ~10-15 μL of HBr were added to the 5 μL of sample, and then the sample was dried down again to 5 μL. Next, ~30 μL of HBr were added to the sample; this was the load solution. The samples were then ready for column chemistry following the 0.5 M HBr U-Pb column procedure for zircon (Ratajeski et al., 2001).

REFERENCES CITED

Aleinikoff, J.N., Southworth C.S., Yacob E.Y., Fanning C.M., 2004, Isotopic constraints on the time of deposition of the Thunderhead Sandstone, Ocoee Supergroup: U-Pb geochronology of monazite and xenotime overgrowths: Geological Society of America Abstracts with Programs, v. 36, p. 98.

Costello J. O., and Hatcher R.D., Jr., 1991, Problems of stratigraphic correlation between the Great Smoky, Snowbird, and Walden Creek Groups between the Great Smoky Mountains National Park, central East Tennessee and Ocoee Gorge, southeastern Tennessee, *in* Kish, S.A., ed., Studies of Precambrian and Paleozoic Stratigraphy in the Western Blue Ridge, Carolina Geological Society, p. 13-25.

Hadley J. B., and Goldsmith R., 1963, Geology of the eastern Great Smoky Mountains, North Carolina and Tennessee: U.S. Geological Survey Professional Paper, v. 349-B.

King P. B., Hadley J.B., Neuman R.B., Hamilton W., 1958, Stratigraphy of the Ocoee Series, Great Smoky Mountains, Tennessee and North Carolina: Geological Society of America Bulletin, v. 69, p. 947-966.

Kohn, M.J., and Malloy, M.A., 2004, Formation of monazite via prograde metamorphic reactions among common silicates: implications for age determination: Geochimica et Cosmochimica Acta, v. 68, p. 101-113.

Ludwig, K.R., 1989, Pb-Dat: A computer program for processing raw Pb-U-Th isotope data: U.S. Geological Survey Open-File Report, v. 88-557, p. 37.

—, 1990, Isoplot: A plotting and regression program for radiogenic isotopic data: U.S. Geological Survey Open-File Report, v. 90-91, p. 39.

Rast N., and Kohles K.M., 1986, The origin of the Ocoee Supergroup: American Journal of Science, v. 286, p. 593-616.

Ratajeski, K., Glazner, A.F., Miller, B.V., 2001, Geology and geochemistry of mafic to felsic plutonic rocks in the Cretaceous intrusive suite of Yosemite Valley, California: Geological Society of America Bulletin, v. 113, p. 1486-1502.

Stacey, J.S., and Kramers, J.D., 1975, Approximation of terrestrial lead isotope evolution by a two-stage model: Earth and Planetary Science Letters, v. 26, p. 207-221.

TABLE DR1. ELEMENT CONCENTRATIONS, ISOTOPE RATIOS, AND CALCULATED AGES OF GREAT SMOKY MONAZITES

Sample ID	Total U* ppm	Total Pb* ppm	common Pb (pg)	206 Pb / 204 Pb	208 Pb / 206 Pb	206 Pb / 238 U	% err	207 Pb / 235 U	% err	207 Pb / 206 Pb	% err	Age (Ma) ± 2σ 206 Pb / 238 U	Age (Ma) ± 2σ 207 Pb / 235 U	Age (Ma) ± 2σ 207 Pb / 206 Pb	corr. coef.	%U-Pb disc.
K00-17a m2	110.11	20.55	57.17	92.555	1.527	0.0616	0.5782	0.4760	0.8359	0.0561	0.5726	**385.2 ± 2.2**	**395.3 ± 3.3**	**454.9 ± 12.7**	0.73	15.77
K00-18 m2	331.75	58.60	104.99	159.910	1.306	0.0715	0.2502	0.5505	0.4046	0.0558	0.3034	**445.4 ± 1.1**	**445.3 ± 1.8**	**445.1 ± 6.7**	0.66	-0.05
K00-26a m4	334.91	68.11	165.59	110.393	1.407	0.0728	0.1698	0.5676	0.4606	0.0566	0.4116	**452.7 ± 0.7**	**456.5 ± 2.1**	**475.4 ± 9.1**	0.46	4.94
K00-51c2 m1	148.79	32.70	75.60	105.159	1.741	0.0707	0.4263	0.5430	0.9167	0.0557	0.7732	**440.6 ± 1.9**	**440.4 ± 4.0**	**439.5 ± 17.2**	0.54	-0.24
K00-51c2 m5	101.90	22.82	52.29	105.265	1.785	0.0715	0.5264	0.5466	1.0314	0.0555	0.8440	**445.1 ± 2.3**	**442.8 ± 4.6**	**430.5 ± 18.8**	0.58	-3.53
K00-54 m2	41.09	8.67	15.32	139.074	1.859	0.0718	1.3458	0.5498	1.5806	0.0555	0.7832	**447.1 ± 6.0**	**444.9 ± 7.0**	**433.1 ± 17.5**	0.87	-3.35
K00-54 m5	97.34	16.26	12.25	377.458	1.476	0.0720	0.6212	0.5561	0.7360	0.0560	0.3758	**448.1 ± 2.8**	**449.0 ± 3.3**	**453.3 ± 8.3**	0.86	1.17
K00-56a m2	49.33	22.68	146.48	33.065	1.700	0.0709	0.6110	0.5474	2.2605	0.0560	2.0647	**441.4 ± 2.7**	**443.3 ± 10.0**	**453.1 ± 45.8**	0.44	2.66
K00-57a m1	144.05	36.29	65.60	115.382	2.358	0.0706	0.4239	0.5499	0.5667	0.0565	0.3582	**439.7 ± 1.9**	**445.0 ± 2.5**	**472.4 ± 7.9**	0.78	7.16
K00-58a m1	159.38	29.92	27.38	280.422	1.725	0.0717	0.3825	0.5528	0.4388	0.0559	0.2058	**446.6 ± 1.7**	**446.8 ± 2.0**	**448.2 ± 4.6**	0.88	0.37
K00-58a m2	136.89	32.80	30.54	218.792	2.495	0.0715	0.4583	0.5491	0.6176	0.0557	0.3959	**445.0 ± 2.0**	**444.4 ± 2.7**	**441.3 ± 8.8**	0.77	-0.87
K00-58c m2	85.98	22.01	71.34	66.509	2.120	0.0643	0.6384	0.5051	1.6744	0.0570	1.4866	**401.5 ± 2.6**	**415.1 ± 7.0**	**491.7 ± 32.8**	0.47	18.91
K00-62 m2	27.19	10.47	20.20	80.470	3.974	0.0739	1.7891	0.5783	2.2623	0.0568	1.3123	**459.6 ± 8.2**	**463.4 ± 10.5**	**482.2 ± 29.0**	0.81	4.87
K00-62 m3	43.97	9.59	27.23	91.792	1.533	0.0728	1.1641	0.5648	1.5438	0.0562	0.9620	**453.2 ± 5.3**	**454.6 ± 7.0**	**461.7 ± 21.3**	0.78	1.89
K00-63a m8	25.00	6.05	18.41	78.527	1.887	0.0710	2.0198	0.5386	3.0903	0.0550	2.2037	**441.9 ± 8.9**	**437.5 ± 13.5**	**414.2 ± 49.3**	0.70	-6.91
K00-63a m12	82.76	16.43	21.73	187.790	1.808	0.0711	0.6982	0.5456	0.8713	0.0557	0.4973	**442.5 ± 3.1**	**442.1 ± 3.9**	**439.9 ± 11.1**	0.82	-0.63
K03-3a m1	48.71	21.84	133.22	33.146	2.112	0.0661	0.7438	0.5016	5.1854	0.0550	4.9126	**412.9 ± 3.1**	**412.8 ± 21.4**	**412.3 ± 109.8**	0.43	-0.14
K03-3a m2	125.61	27.88	53.26	124.642	1.859	0.0722	0.4751	0.5561	0.8097	0.0559	0.6256	**449.3 ± 2.1**	**449.0 ± 3.6**	**447.3 ± 13.9**	0.64	-0.45
K03-3b m1	268.07	39.58	61.99	185.999	1.289	0.0620	0.3309	0.4736	0.6013	0.0554	0.4816	**388.0 ± 1.3**	**393.6 ± 2.4**	**426.9 ± 10.7**	0.60	9.38
C04-4b m2	133.84	32.76	87.98	86.102	1.875	0.0715	0.4180	0.5669	1.3985	0.0575	1.2805	**445.2 ± 1.9**	**456.0 ± 6.4**	**511.0 ± 28.2**	0.42	13.32
C04-4b m3	259.62	75.67	85.34	148.070	3.339	0.0683	0.2666	0.5241	0.6324	0.0557	0.5489	**425.9 ± 1.1**	**427.9 ± 2.7**	**438.9 ± 12.2**	0.50	3.08
C04-6 m1	520.79	100.06	122.53	210.670	1.655	0.0722	0.1538	0.5557	0.2430	0.0558	0.1805	**449.5 ± 0.7**	**448.7 ± 1.1**	**444.5 ± 4.0**	0.67	-1.17

‘m’ followed by a number in the sample ID refers to the monazite grain number

*Normalized concentrations based on an assumed sample weight of 0.010 mg recovered from each spot. These apparent concentrations are irrelevant to the age.