Are titanite grains in Middle and Late Jurassic tuffs of the Carmel and Morrison Formations of Utah volcanic in origin or detrital grains from non-volcanic sources?

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ABSTRACT

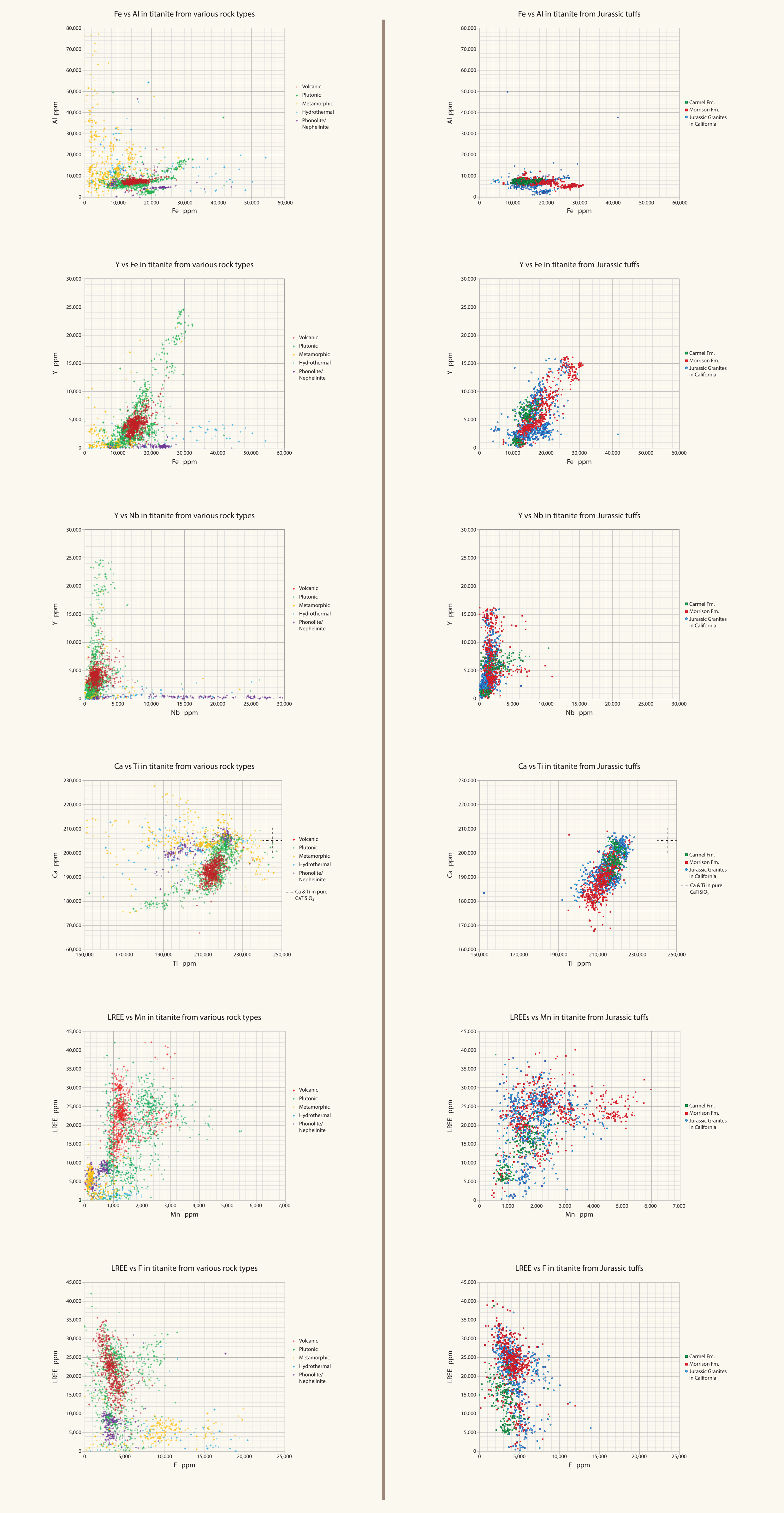
Titanite (sphene) is a common accessory phase in plutonic and metamorphic rocks, but has been reported to be uncommon in volcanic rocks. This does not appear to be true for altered Middle and Late Jurassic fallout tuffs preserved in the Temple Cap, Carmel, and Morrison formations in Utah where about 40% of the ash beds contain titanite. However, since these titanite grains only comprise a trace percentage of the total residual minerals recovered from any of the thin altered ash beds, their origin might be questioned. Were they erupted along with other recovered phenoclasts, or are they detrital in origin? In order to answer this question, we have accumulated a large number of geochemical analyses on major and trace elements from the literature, as well as from our own samples for comparison. Titanite from the altered tuffs is most similar to titanite from other volcanic rocks. This is apparent for REE, Y, Fe, and Mn concentrations, which are typically higher in volcanic titanite, and for Al and F, which are typically lower. They are also similar to plutonic titanite grains, particularly those from Jurassic plutons of southern California. However, titanite grains from the Jurassic tuffs and other volcanic rocks are typically not as strongly zoned as plutonic titanite and lack rim zones that in many plutonic titanites are low in REE and Y and higher in F. We interpret this stronger zoning to be the result of long crystallization and cooling histories of plutonic titanite. Titanite compositions from metamorphic and hydrothermal environments are quite different than titanite from the Jurassic tuffs with higher Al and F and lower REE, Fe, Y, and Mn. With only a few exceptions, the geochemical data support a volcanic origin for the titanite found in the altered tuff beds of the Carmel, Temple Cap, and Morrison formations.

Data Sources (in addition to 2780 in house analyses)

Authors	Location	Rock type	No. Analyses	Classification
Che et al. 2013	Yukon & British Columbia	altered granodiorite	6	Hydrothermal
Xiao-Dong Deng et al 2014	Daye District, China	Skarn	18	Hydrothermal
Xiao-Dong Deng et al 2014	Daye District, China	Altered Diabase Dike	9	Hydrothermal
Yu Hu et al., 2016	Yunnan, China	quartz syenite porphyry	28	Hydrothermal
Cundari, 1979	Italy	Leucite lava - phonolite	1	Phon/Neph
Dawson & Hill, 1998	Tanzania	Nephelinite Lava	5	Phon/Neph
Giannetti & Luhr, 1983	Italy	Phonolite	1	Phon/Neph
Giannetti & Luhr, 1983	Italy	Trachyte	3	Phon/Neph
Holenyi & Annersten, 1987	Germany	Sanidine volcanic rock	1	Phon/Neph
Luhr et al., 1984	El Chichon, Mexico	Trachyandesite	1	Phon/Neph
Olin & Wolff, 2012	Canary Islands	Phonolite	2	Phon/Neph
Paslick et al., 1996	Tanzania	Foidite	6	Phon/Neph
Peterson, 1989	Kenya	Nephelinite lava	1	Phon/Neph
Smith, 1970	Cameroon	Nephelinite Lava	5	Phon/Neph
Ventura et al., 1999	Italy	Alkali Syenite Lava	7	Phon/Neph
Wolff, 1984	Canary Islands	Phonolite lava	1	Phon/Neph
Che et al. 2013	Yukon & British Columbia	granodiorite	8	Plutonic
March 2016 Barth data	Wheeler Crest Granodiorite	Granodiorite, Triassic	32	Plutonic
March 2016 Barth data	Tinemaha, California	Granodiorite, Jurassic	102	Plutonic
McLeod et al 2011, Ross of Mull	Scotland	diorite dike	17	Plutonic
McLeod et al 2011, Ross of Mull	Scotland	granite	10	Plutonic
McLeod et al 2011, Ross of Mull	Scotland	diorite	22	Plutonic
McLeod et al 2011, Ross of Mull	Scotland	granite-diorite hybrid	31	Plutonic
McLeod et al 2011, Ross of Mull	Scotland	vesicular diorite	48	Plutonic
McLeod et al 2011, Ross of Mull	Scotland	veined diorite	22	Plutonic
Middleton et al 2013	France	Monzogranite	2	Plutonic
Xiao-Dong Deng et al 2014	Daye District, China	Quartz Diorite	14	Plutonic
Xu et al 2015	Jinshajiang, China	Cu porphry	15	Plutonic
Xu et al 2015	Jinshajiang, China	Barren porphry	6	Plutonic
Yu Hu et al., 2016	Yunnan, China	quartz syenite porphyry	8	Plutonic
Colombini et al, 2011	Nevada, USA	Dacite Mingled lava	5	Volcanic
Colombini et al, 2011	Nevada, USA	Rhyolite Tuff	5	Volcanic
Colombini et al, 2011	Nevada, USA	Rhyolite Lava	5	Volcanic
Nakada, 1991	Andes Mountains	Dacite	7	Volcanic
Pamukcu et al, 2013	California, USA	Rhyolite-Peach Spring Tuff	12	Volcanic
Aleinikoff et al 2002	Connecticut	orthogneiss	3	Metamorphic
Bernau & Franz, 1987	Egypt	Calc-Silicate	13	Metamorphic
Bernau & Franz, 1987	Greece	Piemontite-Albite Gneiss	3	Metamorphic
Carmichael, 1970	Ontario	calc silicate	4	Metamorphic
Carswell et al., 1996	China	Eclogite	8	Metamorphic
Cave et al 2015	New Zealand	greywacke & argillite	21	Metamorphic
Che et al. 2013	Yukon & British Columbia	Skarn	9	Metamorphic
Che et al. 2013	Yukon & British Columbia	Hornfels	4	Metamorphic
Chen et al 2016	Sulu Orogen, China	Metagranite	7	Metamorphic
Cotkin, 1987	California	Blueschist	2	Metamorphic
Coulson & Chambers, 1996	Greenland	Metasomatised basalt	1	Metamorphic
Coulson & Chambers, 1996	Greenland	Metasomatised sediment	4	Metamorphic
Coulson & Chambers, 1996	Greenland	Metasomatised syenite	3	Metamorphic
Coulson & Chambers, 1996	Greenland	Metasomatised granite-gneiss	2	Metamorphic
Enami et al., 1993	California	meta-sediments	13	Metamorphic
Enami et al., 1993	Japan	granitoid	3	Metamorphic
Ernst & Dal Piaz, 1978	Italy	Eclogite	6	Metamorphic
Franz & Spear, 1985	Austria	Eclogite	21	Metamorphic
G.M. Bancroft et al. 1987	Ontario	Gneiss	3	Metamorphic
Gao et al 2012	Dabie, China	Metagranite UHP	35	Metamorphic
Ghent & Stout, 1984	Canada	Metabasite	11	Metamorphic
Gilotti, 1989	Sweden	Metadiabase dike	1	Metamorphic
Guo et al 2014	North China	Eclogite	22	Metamorphic
Harlov et al 2006	Tamil Nadu, southern India	Felsic to Intermediate	5	Metamorphic
Harlov et al 2006	Bamble Sector, SE Norway	Felsic to Intermediate	5	Metamorphic
Harlov et al 2006	Ivrea-Verbano Zone, Italy	Felsic to Intermediate	5	Metamorphic
Harlov et al 2006	Otztal Complex, Austria	Felsic to Intermediate	3	Metamorphic
Holenyi & Annersten, 1987	Sweden	Metasedimentary rock	1	Metamorphic
J. Konzett et al. 1996	Italy	amphibolite	2	Metamorphic
Jing-Liang et al 2014	Xu–Huai, China	Eclogite 10-15 kb	22	Metamorphic
Kay, 1983	Alaska - greenschist facies	Meta-quartz monzodiorite	2	Metamorphic
M.T. Gomez-Pugnaire et al. 1996	Northern Urals	ecoglite	1	Metamorphic
M.T. Gomez-Pugnaire et al. 1996	Northern Urals	blueschist	2	Metamorphic
Makanjuola and Howie, 1972	France	blueschist	4	Metamorphic
Markl and Piazolo 1999	Antarctica	Calcsilicate	17	Metamorphic
Mevel, 1981	Vema Fracture Zone	Metabasalt	1	Metamorphic
Moore & McStay, 1990	South Africa - granulite facies	Plag-Qtz Gneiss	1	Metamorphic
Moore and McStay, 1990	South Africa	calcic granofels	1	Metamorphic
N.C.N. Stephenson et al. 1997	East Antarctica	calcsilicate granulite	12	Metamorphic
Ng et al 2016	Jade Tract, Myanmar	Omphacitite & Jadeite	11	Metamorphic
Nishiyama, 1990	Japan	Metabasite	2	Metamorphic
Pan & Fleet, 1992	Hemlo Gold Mine, Ontario	Green-mica schist	10	Metamorphic
Pedersen, 1979	Greenland	Shale Buchite Xenolith	1	Metamorphic
Perseil & Smith, 1995	Italy, Eclogite facies	Quartzite	20	Metamorphic
Sobolev and Shatsky, 1990	Russia	biotite gneiss - high P	1	Metamorphic
T. Itaya et al. 1985	New Caledonia	high P schists	6	Metamorphic
T.H.D. Hartel et al. 1996	Ontario	mafic granulite	3	Metamorphic
T.M. Boundy et al.,1997	western Norway	Granulite-eclogite	2	Metamorphic
Trzcienski et al., 1984	New Brunswick - blueschist	Metabasite	1	Metamorphic
Tulloch, 1979	New Zealand	Metagranodiorite	2	Metamorphic
Wintsch and Yi 2002	Connecticut	Gastonbury Gneiss	4	Metamorphic
Yau et al., 1984	Franklin, New Jersey - granulite	Marble	1	Metamorphic
Yen_Hong Shan et al. 1991	Taiwan	orthogneiss	1	Metamorphic
Zhang et al 2016	Tibet	Amphibolite	6	Metamorphic

Variation Diagrams

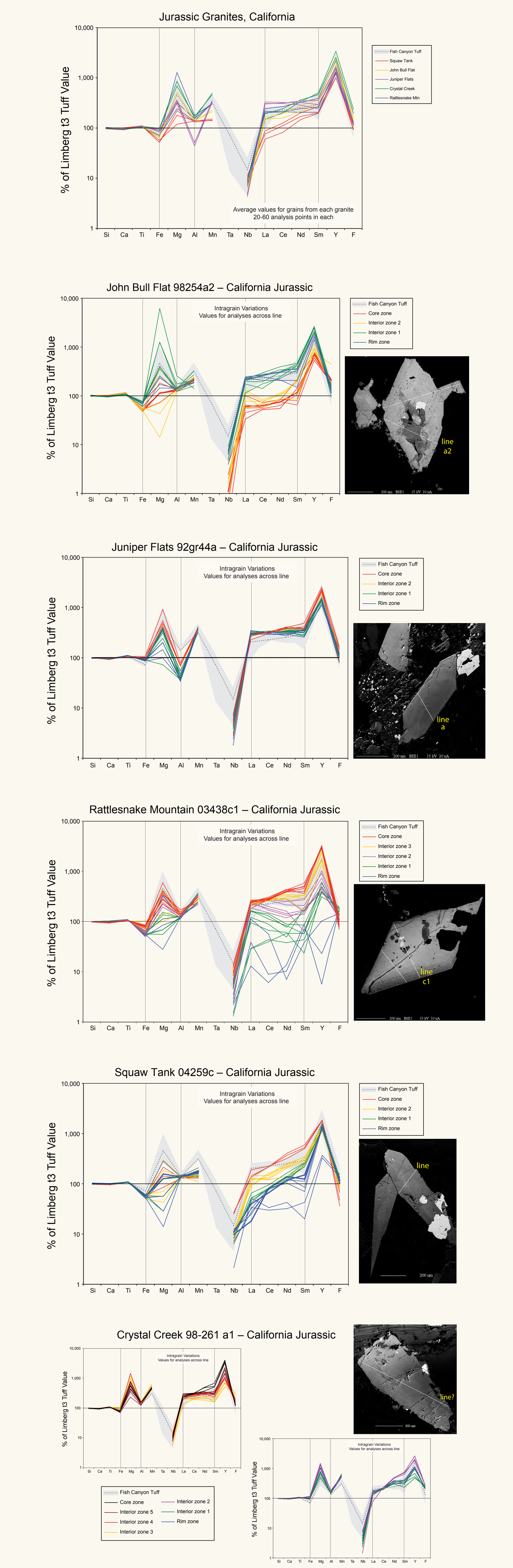
Titanites from various rock types are shown on the left side of this panel and from Jurassic tuffs and granites on the right side for comparison. Titanite from the tuffs are quite similar on these diagrams to volcanic and intrusive titanites, but quite different from titanite from other rock types.



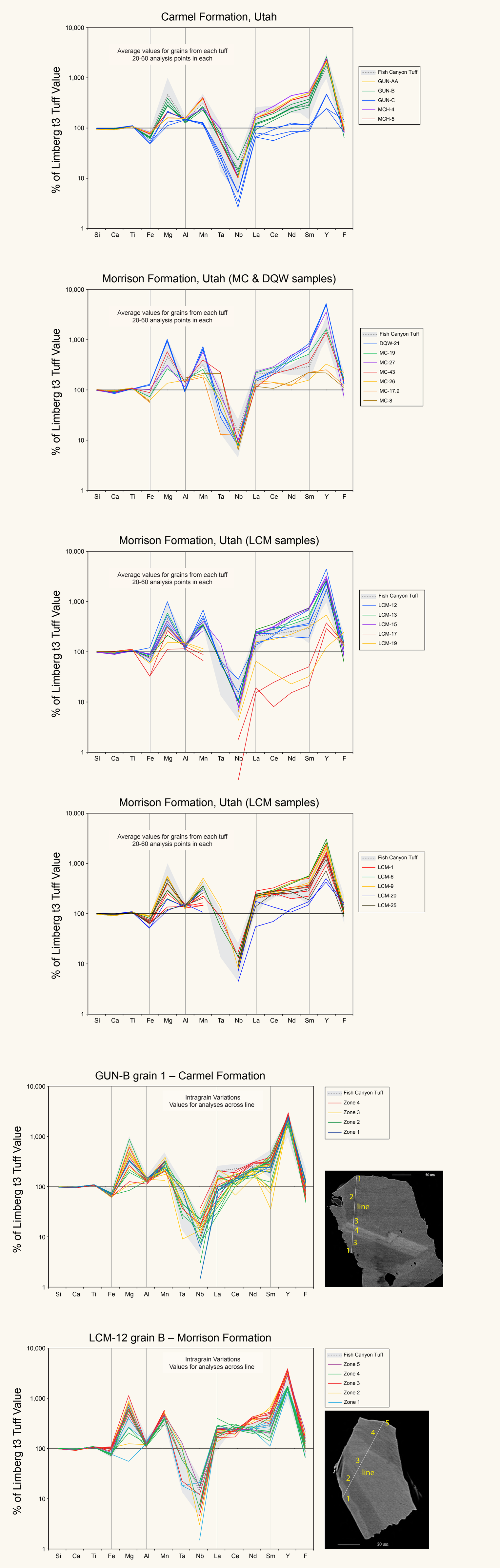
Spider Diagrams

In these diagrams we have used the average value of each element from titanites in the phonolitic Limberg Tuff (Kaiserstuhl, Germany) against which the other samples have been normalized. The element patterns can be used to distinguish between different rock types as well as to see the core to rim variations within grains.

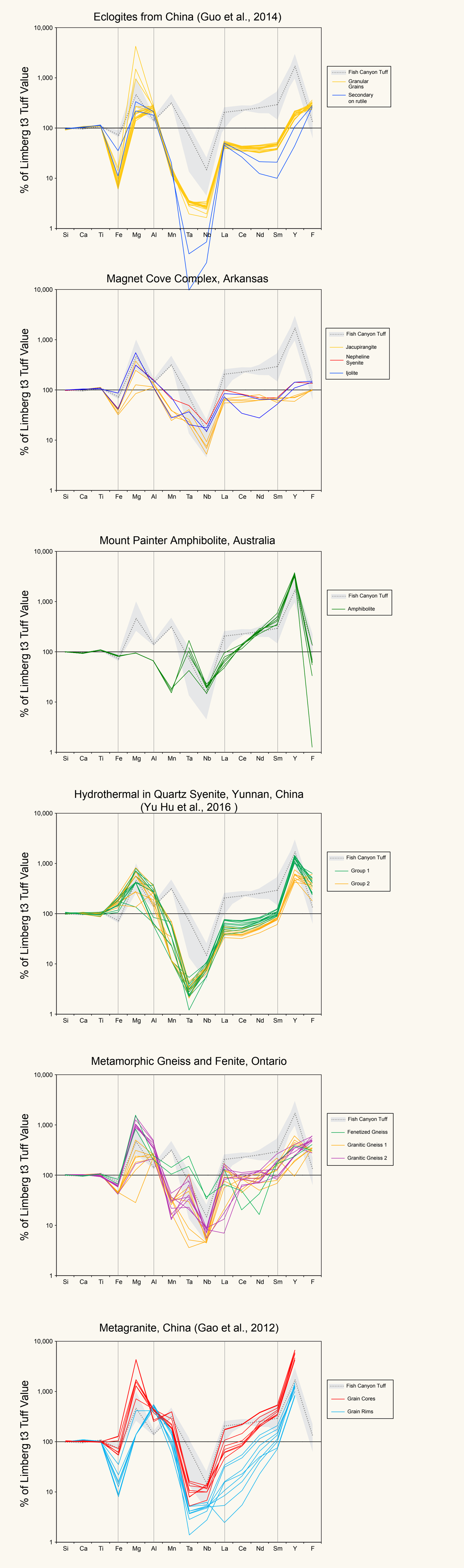
TITANITE from CALIFORNIA JURASSIC GRANITES



TITANITE from CARMEL and MORRISON FORMATIONS



TITANITE from OTHER ROCK TYPES



Crystallization Paths

Individual titanite crystals contain information on the local changes in magma composition. In plutonic titanites, these changes can be quite substantial. On some variation diagrams, these changes can be viewed as compositional trends or pathways. For plutonic titanites these pathways are often quite long, covering a wide range of compositions, while for volcanic titanites the pathways are typically fairly short. Here we show examples of these pathways for both plutonic titanites from California granites as well as from volcanic titanites from our Jurassic ash beds, some Tertiary tuffs of the Great Basin and Colorado, and titanites from other rock types.

CONCLUSIONS

Titanite in bentonitic ash beds of the Jurassic Morrison and Carmel Formations of Utah is most similar in composition to volcanic and plutonic titanite, and is unlike titanite from hydrothermal, metamorphic, and silica-undersaturated rocks (nephelinites, phonolites, foidites, etc.). Compared to metamorphic titanite, volcanic and plutonic titanite typically has higher La, Ce, Fe, Mn, and Y, but lower Al, F, and Ca. Many metamorphic titanites have a steeper slope on our normalized spider diagrams from La through Sm than do volcanic and plutonic titanites.

Compared to hydrothermal titanite, volcanic and plutonic titanite is typically higher in REEs and Y, but lower in Nb, F, and Ca. Values for Fe and Al in hydrothermal titanite are quite varied and can be as high or higher than many volcanic, plutonic, and metamorphic titanites.

High Nb content is the most distinctive feature of titanite from alkaline and silica-undersaturated rocks (e.g., Limberg Tuff, Magnet Cove Complex). These titanites also tend to be low in Y, REEs, F, and Mn compared to volcanic and plutonic titanite.

Separating volcanic from plutonic titanite is not as straightforward. However, plutonic titanite grains typically contain fairly long crystallization paths when compared to volcanic titanite. They may also have grain rims that are similar to hydrothermal titanite, and these grain rims may in fact be hydrothermal.

In conclusion, the evidence gathered here strongly suggests that most of the titanite grains examined from the Jurassic Morrison and Carmel Formations are indeed volcanic in origin and not detrital contaminants from other rock types. In addition, the distinctive compositions of titanites from each ash bed suggests that there was not a significant amount of intermixing of titanite between ash layers.