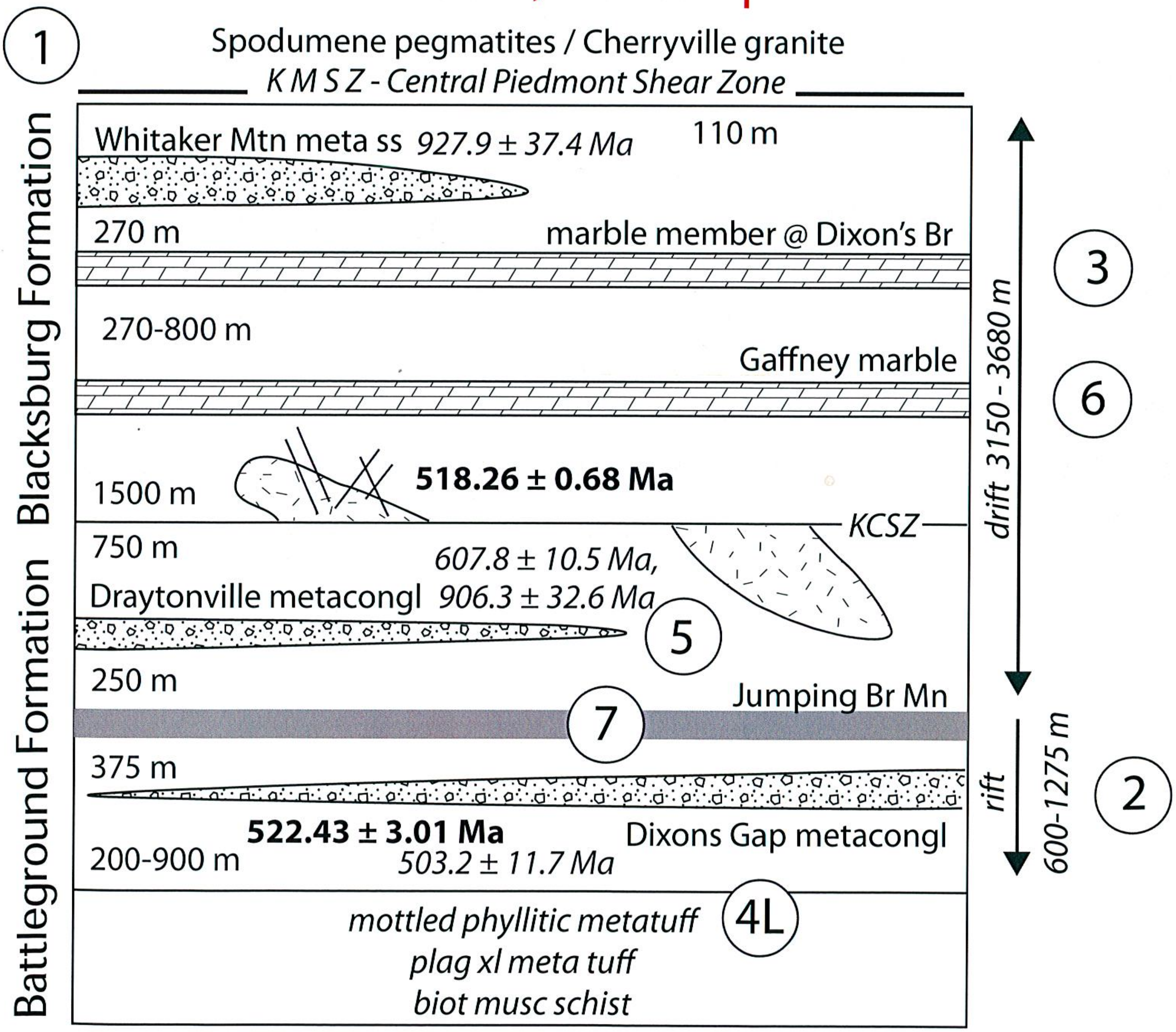
Carolina Geological Society
2014 Annual Meeting & Field Trip
October 31 - November 2

Recognizing the Cambrian Rheic margin of Carolinia in the Kings Mountain terrane

Allen Dennis, Field Trip Leader



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Front cover: Schematic stratigraphic section of KMt lower-plate stratigraphy. Day 1 stops are indicated. Plain type: approximate stratigraphic thicknesses between particular horizons. Age of youngest zircon grain(s) measured by laser ablation U-Pb technique shown in italics (1σ error) from Dixon's Gap metaconglomerate, Draytonville metaconglomerate, and Whitaker Mountain meta-sandstone; Bold numbers indicates ID-TIMS age of youngest zircon grain from Dixon's Gap metaconglomerate (2σ error), and crystallization age of granodiorite dikes at base of the Blacksburg Formation (2σ error). Data from Dennis & Baker (2012) and Dennis & Miller (2013).

Back cover: A. Synoptic probability density curves for detrital zircon ages from Dixon's Gap metaconglomerate (and along strike-equivalent Stepp's Gap; black), Draytonville metaconglomerate (red), Whitaker Mountain metasandstone (blue); note that black and red/blue curves are scaled differently according to the histograms from which they are constructed (left ordinate axis, Dixon's Gap/Stepp's Gap; right ordinate axis, Draytonville/Whitaker Mtn). Loss of local arc-derived detritus occurs in the 625 m above Dixon's Gap metaconglomerate member: we interpret the Jumping Branch manganiferous member to mark the transgression accompanying subsidence and the change in provenance. (Dennis & Baker, 2012). Horizontal bars at base correspond to Amazonian age provinces (Chew et al., 2010).

B. Carbon isotopes for Blacksburg Formation dolomitic marbles. Range of $\delta^{13}C$ from Blacksburg dolostones (pale yellow overlay) overlaid on C and Sr Cambrian geochemical trends, relative to ages presented here: Pink line: youngest grain (DG-80, Dixon's Gap metacong.) by LA-ICPMS; pink line with error bars: weighted average of six youngest grains, Dixon's Gap metacong.; red line with error bars: ID-TIMS age of youngest grain (DG-26, Dixon's Gap metacong.) analyzed; blue line with error bars: age of granodiorite dikes (KM84-5) intruding base of Blacksburg Formation. Redrafted from Shergold & Cooper, 2004. (Dennis et al, 2012, Dennis & Miller, 2013).

Recognizing the Cambrian Rheic margin of Carolinia in the Kings Mountain terrane

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INTRODUCTION

This trip has a very simple theme: to visit some of the distinctive marker horizons in the Kings Mountain terrane, and discuss them in the context of recent geochronology and isotopic studies. My conclusion based on the data I collected is that the Kings Mountain terrane accumulated on the lower plate of the rifted margin of the Carolina terrane as Carolinia separated from the Paraguan craton of Amazonian Gondwana in the Cambrian. However this was not the hypothesis I started with. My interest in the marker beds of the Kings Mountain belt began when I recognized the manganiferous schist-gondite horizon (Jumping Branch Mn Member of Battleground Formation) in the Croft State Park in the northern part of the Glenn Springs (SC 7.5') quad as part of my Ph.D. field work, just south of the last stop of day one of this trip. My interest was rekindled in Fall 2002 when I heard Paul Hoffman talk for three hours about Snowball Earth during a seminar. The stratigraphy and what were thought to be "good" ages for the Kings Mountain terrane seemed to make them an ideal candidate for testing Snowball Earth hypothesis as a possible explanation for their origin. Recent discoveries of Ediacaran fauna in North Carolina and recognition of Gaskiers cap carbonate in Avalon encouraged me.

I prepared a hypothesis to test a Snowball Earth origin for the Kings Mountain terrane rocks by dating detrital grains separated from the distinctive Battleground Formation conglomerates that lie above and below the manganiferous formation. Additionally I planned a carbon isotope profile for the dolomitic marbles in the Blacksburg Formation. Detrital zircon grain studies are valuable because not only do they provide a maximum age for the formation (i.e., the formation can be no older than the youngest grain), but also they yield a characteristic age spectrum of igneous rocks that were weathered to yield that sediment. The results were surprising. I sampled the lowermost horizon, the Dixon's Gap metaconglomerate, at Dixon's Gap (Stop 1-2) and at Stepp's Gap and the results (n=104, 110) were indistinguishable. 50% of the grains were Cambrian or Ediacaran in age and the remainder were from a variety of Gondwanan Mesoproterozoic age provinces. The youngest grain (of >200) by the laser ablation system at the University of Arizona Laserchron Center was 503.2 ± 9 (1σ). That is a middle middle Cambrian age. It seemed reasonable to pool the youngest six grains from Dixon's Gap and Stepp's Gap and get a weighted average for that population: 512.9 ± 9 Ma (2σ). The results from the Draytonville metaconglomerate (Stop 1-5) 600 m above the Dixon's Gap) were equally surprising. A single grain of >100 yielded an Ediacaran age (606.2 ± 23 Ma, 1σ), and the remainder yielded Mesoproterozoic to Archean ages including a grain 3294 ± 16 Ma. Near the top of the Blacksburg Formation the sandstone at Whitaker Mountain yielded all Mesoproterozoic (Gondwanan) grains. Within the 600 m of section Dixon's Gap and Draytonville a dramatic change in provenance occurred; the only marker bed between those two is the Jumping Branch Manganiferous Member, the finest grained rocks in the entire Battleground-Blacksburg section. I interpreted the Jumping Branch to represent a relative sea level high or transgression between the two conglomeratic horizons.

In recent times carbon isotope stratigraphy has become increasingly refined, and widely used in the correlation of non-fossiliferous carbonate rocks well into the Proterozoic; additionally the interpretation of environmental conditions represented by these data has become very sophisticated. The lower and upper dolomitic marbles of the Blacksburg Formation (Gaffney marble and marble member at Dixon's Branch respectively) seemed to be ripe for this sort of study. Particularly in light of a ≈ 503 Ma (or the 512 ± 9 weighted average) Ma age near the base of the sedimentary Battleground Formation, the exposed dolomitic marbles of the Blacksburg Formation might show a strong (+4 per mil) positive excursion in $\delta^{13}C_{carb}$. This is called the Steptoean Positive Carbon Isotope Excursion (SPICE) and is interpreted to represent a period of extraordinary biologic productivity (photosynthesis) during which atmospheric oxygen may have been as great as 30%. This oxygen concentration is thought to have fueled the Global Ordovician Biodersification Event (GOBE; e.g., Chickamauga Group limestone fauna, Trenton-Black River fauna). SPICE marks the base of the youngest epoch of the Cambrian (Furongian) at ≈ 497 Ma, and is coincident with the Conasuaga-Knox (Copper Ridge) contact at Thorn Hill, TN. I collected about three dozen carbonate samples from the two carbonate members. I discarded samples that showed any graphite or carbonaceous material, and powdered and roasted about 2 dozen for analysis at the University of South Carolina In Bob Thunell's lab. These samples ranged in d13C between 0 — -2, typical of much of Series 2/3 of the Cambrian. In an effort to better bracket the age of deposition of the Blacksburg carbonates, Brent Miller analyzed $^{87}Sr/^{86}Sr$ from ten of the Gaffney marble, marble member at Dixon's Branch samples. The analyses ranged from 0.711 – 0.712 and are interpreted to be diagentically altered.

At this time it was clear to me that the rocks of the Kings Mountain terrane were part of the passive margin of Carolinia as Carolinia rifted from Amazonian Gondwana or more likely the Paraguan craton of Amazonian Gondwana to form the Rheic Ocean. Since 2005, I had participated in IGCP 497: Rheic Ocean, and I had learned the stratigraphies on the Gondwanan side of the Rheic. Furthermore it was clear to me that rocks of Kings Mountain terrane really are their own terrane: they experienced peak metamorphism ca. 323 Ma, in contrast to rocks of the adjacent Charlotte terrane that experienced peak metamorphism 538±5 – 535±5 Ma, the rocks of the Kings Mountain terrane had not even been deposited at the time the Charlotte terrane was metamorphosed, and the Tinsley Bridge fault separates Charlotte terrane rocks from Kings Mountain terrane rocks. Sedimentary rocks of the Battleground Formation up to the Jumping Branch Manganiferous Member represent the Rheic rift, and above the Jumping Branch the Rheic drift. Carbonate rocks of the Blacksburg Formation indicate platform sedimentation on the Rheic drift margin of Carolinia. All this occurred prior to late Cambrian time (Furongian).

November 2012 I organized a GSA field trip with John Shervais and Dennis LaPoint to look at rocks of the western Carolina terrane when the Annual Meeting was held in Charlotte. Almost all of the stops we made on Day One of that trip will be repeated on this trip. Brent Miller, Texas A&M University, participated on that trip and at the end of the first day offered to date the youngest grains from the Dixon's Gap and Stepp's Gap mounts by the Isotope Dilution –Thermal Ionization Mass Spectrometry (ID-TIMS) method at his lab at Texas A&M. His results were consistently older than the laser ablation ages acquired at the Arizona Laserchron center, and he determined that the youngest grain has an age of 522.43 ± 3.01 Ma (2σ). This is about the same age as the Cambrian Terreneuvian-Series 2 (earliest trilobites) boundary. Earlier Jim Hibbard had told me that he and Brent Miller had collected samples of granodiorite dikes that cut trondjhemite that cuts the lowermost units of the Blacksburg Formation from core from the Kings Mountain gold mine. Brent separated zircons from these dikes and analyzed them by ID-TIMS, and they yielded an age of 518.26 ± 0.68 Ma (2σ).

Thus we have pretty good age constraints on the sedimentary rocks of the Kings Mountain terrane: they are no older than 522.43 ± 3.01 Ma (2σ, youngest detrital grain of the Dixon's Gap metaconglomerate member, Dennis and Miller, 2013). Granodiorite dikes that cut plutons that cut the base of the Blacksburg Formation are 518.3 ± 0.7 Ma (2σ, Dennis and Miller, 2013). $\delta^{13}C$ measurements of carbonate from the Gaffney marble and the marble member of Dixon's Branch support the interpretation that the Blacksburg Formation is no younger than Cambrian Series 3 ($> \approx 497$ Ma). Thus 1575-2275 m of Battleground Formation accumulated in as few as 480 ka or as long as 7.9 Ma, or at a rate between 200 m/Ma and 4.8 km/Ma. 2150-2680 m thick Blacksburg Formation accumulated in less than 20 Ma (ca. 518 – ca. 497).

There are two features to note regarding provenance studies of the Battleground and Blackburg Formations. There is a dramatic change in provenance between the Dixon's Gap metaconglomerate and units above and including the Draytonville metaconglomerate. Dixon's Gap metaconglomerate comprises 50% Carolinian grains (peaks at ca. 540 and 615 Ma) and the balance Meso- and Paleoproterozoic grains. 625 m above Dixon's Gap metaconglomerate lies the Draytonville metaconglomerate. A single detrital zircon (n=102) yields an Ediacaran age (608 ± 11 Ma, 1σ). The remainder are Mesoproterozoic to Archean in age. A sample analyzed from the Whitaker Mountain metasandstone near the top of the Blacksburg Formation is composed of Proterozoic grains no younger than 927.9 ± 37.4 Ma (1σ). Secondly all samples are dominated by zircon populations ca 1200 Ma and 1.55-1.3 Ga. These populations are complemented by additional populations ca. 1780 Ma and 2 Ga. These populations suggest proximity to the Amazonian craton and specifically the Paraguan Craton (e.g., Chew et al, 2010). Dennis and Baker (2012) suggested the transition between Dixon's Gap and Draytonville metaconglomerates marked subsidence accompanying loss of subcrustal lithosphere and the burial of locally derived Carolinian source material. The transition is marked by a transgression at the regionally extensive Jumping Branch Manganiferous Member. Dennis and Baker (2012) interpreted the Jumping Branch Manganiferous Member to mark the transition from rift to drift on Cambrian Carolinian Rheic margin.

Remarkably, the youngest rocks in the Carolina superterrane are the only ones that contain a diagnostic Gondwanan fauna. These are the Middle Cambrian rocks of the Asbill Pond Formation (Secor and Snoke, 2002). These rocks belong to the *P. atavus* zone of the Drumian (504.5-503 Ma). The peri-Gondwanan trilobite fauna includes nine genera and a dozen species. The trilobite-bearing mudstone lies in angular unconformity above 550 Ma meta-andesites of the Persimmon Fork Formation and overlying conformable Emory Formation. Samson et al reported the youngest detrital grain in the Emory Formation to be ca. 537 Ma. Thus the entire Kings Mountain terrane sedimentary section was deposited in the time represented by the angular unconformity beneath the Asbill Pond Formation, and these two sedimentary sections represent the youngest stratified rocks described from Carolinia. Both were deposited while Carolinia was proximal to the Paraguan Craton of Amazonia. The earliest (?) Rheic ocean floor crust may be in the Ellsworth Belt in the Gander terrane where pillow basalts with MORB chemistries are intercalated with the Ellsworth Schist (508.6 ± 0.8 Ma, 2σ) and Castine volcanics (503.5 ± 2.5 Ma, 2σ). What can account for the differences in timing and stratigraphy between the Asbill Pond Formation and Kings Mountain terrane? I interpret it to be the contrast in setting between the lower plate (KMT) and the upper plate (Asbill Pond Formation) during asymmetric rifting that separated Carolinia from Amazonia.

Finally, the Kings Mountain terrane has a unique feature among Carolinian, Ganderian, and Avalonian syn-Rheic rift-drift strata. Going up section it loses its Carolinian provenance, and sediments seem to be derived from the Paraguan craton supplemented by material from other Amazonian age provinces. Dennis (2015) and Dennis and others (submitted) suggest that this is a consequence of contrasting upper- and lower plate stratigraphies during asymmetric rifting. The Kings Mountain terrane accumulated in the lower plate across the asymmetric detachment from most of the Carolina terrane. The Kings Mountain terrane was separated from the Asbill Pond Formation in the upper plate by either a detachment, a transfer or accommodation zone or both. Furthermore we interpret that we can locate the Kings Mountain terrane in the footwall of the detachment relative to the transition to Amazonian basement that is not basement to Carolinia and the Furongian (Late Cambrian) ridge incision that separated the Kings Mountain terrane from Amazonia. Ultimately ridge incision transferred lower plate Kings Mountain terrane to Carolinia. Carboniferous terrane dispersal is interpreted to be responsible for the current juxtaposition of the Kings Mountain terrane with the Charlotte terrane.

Acknowledgements: This work was supported by the SCANA Chair in Physical Sciences, University of South Carolina Aiken, a Magellan Scholar Award (to Matt Baker), and the University of South Carolina. I am very fortunate to work with Brent Miller, Jim Hibbard, Bob Thunell, and Eric Tappa. I gratefully acknowledge NSF EAR-1032156 for support of the Arizona Laserchron Center; while in Tucson, Mark Pecha, Clayton Loehn, and George Gehrels assisted in this study.

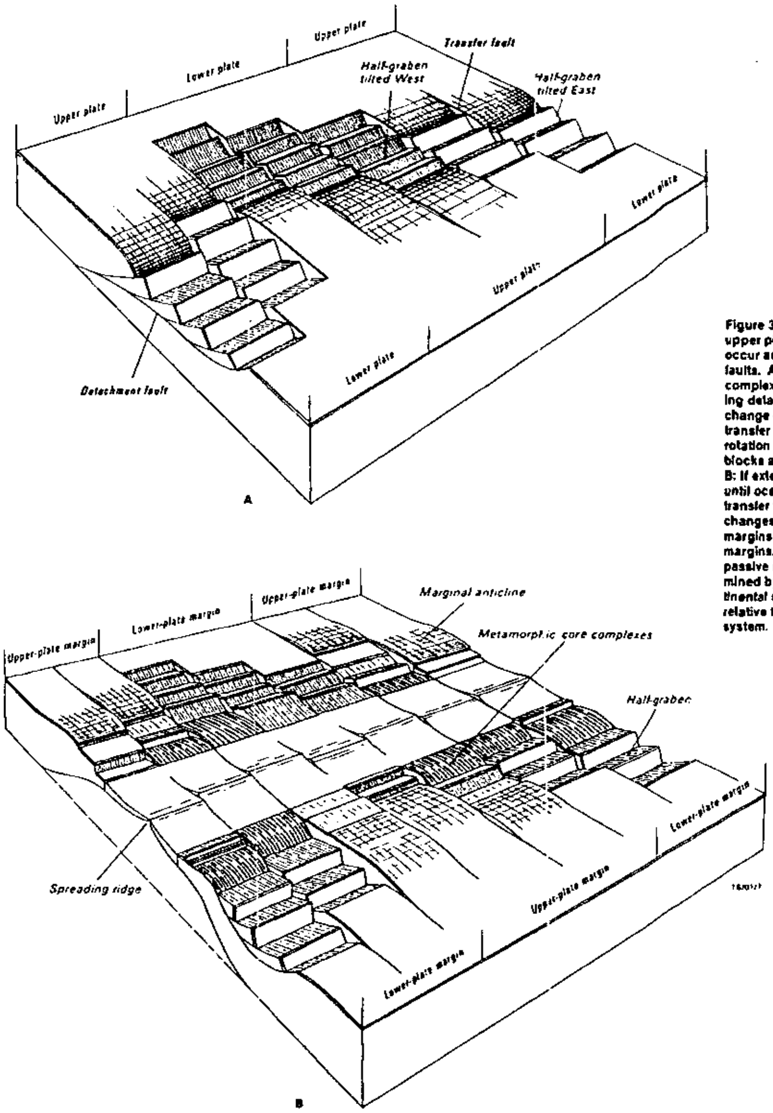

Figure 3. Changes from upper plate to lower plate occur across transfer faults. A: Half-graben complex. When underlying detachment faults change dip across transfer faults, sense of rotation of overlying tilt blocks also changes. B: If extension continues until ocean basin forms, transfer faults mark changes from *upper-plate* margins to *lower-plate* margins. Architecture of passive margin is determined by where final continental separation began relative to detachment system.

Figure from Lister et al. (1986) contrasting structural style and stratigraphy in lower plate and upper plate passive margin settings when the margin forms as a result of an asymmetric detachment. The differences observed between the Kings Mountain terrane and the Asbill Pond Formation may be a consequence of formation in a lower plate or upper plate setting respectively.

INTERNATIONAL CHRONOSTRATIGRAPHIC CHART

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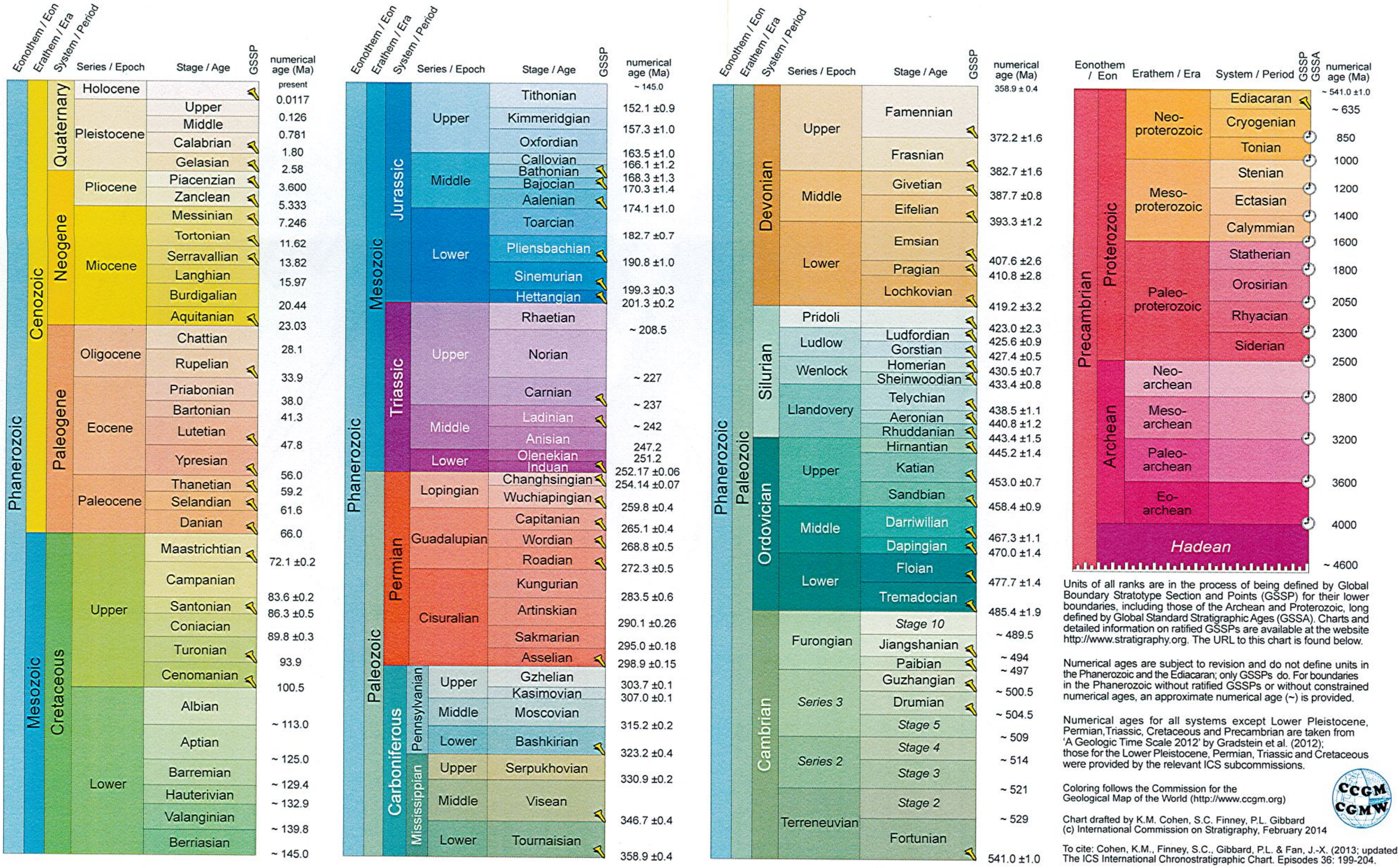

Eonothem / Eon	Erathem / Era	System / Period	Series / Epoch	Stage / Age	GSSP	numerical age (Ma)
						present
Phanerozoic	Cenozoic	Quaternary	Holocene		▼	0.0117
			Pleistocene	Upper		0.126
				Middle		0.781
				Calabrian	▼	1.80
				Gelasian	▼	2.58
		Neogene	Pliocene	Piacenzian	▼	3.600
				Zanclean	▼	5.333
			Miocene	Messinian	▼	7.246
				Tortonian	▼	11.62
				Serravallian	▼	13.82
				Langhian		15.97
				Burdigalian		20.44
				Aquitanian	▼	23.03
		Paleogene	Oligocene	Chattian		28.1
				Rupelian	▼	33.9
			Eocene	Priabonian		38.0
				Bartonian		41.3
				Lutetian	▼	47.8
				Ypresian	▼	56.0
			Paleocene	Thanetian	▼	59.2
				Selandian	▼	61.6
				Danian	▼	66.0
	Mesozoic	Cretaceous	Upper	Maastrichtian	▼	72.1 ±0.2
				Campanian		83.6 ±0.2
				Santonian	▼	86.3 ±0.5
				Coniacian		89.8 ±0.3
				Turonian	▼	93.9
				Cenomanian	▼	100.5
			Lower	Albian		~ 113.0
				Aptian		~ 125.0
				Barremian		~ 129.4
				Hauterivian		~ 132.9
				Valanginian		~ 139.8
				Berriasian		~ 145.0

Eonothem / Eon	Erathem / Era	System / Period		Series / Epoch	Stage / Age	GSSP	numerical age (Ma)
							~ 145.0
Phanerozoic	Mesozoic	Jurassic		Upper	Tithonian		152.1 ±0.9
					Kimmeridgian		157.3 ±1.0
					Oxfordian		163.5 ±1.0
				Middle	Callovian		166.1 ±1.2
					Bathonian	▼	168.3 ±1.3
					Bajocian	▼	170.3 ±1.4
					Aalenian	▼	174.1 ±1.0
				Lower	Toarcian		182.7 ±0.7
					Pliensbachian	▼	190.8 ±1.0
					Sinemurian	▼	199.3 ±0.3
					Hettangian	▼	201.3 ±0.2
		Triassic		Upper	Rhaetian		~ 208.5
					Norian		~ 227
					Carnian	▼	~ 237
				Middle	Ladinian	▼	~ 242
					Anisian		247.2
				Lower	Olenekian		251.2
					Induan	▼	252.17 ±0.06
	Paleozoic	Permian		Lopingian	Changhsingian	▼	254.14 ±0.07
					Wuchiapingian	▼	259.8 ±0.4
				Guadalupian	Capitanian	▼	265.1 ±0.4
					Wordian	▼	268.8 ±0.5
					Roadian	▼	272.3 ±0.5
				Cisuralian	Kungurian		283.5 ±0.6
					Artinskian		290.1 ±0.26
					Sakmarian		295.0 ±0.18
					Asselian	▼	298.9 ±0.15
		Carboniferous	Pennsylvanian	Upper	Gzhelian		303.7 ±0.1
					Kasimovian		307.0 ±0.1
				Middle	Moscovian		315.2 ±0.2
				Lower	Bashkirian	▼	323.2 ±0.4
			Mississippian	Upper	Serpukhovian		330.9 ±0.2
				Middle	Visean	▼	346.7 ±0.4
				Lower	Tournaisian	▼	358.9 ±0.4

Eonothem / Eon	Erathem / Era	System / Period	Series / Epoch	Stage / Age	GSSP	numerical age (Ma)
						358.9 ± 0.4
Phanerozoic	Paleozoic	Devonian	Upper	Famennian	▼	372.2 ±1.6
				Frasnian	▼	382.7 ±1.6
			Middle	Givetian	▼	387.7 ±0.8
				Eifelian	▼	393.3 ±1.2
			Lower	Emsian	▼	407.6 ±2.6
				Pragian	▼	410.8 ±2.8
				Lochkovian	▼	419.2 ±3.2
		Silurian	Pridoli		▼	423.0 ±2.3
			Ludlow	Ludfordian	▼	425.6 ±0.9
				Gorstian	▼	427.4 ±0.5
			Wenlock	Homerian	▼	430.5 ±0.7
				Sheinwoodian	▼	433.4 ±0.8
			Llandovery	Telychian	▼	438.5 ±1.1
				Aeronian	▼	440.8 ±1.2
				Rhuddanian	▼	443.4 ±1.5
		Ordovician	Upper	Hirnantian	▼	445.2 ±1.4
				Katian	▼	453.0 ±0.7
				Sandbian	▼	458.4 ±0.9
			Middle	Darriwilian	▼	467.3 ±1.1
				Dapingian	▼	470.0 ±1.4
			Lower	Floian	▼	477.7 ±1.4
				Tremadocian	▼	485.4 ±1.9
		Cambrian	Furongian	*Stage 10*		~ 489.5
				Jiangshanian	▼	~ 494
				Paibian	▼	~ 497
			Series 3	Guzhangian	▼	~ 500.5
				Drumian	▼	~ 504.5
				Stage 5		~ 509
			Series 2	*Stage 4*		~ 514
				Stage 3		~ 521
			Terreneuvian	*Stage 2*		~ 529
				Fortunian	▼	541.0 ±1.0

Eonothem / Eon		Erathem / Era	System / Period	GSSP GSSA	numerical age (Ma)
					~ 541.0 ±1.0
Precambrian	Proterozoic	Neoproterozoic	Ediacaran	▼	~ 635
			Cryogenian	◷	850
			Tonian	◷	1000
		Mesoproterozoic	Stenian	◷	1200
			Ectasian	◷	1400
			Calymmian	◷	1600
		Paleoproterozoic	Statherian	◷	1800
			Orosirian	◷	2050
			Rhyacian	◷	2300
			Siderian	◷	2500
	Archean	Neoarchean		◷	2800
		Mesoarchean		◷	3200
		Paleoarchean		◷	3600
		Eoarchean		◷	4000
	Hadean				~ 4600

Units of all ranks are in the process of being defined by Global Boundary Stratotype Section and Points (GSSP) for their lower boundaries, including those of the Archean and Proterozoic, long defined by Global Standard Stratigraphic Ages (GSSA). Charts and detailed information on ratified GSSPs are available at the website http://www.stratigraphy.org. The URL to this chart is found below.

Numerical ages are subject to revision and do not define units in the Phanerozoic and the Ediacaran; only GSSPs do. For boundaries in the Phanerozoic without ratified GSSPs or without constrained numerical ages, an approximate numerical age (~) is provided.

Numerical ages for all systems except Lower Pleistocene, Permian, Triassic, Cretaceous and Precambrian are taken from 'A Geologic Time Scale 2012' by Gradstein et al. (2012); those for the Lower Pleistocene, Permian, Triassic and Cretaceous were provided by the relevant ICS subcommissions.

Coloring follows the Commission for the Geological Map of the World (http://www.ccgm.org)

Chart drafted by K.M. Cohen, S.C. Finney, P.L. Gibbard

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URL: http://www.stratigraphy.org/ICSchart/ChronostratChart2014-02.pdf

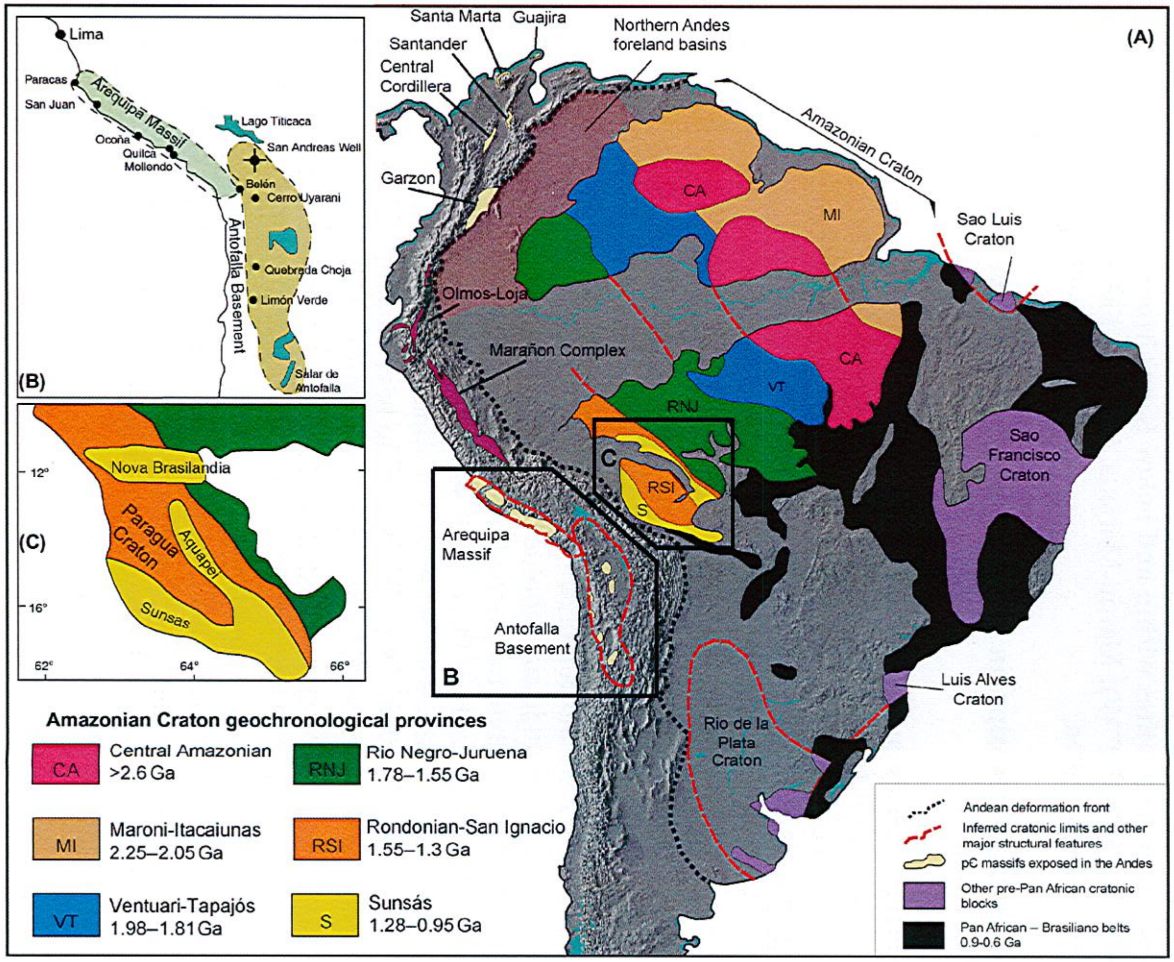


Figure 1. (A) Regional geological map of South America displaying the geochronological provinces of the Amazonian Craton and Andean basement inliers. Modified from Cordani et al. (2009) and Cordani et al. (2000). (B) Main basement inliers of the Central Andes (modified from Ramos 2008). (C) Map of the geology of southwest Amazonia from Elming et al. (2009).

Amazonian Age Provinces, Chew et al., 2010.

DAY 1 OVERVIEW

This day will look at some distinctive stratigraphic members of the Kings Mountain terrane, and will review the evidence that suggests that the terrane represents the Rheic trailing margin as Carolinia rifted from the Amazonian craton. All but stops but Stop 7 were visited on Day 1 of Dennis et al (2012).

Stop 1-1 Spodumene pegmatites within and below Kings Mountain shear zone (35°20'15.10"N 81°18'56.72"W): Martin-Marietta, formerly FMC Lithium Hallman-Beam mine, Bessemer City, NC.

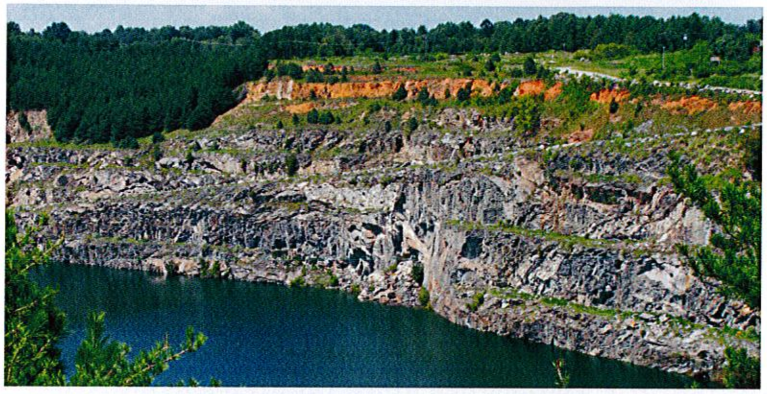
Purpose: To observe Mississippian (Visean) age dikes that have historically been a major lithium resource.

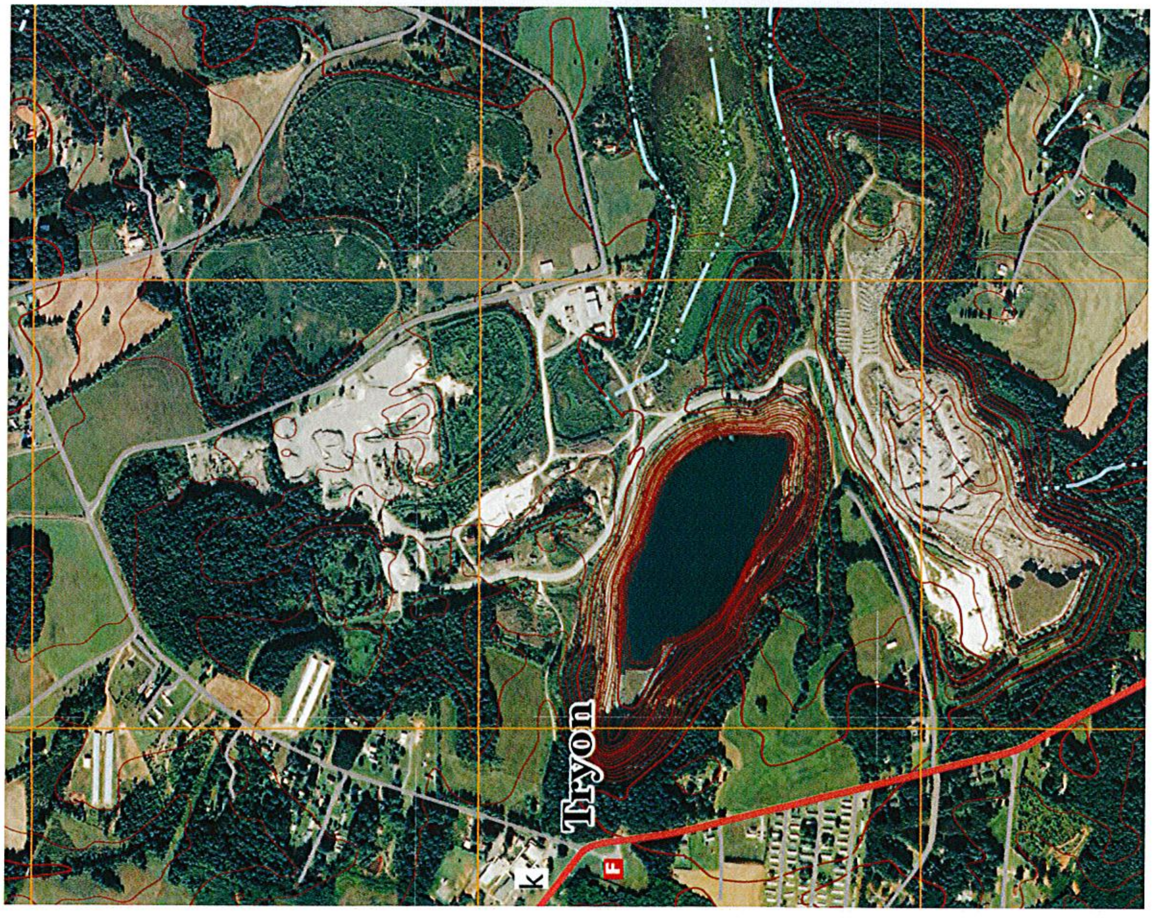
Considerable recent interest in lithium as a battery material and ongoing lithium manufacture in the Kings Mountain area have led to the inclusion of this stop even as these dikes are not central to the theme of this trip. Some of the following discussion is abstracted from the work of Horton et al. (1981, their stop 4 ((35°13'21.52"N 81°21'53"W) now Rockwell Lithium, formerly Chemetall-Foote mine, Kings Mountain, NC), and Kesler, 1961.

Spodumene pegmatites have been recognized in the Kings Mountain area since Graton (1906). The dikes make up a heterogeneous zone 300 m to 1 km x 43 km beneath the central Piedmont shear zone and comprise the tin-spodumene belt of the Carolinas (e.g., Kesler, 1942). The dikes intrude amphibolite and phyllonite schist of the Cat Square terrane. These spodumene-albite (or microcline) -quartz pegmatites contain up to 20% spodumene. There are hundreds of these dikes, and most of them are ≤ 3 m thick. The largest, thickest, and longest dikes are emplaced in joints and range in size from 8 m thick x 150 m long to 130 m x 1000 m. They are thought to have been intruded in a nearly solid state and are variably mylonitized or sheared, and thus may provide a constraint on earliest motion on the Kings Mountain shear zone. There is a relationship between the Cherryville granite and the spodumene pegmatites. Field observations support the following sequence: spodumene pegmatites intruded first, followed by the granitic dikes of Cherryville granite, with the Cherryville intruding last. The spodumene dikes yield an Rb-Sr age of 340±10 Ma (2σ) (Kish and Fullagar, 1996; cf. 352±10 Ma, Kish, 1977). Granitic dikes associated with the Cherryville granite yield whole-rock Rb-Sr age at 341±40 Ma (2σ); the Rb-Sr whole rock age of the Cherryville granite is 351±20 Ma (Kish and Fullagar, 1996).

According to Stewart (1978), the spodumene pegmatites are anatectic melts of lithium-rich metasedimentary rocks (cf. Salar de Uyuni, Bolivia).

Spodumene xls from Hallman-Beam mine. Li pegmatites cut Cat Square paragneiss.

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Stop 1-2: Dixon Gap metaconglomerate member of Battleground Formation, trail from Boulders Access Area, Crowders Mountain State Park, NC. (35°10'15.04"N 81°21'56.00"W to 35°10'23.42"N 81°21'45.26"W): The outcrops are located on the Ridgeline trail between the Boulders Access Visitor Center, Crowders Mountain State Park, and where the trail crosses Bethlehem Road (NC; becomes Love Valley Road in SC). The outcrops are located in the state park, and collecting is possible only with a permit.

Purpose: To observe a Late Middle Cambrian rift-facies coarse conglomeratic horizon in the Battleground Formation deposited above highly altered volcanic rocks.

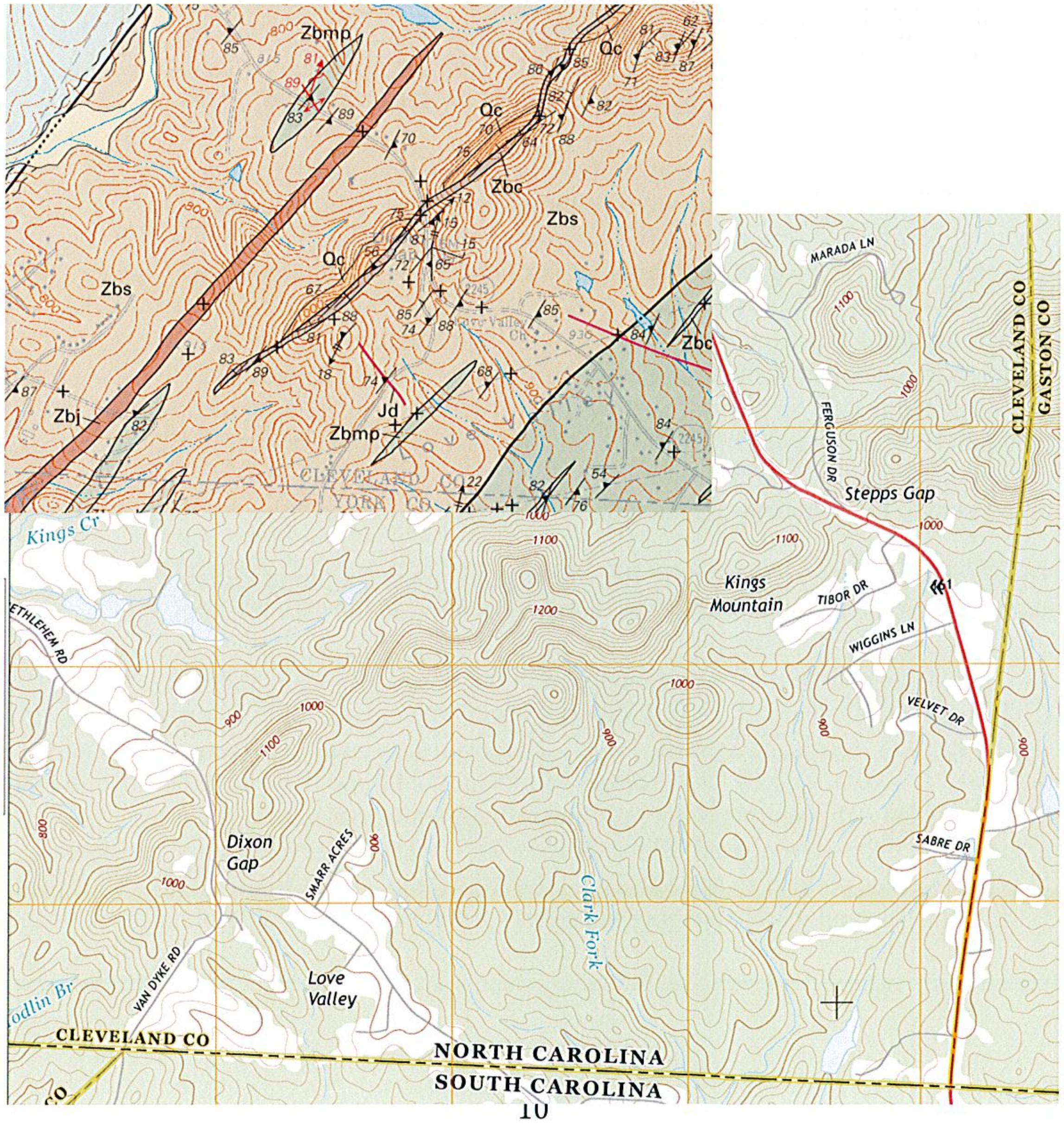
DESCRIPTION: Along this brief hike we will observe a well-known metaconglomerate member of the Battleground Formation (Horton, 2008). Quartz pebble clasts (up to 1 cm x 2 cm x 4 cm) are abundant, and lithic clasts are also observed. These rocks lie about 850 m above an interpreted nonconformity with the mottled phyllitic metatuff (Zbmp of Horton, 2008) and the volcanic "basement" units in the lower part of the Battleground Formation. The upper, epiclastic portion of the Battleground Formation is dominated by quartz sericite schist and phyllite (Zbs of Horton, 2008), and this is the unit in which the marker beds are found.

Dennis and Baker (2012) and Dennis and Miller (2013) report the results of detrital zircon studies from a metasandstone horizon collected along this hike. There are three significant results from data collected here. 1) More than 15% of (104) analyses were younger than 580 Ma, thus overlying units appear to post-date the (580 Ma) Gaskiers glacial event (cf. Dennis, 2009). 2) The youngest grains from Dixon's Gap (and correlative rocks at Stepp's Gap) analyzed at the Arizona Laserchron Center were removed from the mount, and analyzed by ID-TIMS at Texas A&M University (Dennis and Miller, 2013). The youngest of these grains yields an age of 522.43 ± 3.01 (2σ) Ma. Thus undivided metadacite and metatrondhjemite within the Battleground Formation and metatrondhjemite and hornblende gneiss within the Blacksburg Formation must be no older than Cambrian Series 2. Additionally, the metamorphic fabric observed in the Blacksburg Formation must be younger the metamorphic fabric in rocks of the Charlotte terrane, immediately south, earliest Cambrian in age (e.g., Dennis and Wright, 1997). Thus the Kings Mountain sequence of Horton (2008) is a fault-bounded terrane with a distinct history that differs from adjacent terranes (Charlotte, Cat Square); the Kings Mountain terrane is interpreted as belonging to the peri-Gondwanan Carolina superterrane or Carolinia. 3) Almost 40% of the analyzed grains were Ediacaran (635-542 Ma) in age, with almost all the remaining grains interpreted to correspond to Rio Negro-Jururena (1.8-1.55 Ga), Rondonian-San Ignacio (1.5-1.3 Ma), and Sunsas (1.25-0.9 Ga) age provinces of the Amazonian craton.

The Dixon's Gap member is also present at Stepp's Gap 5 km to the east, also within the Crowder's Mountain Park. Dennis and Baker (2012) report results of detrital zircon study from a metaconglomerate at Stepp's Gap. 1) About 10% of analyses were younger than 580 Ma. 2) Almost 40% of analyzed grains were Ediacaran in age, with almost all the remaining grains corresponding to Rio Negro-Jururena (1.8-1.55 Ga), Rondonian-San Ignacio (1.5-1.3 Ma), and Sunsas (1.25-0.9 Ga) age provinces of the Amazonian craton.

Dennis and Baker (2012) interpreted the rocks of the Dixon's Gap metaconglomerate to have been deposited during the opening of the Rheic Ocean, as Carolinia rifted away from the Amazonian craton. The Mesoproterozoic components of the age spectrum of Dixon's Gap metaconglomerate are comparable to spectra reported by Samson et al. (2001) and Pollock et al. (2010) for the Richtex Formation and Tillery Formation respectively. The Middle Cambrian (Drumian, *P. atavus* zone, 504.5-503 Ma) peri-Gondwanan fossil-bearing Asbill Pond Formation of the Carolina Slate Belt (Secor and Snoke, 2002) is younger than the Blacksburg Formation of the Kings Mountain terrane according to the data of Dennis and Miller (2012). The Asbill Pond Formation overlies in angular unconformity epiclastic rocks of the Emory Formation (no older than 537 Ma), which conformably overlies 550 Ma Persimmon Fork Formation metavolcanic rocks.

Geologic map insets taken from Horton (2008) unless otherwise noted.



Stop 1-3: Marble member at Dixon's Branch of Blacksburg Formation, Vulcan Quarry, Blacksburg, SC. (35°9'52"N 81°25'53"W): Enter Vulcan property from Mill Creek Road, north of Antioch Road.

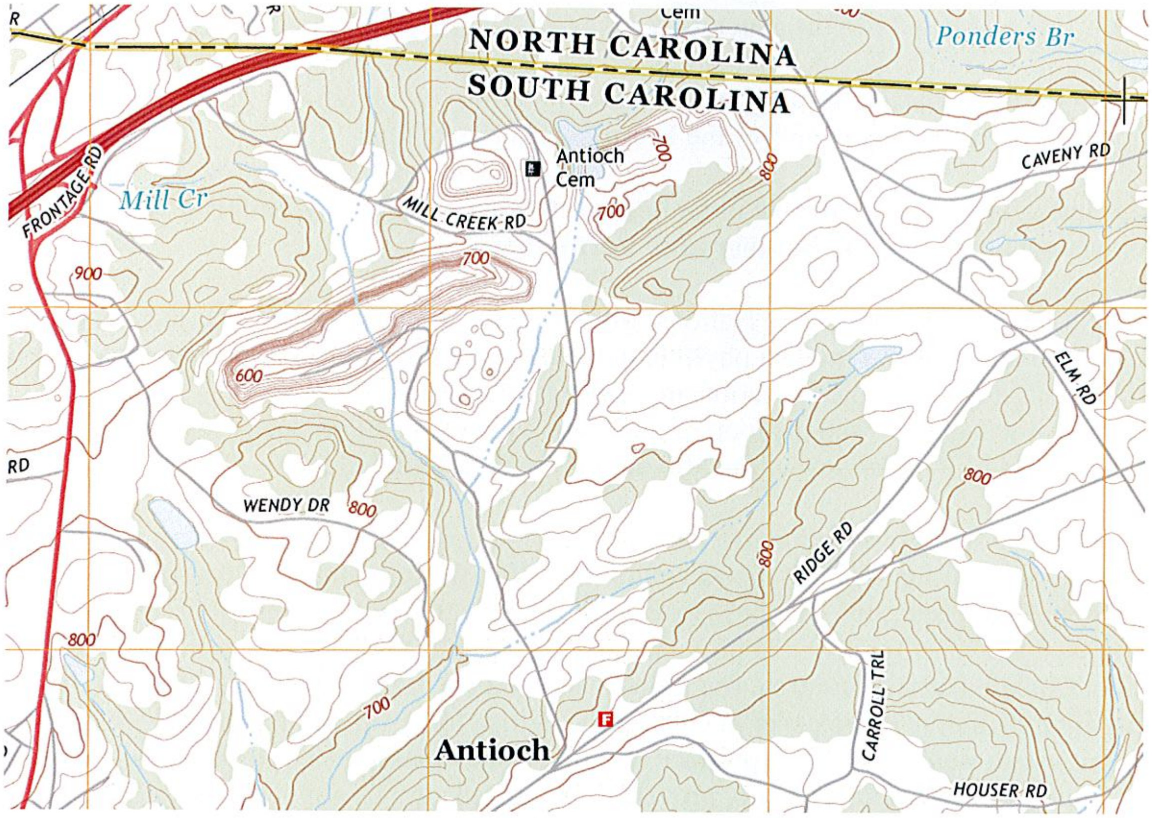
Purpose: To observe a quarry exposure of the upper dolomitic marble within Blacksburg Formation near the top of the preserved Carolinian Rheic drift sequence, nominally 3100-3700 m above the Dixon's Gap metaconglomerate member of the Battleground Formation (Stop 1-2). These rocks lie 2150 m above the base of the Blackburg Formation and about 600 m from the top of the formation.

DESCRIPTION: At this location the upper carbonate unit (≈ 100 m) of the Blacksburg Formation can be observed. There are some conspicuous amphibolitic horizons within this unit. Some of the rocks that are seen here appear to be less highly metamorphosed than others, and some appear to show "algal" laminations. In the currently active area of the quarry the unit dips steeply to the northwest, and there is evidence of folding on the scale of several meters. These dolomitic marbles lie nominally 3100-3700 m above the Dixon's Gap metaconglomerate and must have been deposited after 518.26 ± 0.68 Ma (Dennis and Miller, 2013). These rocks are the youngest stratified rocks that will be visited on this trip and are among the youngest in the Kings Mountain terrane.

Dennis et al. (2012) report the results of a $\delta^{13}C$ profile prepared from sampling this quarry. Samples to be analyzed were neither graphitic or carbonaceous, were roasted for 1 hour at 380°C, and reacted with H2O2 prior to analysis. Samples yielded d13C values between -2 and 0, typical of Cambrian Series 2 and 3 values (Shergold and Cooper, 2004, Peng et al., 2012). The samples do not show evidence of SPICE (Steptoean Positive Carbon Isotope Excursion, up to +4 d13C, e.g., Saltzmann et al.) and these rocks are interpreted to be older than Furongian (pre- 497 Ma, Late Cambrian). These rocks were also analyzed from $^{87}Sr/^{86}Sr$ at Texas A&M University in an effort to identify the pronounced Sr ratio declivity (0.7089 – 0.7094) that begins in the Drumian and continues through the Furongian. These samples yielded 87Sr/86/Sr between 0.711 - 0.712, and are interpreted to be diagenetically altered.

These rocks are interpreted to have been deposited on the Carolinian Rheic drift margin and represent the development of a carbonate platform on the Carolinian margin.

Two dolomitic marble horizons are mapped in the Kings Mountain and Grover 7.5' quads (Horton, 2008); the base of the Blacksburg Formation contains a third, lowermost marble (LaPoint, 1995; Keith and Sterrett, 1931). The lowermost marble is recognized and described from cores taken for the Kings Mountain gold mine (LaPoint, 1995; Keith and Sterrett, 1931). This marble is cut by a metatrondhjemite that in turn is cut by granodiorite dikes (Dennis and Miller, 2013). An ID-TIMS age of zircons separated from these dikes yielded an age 518.26 ± 0.68 Ma (Dennis and Miller, 2013). Thus the Gaffney marble and marble member at Dixon's Branch can be no older than ca. 518 Ma.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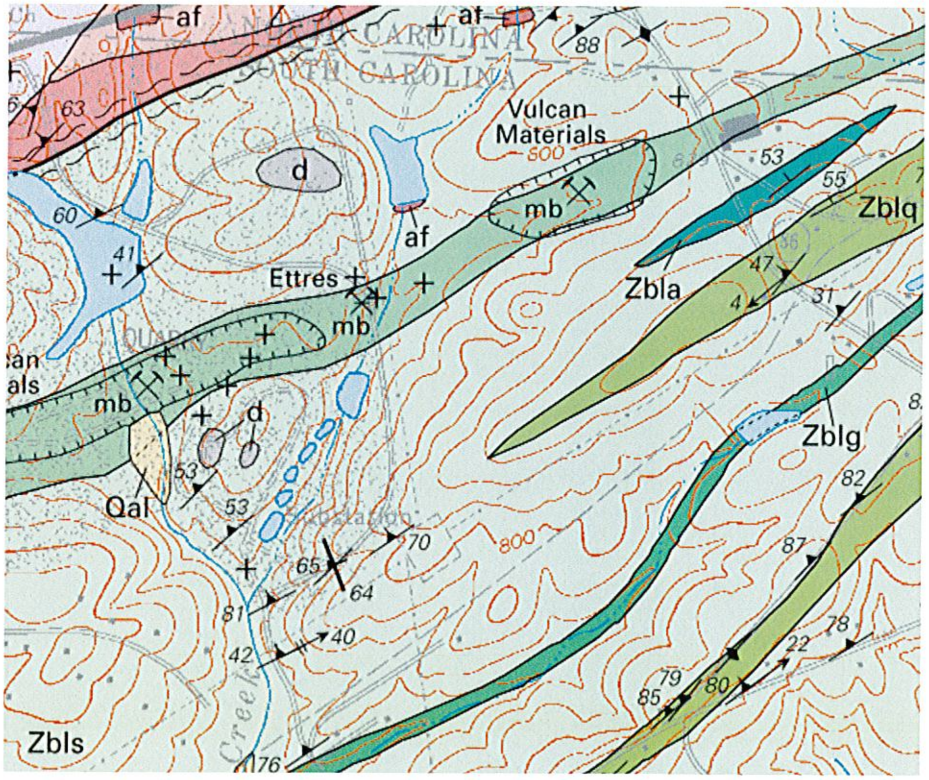
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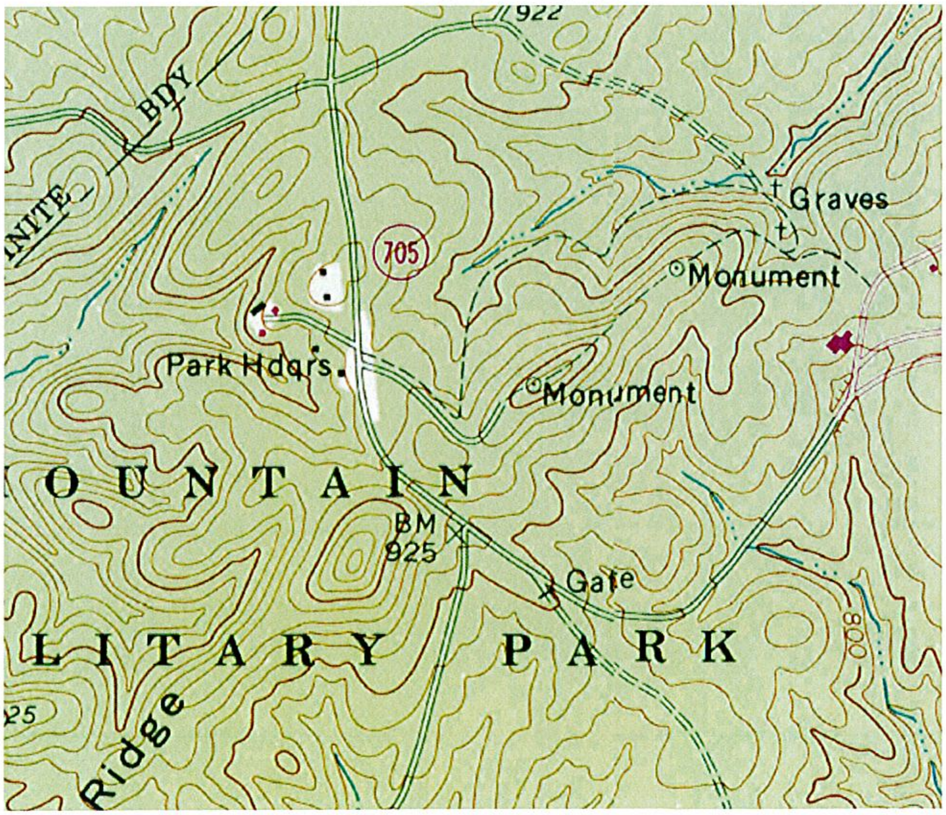
Zbls
76

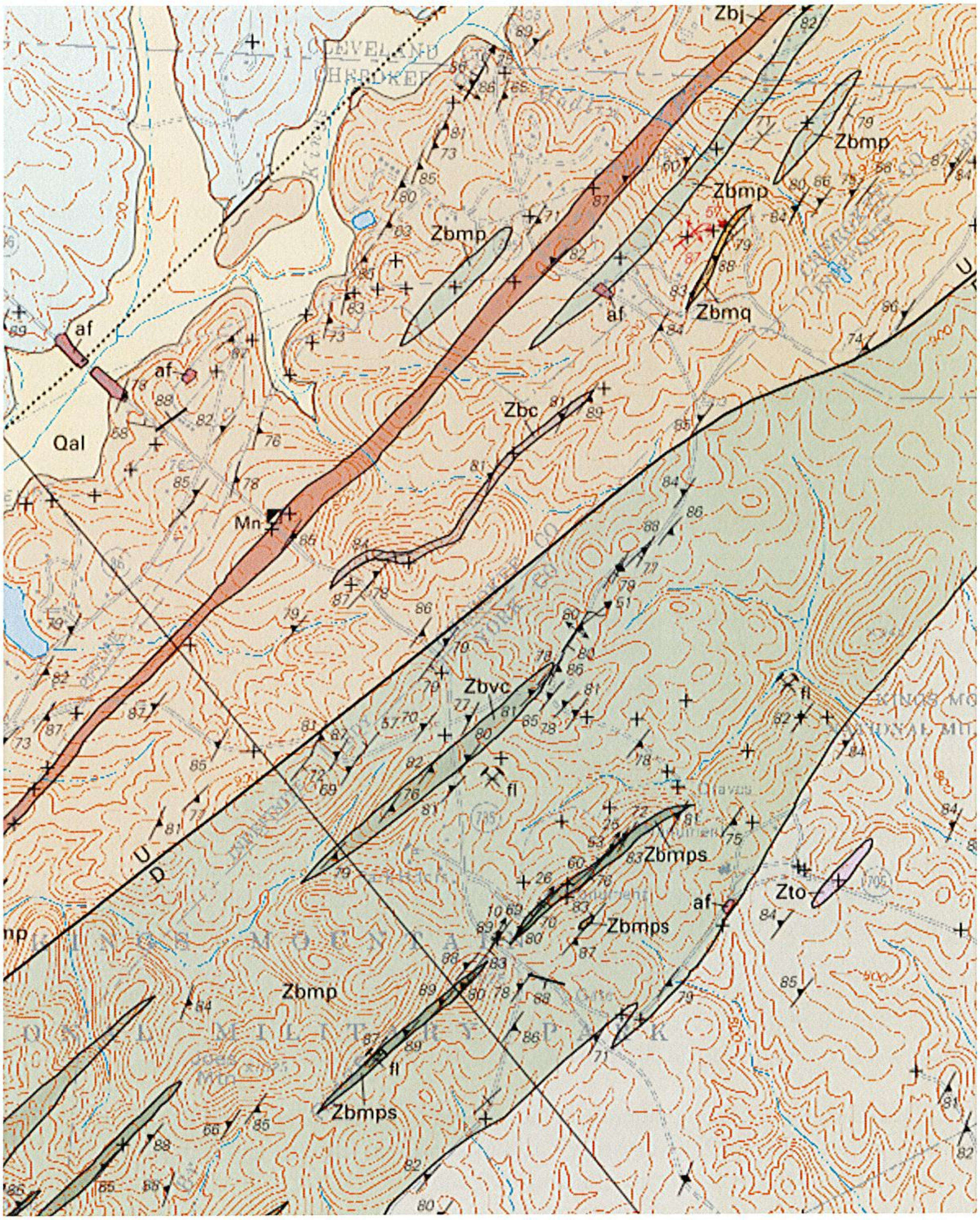
Stop 1-4L: Mottled phyllitic metatuff of the Battleground Formation. (35°08'29.0"N 81°22'35.7"W) The Kings Mountain National Military Park visitors center is located in South Carolina north of Battleground Road (SC SR-46-705; Highway 216) approximately 3.1 miles south of the North Carolina state line.

Purpose: To observe volcanic units interpreted to conformably underlie the upper, epiclastic portion of the Battleground Formation.

Lunch Stop – Kings Mountain National Military Park Visitors Center. Our lunch stop is a good area to observe mottled phyllitic metatuff of the Battleground Formation on which the epiclastic parts of the formation are interpreted to conformably overlie. Additionally there is a self-guided walking loop of the Kings Mountain battlefield, a very good museum and film overview of this Revolutionary War battlefield.

The battle of Kings Mountain, October 7, 1780, was fought entirely by Americans, and is considered a turning point in the Revolutionary War. Colonial frontiersmen from Virginia, Tennessee, the Carolinas and Georgia, led by Colonel Campbell of Virginia defeated a loyalist force of 125 provincial rangers and 1000 Carolina tory militia led by Scot Colonel Patrick Ferguson.The military importance of this battle was described by Sir Henry Clinton, commander in chief of the British forces in North America, as "an event which was immediately productive of the worst Consequences to the King's affairs in South Carolina, and unhappily proved the First Link of a Chain of Evils that followed each other in regular succession until they at last end in the total loss of America." [adapted from the nomination form to list this area on the National Register of Historic Places, March 17, 1976.]

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CLEVELAND
CHEROKEE
KINGS MOUNTAIN
NATIONAL MILITARY PARK

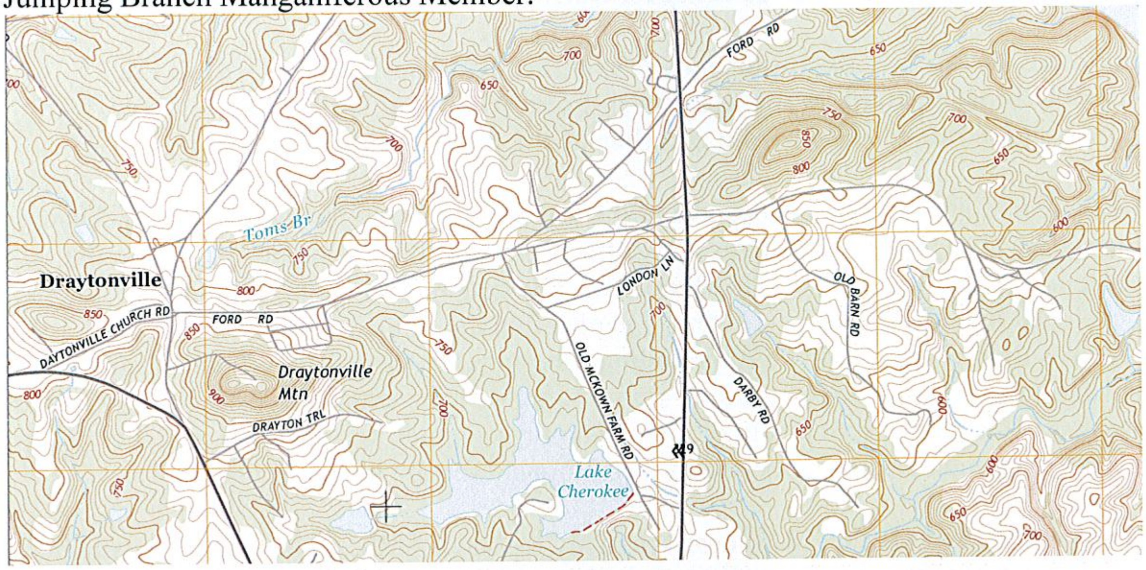
Stop 1-5: Draytonville metaconglomerate at Mountain Top Road, Draytonville, SC. (35°2’47.45”N 81°35’28.07”W): Draytonville is accessed by Highway 105 (Wilkinsville Highway), SE of Gaffney, SC. Mountain Top Road is less than 0.2 mile north of the intersection of Draytonville Road and Highway 105. Private residence: please request permission before visiting.

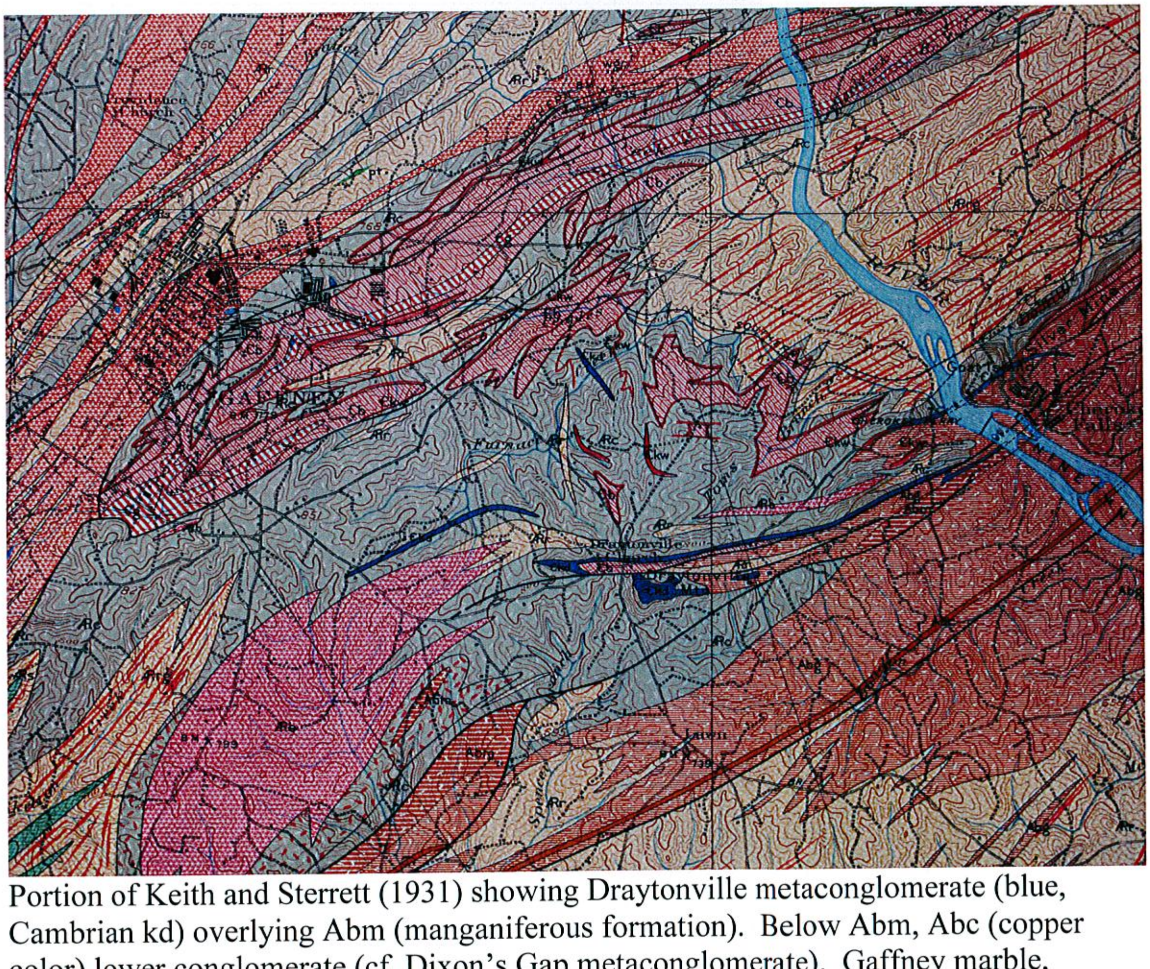
Purpose: To observe the uppermost conglomerate in the Battleground Formation, at or above the Rheic rift-drift transition.

DESCRIPTION: Quartz clasts as large as 6cm x 6cm x 12cm are found here. Several studies have been made on these metaconglomerates (France and Brown, 1981; Hatcher and Morgan, 1981). Dennis and Baker (2012) report the results of a detrital zircon study from this location. Out of 102 grains analyzed, a single grain was reported with an age of 607.8 ± 17.4 Ma (1s); the next oldest grain yields an age of 906.3 ± 32.6 Ma. These rocks are nominally 625 m stratigraphically above the Dixon’s Gap metaconglomerate member, 250 m above the Jumping Branch Manganiferous Member and are 750 m below the top of the Battleground Formation.

More than 75% of the Draytonville zircon grains appear to belong to Sunsas (1.25-0.9 Ga; 46%) and Rondonian-San Ignacio (1.5-1.3 Ga; >30%) age provinces of the Western Amazonian craton, or perhaps more specifically the Paraguan craton (e.g, Chew, . Another 10 percent may belong the the Eastern Amazonian Craton: Maroni – Itacaiunas age province (2.2-1.95 Ga, 7%) and 3% of grains > 2.7 Ga with the oldest yielding an age of 3254.9 ± 1.6 Ma (Central Amazonian age province?); another 10% of grains fall into the range 1.863-1.55 Ga. As other workers have noted (e.g., Pollock et al, 2010; Samson et al, 2001), detrital zircon studies in Carolina terrane rocks indicate the dominance of the West Amazonian Craton provenance for clastic rocks. These results hold for the entire Kings Mountain terrane. While it will not be visited on this trip, two-thirds of analyzed grains from the sandstone at Whitaker Mountain, the stratigraphically highest member of the Blacksburg Formation, 270 m above the Marble member at Dixon’s Branch (Vulcan Quarry Stop 1-3), yielded ages that belong to the Sunsas age province (1.25-0.9 Ga) with no grain younger than 927.9 ± 37.4 Ma (Dennis and Baker, 2012). We interpret the Whitaker Mountain sandstones of the Blacksburg Formation to be among the very youngest stratified rocks in the Kings Mountain terrane.

The Draytonville metaconglomerate is interpreted to lie at or above the Rheic rift-drift transition on the Series 2/3 Cambrian Carolinian margin (Dennis and Baker, 2012). The overwhelming Mesoproterozoic signal of Draytonville relative to Dixon’s Gap suggests that in the time recorded by the nominal 625 m interval above the Dixon’s Gap conglomerate, the Carolinian arc basement had been exposed, eroded, rifted, thermally subsided, and covered by detritus derived from Mesoproterozoic rocks of the Amazonian craton. Where the rift-drift transition is placed within that 625 m may be somewhat arbitrary, but Dennis and Baker (2012) place it at the Jumping Branch Manganiferous Member (Stop 1-7). Elsewhere where manganiferous formations are recognized on rifted margins (e.g., Damara orogen, Namibia) they are interpreted to be coincident with transgression or relative sea level rise, corresponding to thermal subsidence following passive margin rifting (e.g., Bühn and Stanistreet, 1999). Keith and Sterrett (1931) recognized and named distinctive conglomeratic horizons occurring below and above the Jumping Branch Manganiferous Member.





Portion of Keith and Sterrett (1931) showing Draytonville metaconglomerate (blue, Cambrian kd) overlying Abm (manganiferous formation). Below Abm, Abc (copper color) lower conglomerate (cf. Dixon's Gap metaconglomerate). Gaffney marble, diagonal rule, Cambrian "g" also shown.

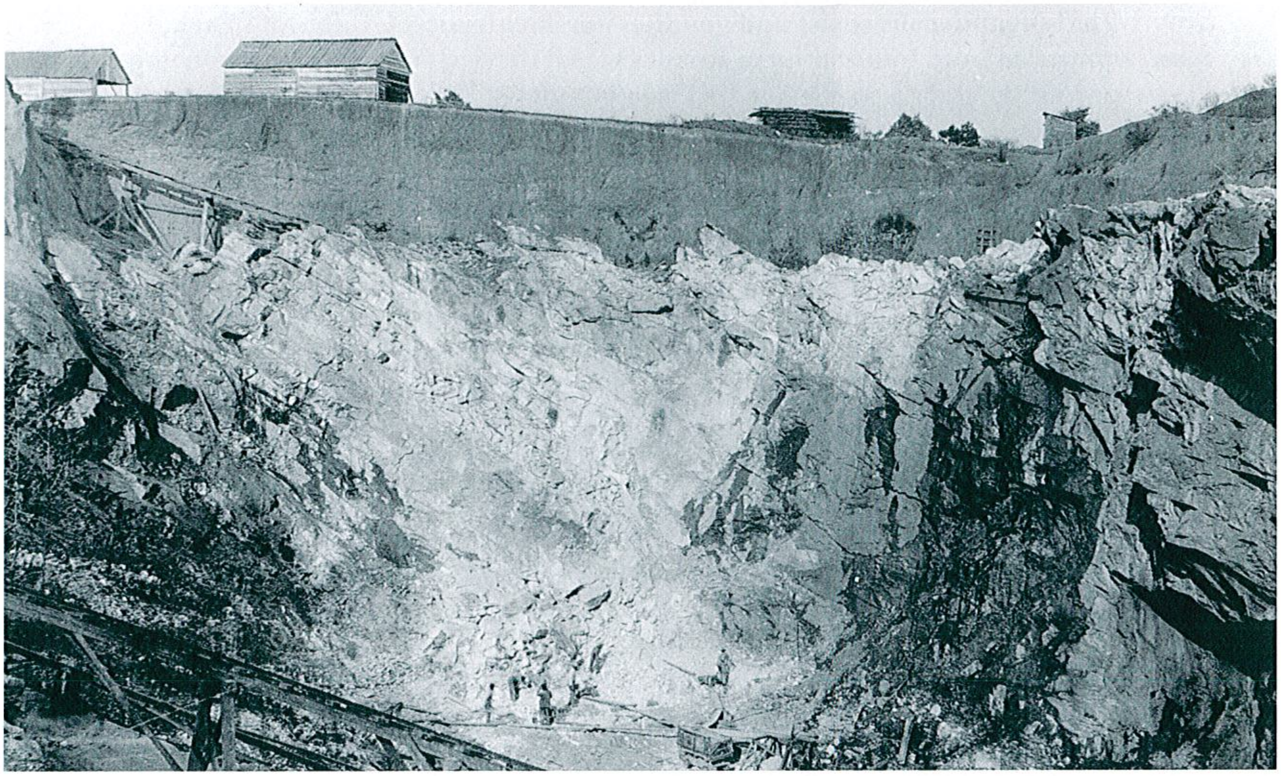
Stop 1-6: Gaffney Marble on shores of old Nesbitt limestone quarry on the southeast edge of the Limestone College campus, Gaffney, SC. (35°3'16.78"N 81°38'54.27"W).

Purpose: To observe the lower marble member (Gaffney marble) within the Carolinian Rheic drift, in the Blackburg Formation, nominally 2875 m above the Dixon's Gap metaconglomerate member of the Battleground Formation.

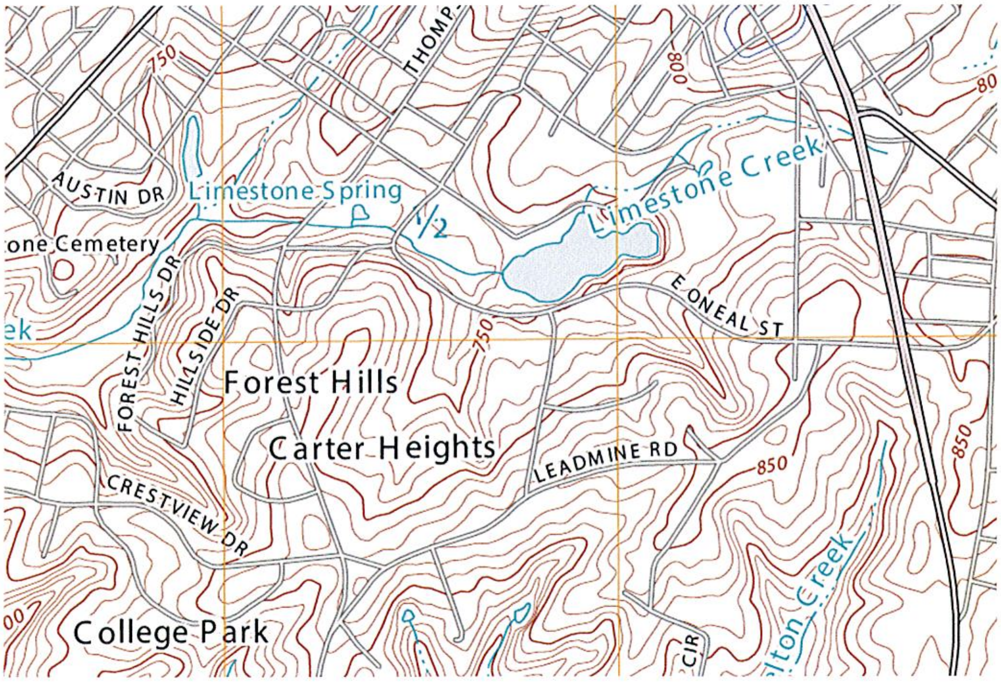
DESCRIPTION: The best exposures of the lower marble or dolostone in the Blacksburg Formation are found on the shores and cliffs of the Nesbitt "limestone" quarry on the campus of Limestone College, Gaffney, SC. The quarry was the largest of many developed in both the (lower) Gaffney member and the (upper) marble member at Dixon's Branch from 1775-1870 providing limestone for fluxing the iron ores from Blacksburg, SC, and the surrounding area (Figure 4). The exposures on the shores of the water-filled quarry are generally of low metamorphic grade and preserve stylolites and "algal" laminations. The thickness of the carbonate section here is about 120 m.

Sloan (1906) and Ruffin (1846) describe many localities of the Gaffney marble which was important both for refining iron ore and as a source of agricultural lime. I searched particularly for large exposures of the Gaffney marble based on Sloan's descriptions; they are very hard to find, and in most cases are marked only by solution valleys now. As we entered the Blacksburg Vulcan quarry (Stop 1-3) from Mill Creek Road, the lowest point on Mill Creek Road was a Gaffney marble solution valley.

The Gaffney Marble lies 1500 m above the base of the Blacksburg Formation. The base of the Blacksburg Formation is cut by a trondhjemite, that is cut by granodiorite dikes that yield an ID-TIMS age of 518.26 ± 0.68 (2s) Ma; thus the base of the Blacksburg Formation is no older than Cambrian, Series 2, Stage 3. Near the base of the Battleground Formation the Dixon's Gap metaconglomerate contains detrital zircon grains as young as 522.43 ± 3.01 (2s) Ma (ID-TIMS, Dennis and Miller, 2013). The marble member at Dixon's Branch lies nominally 270-800 m above the Gaffney marble. The thickness of the upper part of the Battleground Formation (i.e., above the mottled phyllitic metatuff) is estimated to be between 1575-2275 m. The thickness of the exposed rift sequence (above mottled phyllitic tuff to Jumping Branch Manganiferous Member) is interpreted to be 600-1275 m. The thickness of the exposed drift sequence (Jumping Branch Manganiferous Member to top of Blacksburg Formation) is 3150-3700 m.



Nineteenth century photograph of Nesbitt Quarry in Gaffney Marble member of Blacksburg Formation. Note workers on quarry floor. Lower of two marble members in the Blacksburg Formation. Nesbitt Quarry is on the campus of Limestone College, Gaffney, South Carolina. View looks 045. Thickness of marble at this site ≈ 120 m.



Stop 1-7: Manganiferous schist and gondite, north entrance, Croft State Park, Spartanburg, SC, off Johnson Lake Road. (34°53'10"N 81°49'18"W): Beginning at the parking area and for a couple hundred meters south of the radio tower, along the horse trail. *State Park: No collecting without permit.*

Purpose: To observe metal-rich metasedimentary rocks (manganiferous schist and gondite), no older than ca. 519-525 Ma, deposited within rift facies metaclastic rocks in the Battleground Formation.

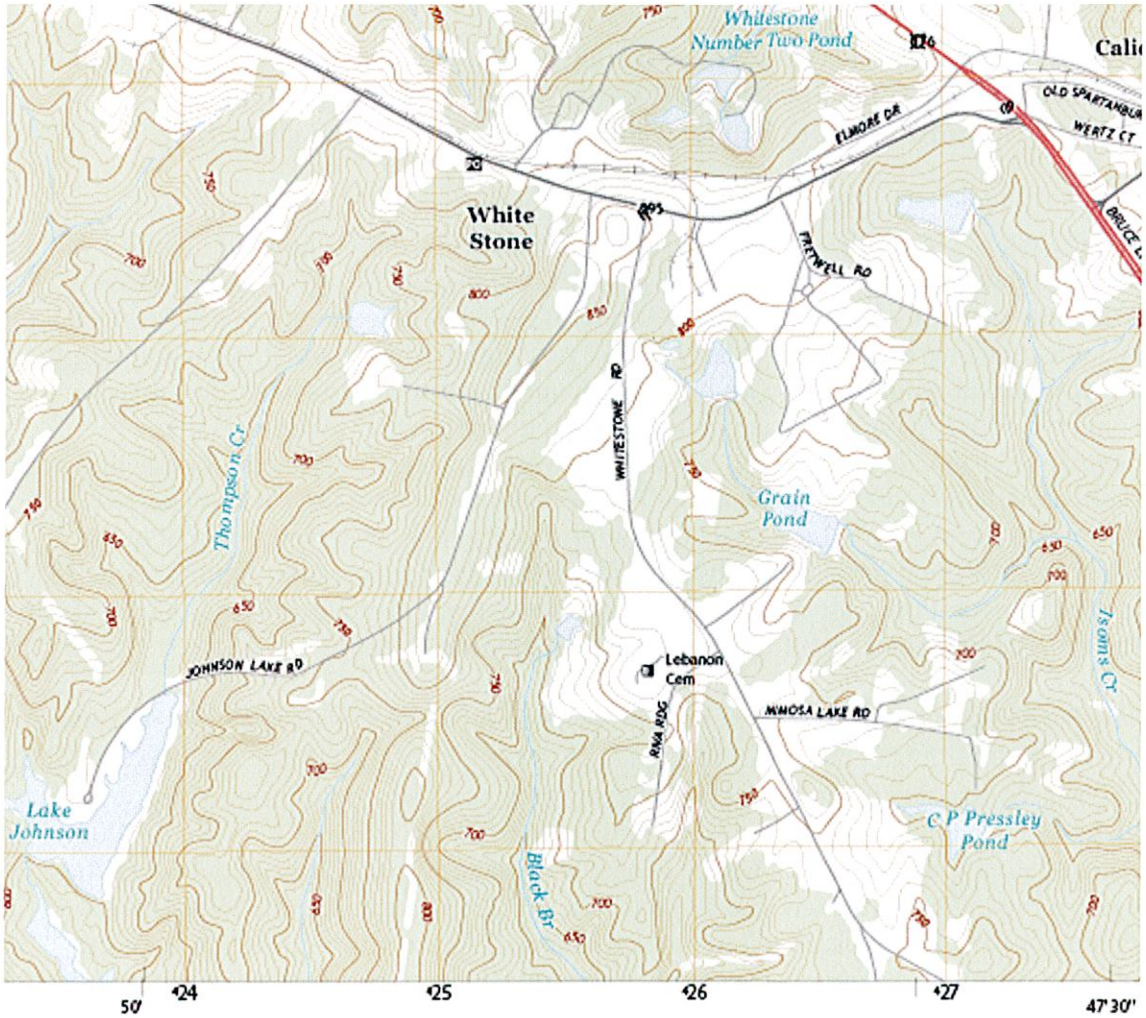
DESCRIPTION: These outcrops, extending south to Fairforest Creek, are the southernmost exposures of the Jumping Branch Manganiferous Member of the Battleground Formation. They were mapped by Steve Mittwede (1989) and me (Dennis, 1989), and are most recently described in a 1988 SEGSA field guide by Mittwede. To the west these rocks and their enclosing schists are bounded by the central Piedmont shear zone, to the east they are bounded by the Tinsley Bridge fault, that separates them from mafic metavolcanic and metaplutonic rocks of the Charlotte terrane. A hike along the horse trail

These exposures along the horse trail are much better than what remains of the type locality (Horton, 1984) within the Kings Mountain National Military Park, visited on the Dennis et al. (2012) field trip.

Though volumetrically insignificant, the manganiferous rocks of the Battleground Formation of the Kings Mountain terrane are one of its most distinctive features. These include interlayered black weathering fine-grained (0.1 mm – 1 mm) spessartine (≈50%)-quartz rock (coticule or gondite) and burnt umber-chocolate fine grained schists, dominantly quartz-sericite stained with manganese oxides and hydroxides. The Jumping Branch Manganiferous Member is traceable almost continuously along the length of the terrane (e.g., Keith and Sterrett, 1931), and its presence hints at possible non-contiguous extensions of the Battleground Formation well south of the Kings Mountain terrane (e.g., within the biotite gneiss unit west of the Cedar Shoals gneiss of Horkowitz (1984); east of Stop 2-4, Dennis et al., 2012). It is difficult to estimate the thickness of this member because of the tight folding and faulting within it, but estimates of its thickness never exceed 70m. The protolith of the spessartine-quartz rock is interpreted to have formed as a distal feature of (basaltic) submarine exhalative activity, with the chocolate brown – burnt umber schists recording a greater pelagic clay input.

Neoproterozoic manganese formations are well known (e.g., Otjosondu, Damara orogen, Namibia, Buhn et al, 1992; Buhn and Stanistreet, 1997), as are Lower Paleozoic Appalachian and Caledonide examples (e.g., Kennan and Kennedy, 1983). In the Appalachian-Caledonides, these units may not be temporally correlative (e.g., Waldron and White, 2011; Romer and Kroner, 2012), but in the peri-Gondwanan terranes of Avalonia, Ganderia, and Carolinia, they may reflect a common stage in the evolution of a rifted margin.

Detrital zircon data from the Battleground Formation record a dramatic change in provenance over the period of time from Dixon's Gap to Draytonville metaconglomerate deposition (nominally 625 m), with the nearly complete loss of Neoproterozoic-Cambrian detritus. This is interpreted to represent the erosion, rifting, thermal subsidence, and subsequent burial of Carolinian arc highlands, under detritus derived from the Amazonian Craton. The Draytonville metaconglomerate (Stop 1-5) is interpreted to have been deposited at or above the Rheic rift-drift transition. Sandwiched between the Dixon's Gap and Draytonville metaconglomerates, and within Horton's (2008) quartz-sericite phyllite and schist unit are the very fine-grained metasedimentary rocks of the Jumping Branch Manganiferous Member of the Battleground Formation. Dennis and Baker (2012) placed the Rheic rift-drift transition at the Jumping Branch Member attributing the fine grain size to transgression accompanying loss of subcrustal lithosphere and thermal subsidence following rifting.



DAY 2 OVERVIEW

This day will look at Carboniferous plutonic rocks intruding the Kings Mountain and Charlotte terranes) and the serpentinite that occurs along the trace of the Kings Mountain shear zone north of the Pacolet quarry. The plutonic rocks were visited on the 1995 CGS trip; the serpentinite was visited on the 1988 SEGSA field trip.

Stop 2-1: Pacolet granite quarry 34°54'30"N 81°46'58"W): The Vulcan Materials quarry is located about 1 mile east of the intersection of US-176 (South Pine Street, Spartanburg) and S-42-108 (Gold Mine Road). When Gold Mine Road turns left (north) continue straight on S-42-227, West Main Street. This outcrop was visited on the 1995 CGS trip.

Purpose: To observe an Upper Pennsylvanian pluton intruded within the Kings Mountain terrane and stitching the Tinsley Bridge fault-Kings Mountain terrane/Charlotte terrane boundary and the central Piedmont shear zone.

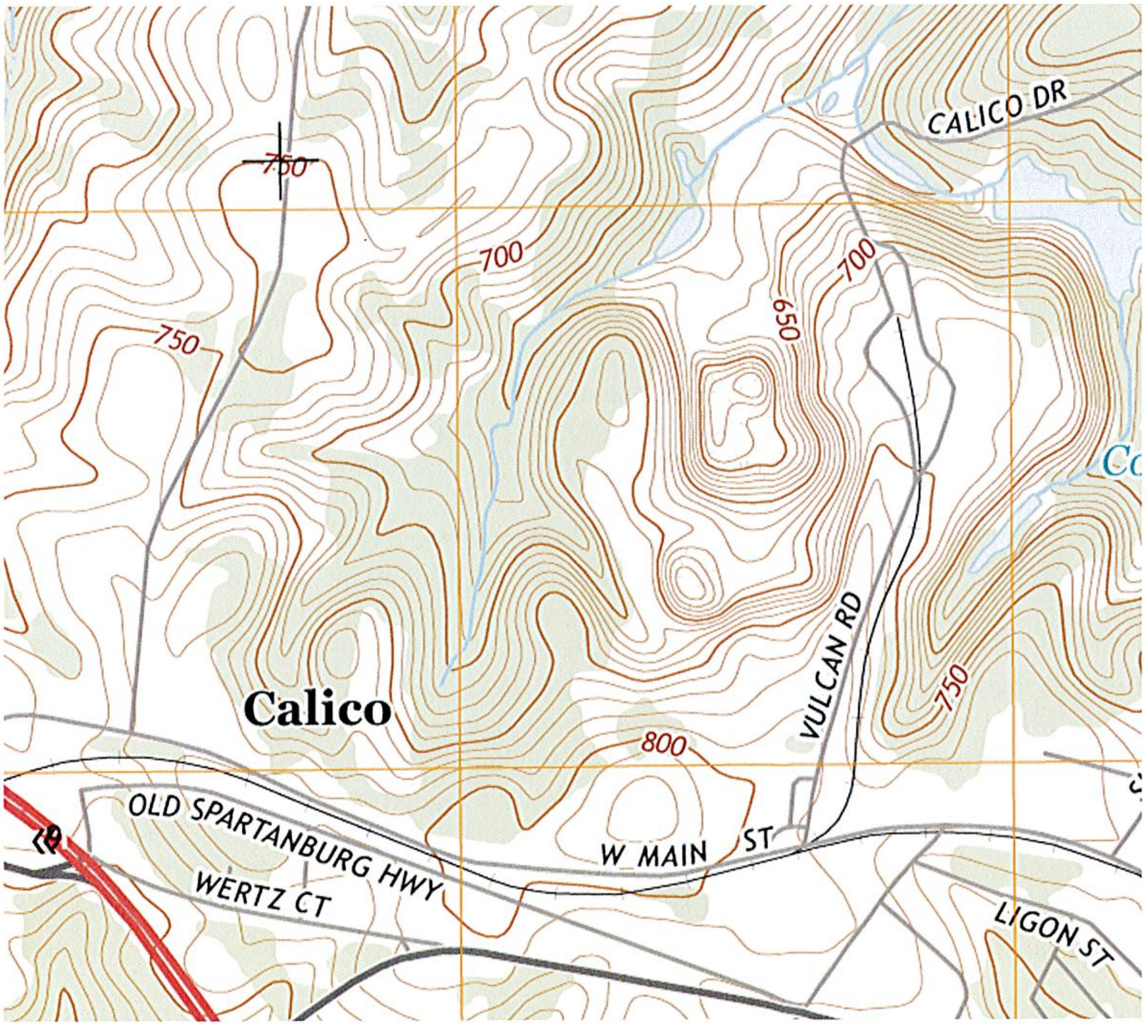
DESCRIPTION: The Pacolet granite ranges from (potassium feldspar) porprhyritic to equigranular. Generally what is observed in the quarry is the equigranular phase. Within the quarry several m-scale darker, equigranular, immiscible "blobs" can be observed within the generally lighter equigranular phase; As dikes enter the more darker blobs they become much narrower. This quarry shows very clearly diking and discrete faulting in the granite that would be obscure in small Piedmont bedrock exposures. The dikes comprise both fine-grained leucogranite and quartz-potassium feldspar-biotite pegmatites. Mutual cross-cutting relations between both types of dikes suggests that both types are related to the intrusion of the Pacolet granite and that the pegmatites are not a distinct different event. East-west striking vein arrays may observed throughout the quarry. These vein arrays seem to have a consistent geometry: veins dipping about 50° north are several times thicker (ca. 1 m) than those that dip about 20° south (10's of cm thick). The kinematic significance of this geometry is not clear.

The Pacolet granite poses several interesting questions. What is its age? Mapes (2002) reports a 304 ± 2 Ma (1σ) age. Sinha et al (1989) report an ID-TIMS U-Pb zircon age of 392 Ma. Mittwede and Fullagar (1987) report an 8 point Rb-Sr isochron of 383 ± 5 Ma, and a 292 Ma biotite age for the Pacolet, with an initial Sr ration of 0.7046 ± 0.0002. Age regionally. Plutons of an Upper Pennsylvanian age are much more typical of the eastern Piedmont; in fact granitic plutons of a ca. 323 Ma age (like the High Shoals granite or the Bald Rock pluton to be seen at Stop 2-3) are much more typical of the western Carolina terrane of the central Piedmont. If the earlier, Devonian age is accepted it predates the metamorphic peak in the Kings Mountain terrane; if it postdates the thermal peak there should be some contact metamorphic effects in Kings Mountain terrane rocks. Retrogression of kyanite to sillimanite within Battleground Formation rocks is noted to the south in the Glenn Springs quad. What regional faults are cut by the Pacolet pluton? This pluton stitches both the Kings Mountain terrane- Charlotte terrane boundary, the Tinsley Bridge fault and the central Piedmont shear zone. Mittwede (1989) and Nystrom (2000) show the pluton in contact with both Inner Piedmont paragneiss and Battleground Formation. To the south of this site the pluton is entirely within the

Battleground Formation. Most workers would agree that the Pacolet postdates most major movement on the central Piedmont suture. A late age on the Pacolet pluton may not be particularly helpful constraining the timing of juxtaposition of Kings Mountain and Charlotte terranes. A Devonian age suggests the pluton is decapitated, and a young age suggests that crosscuts the central Piedmont shear zone.

No more than 1.5 km west of the quarry and 100's of m west of the edge of the pluton the central Piedmont shear zone separates Kings Mountain terrane rocks from Cat Square paragneisses of the Inner Piedmont. Quartz - potassium feldspar - muscovite (rather than biotite) pegmatites are typically observed near the trace of the central Piedmont shear zone south of this area.

South of the quarry a potassium feldspar megacrystic porphyry phase of the pluton was mapped by Mittwede (1989) and Nystrom (2000). Dennis (1989) mapped the megacrystic phase in the Glenn Springs quad in erosional windows through the aluminous schists of the Battleground Formation.



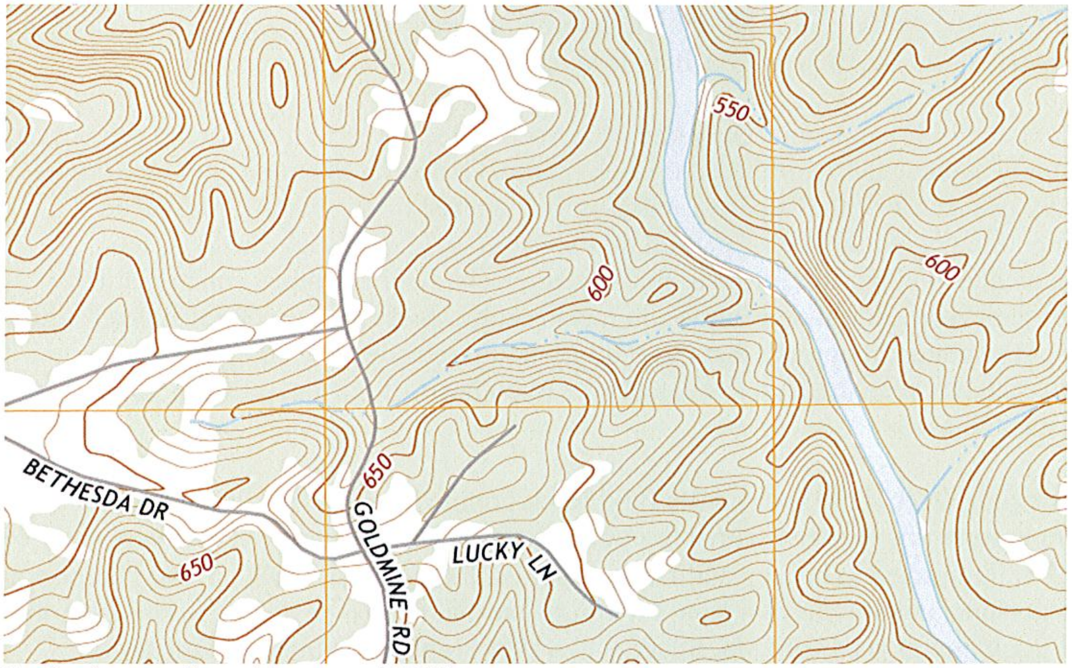
Stop 2-2: Serpentinite of the Hammett Grove Meta-igneous Suite (34°47'15"N 81°33'18"W): These outcrops are located 675 m east of the Bethesda Road-Goldmine Road intersection, accessible from an abandoned entrance to the Pacolet River Heritage Preserve. These outcrops were first visited on an organized field trip for the 1988 SEGSA meeting and were described by Steve Mittwede (1988) as his Stop 13; some of what is written here is abstracted from Mittwede (1988). This is a SC DNR Heritage Preserve and an archeological site, and no collecting or damaging the outcrops is permitted.

Purpose: To observe ultramafic rocks that decorate the central Piedmont shear zone discontinuously over 30 km.

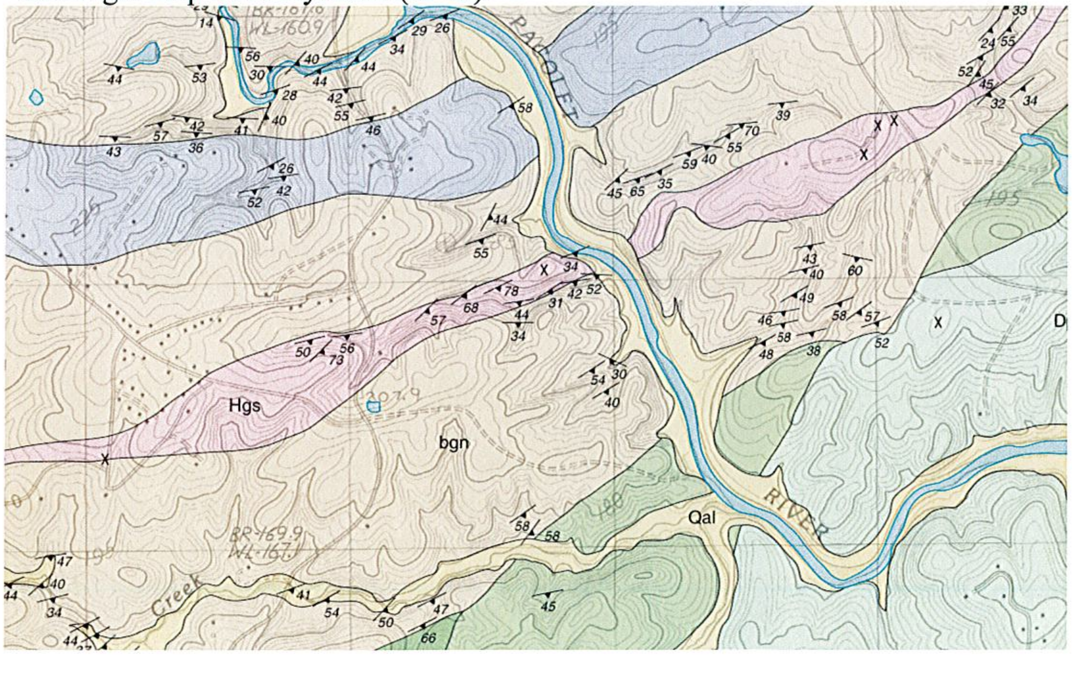
DESCRIPTION: Ultramafic rocks of the Hammett Grove Metaigneous Suite (Mittwede, 1988) crop out in a narrow belt typically between 100-300m wide along the Kings Mountain shear or central Piedmont shear zone, primarily as soapstone, talc schist or serpentinite. The low ridge north of the trail at the outcrop site is covered with soapstone boulders. A few tens of feet beneath the ridge and less than 50 m south of the ridge an unnamed tributary flows east to the Pacolet River. Inner Piedmont paragneiss of the Cat Square terrane outcrop in this tributary and support the ridge south of the tributary. Gneissic or compositional layering in the creek bed strikes 048 and dip 50-58°SE. Gneissic layering is folded into asymmetric west vergent folds, the axes of which plunge 46° towards 155 and are subparallel to intersection lineations plunging 38° to 128. These observations support west vergent transport of ultramafic rocks of the Hammett Grove Suite in the hangingwall.

Mittwede (1988) describes a subhorizontal contact at this site, and describes the outcrop pattern of the Hammett Grove Metaigneous Suite as klippen. The outcrop pattern of the Hammett Grove Metaigneous Suite on maps is a 6 km long straight line oriented 066 southwest of a point 1.6 km east and along strike of this site as the serpentinite approaches the Pacolet granite, and a highly elliptical body 5.5 km long oriented 021 north of that point, nearly parallel to the contact with the Pacolet granite. In fact Mittwede (1989) extends the 066 segment 22 km southwest of this stop discontinuously to Moore, SC; at Moore it is 14 km west of the central Piedmont shear zone. Mittwede correlated the Hammett Grove Suite with soapstones and other ultramafic rocks mapped by Keith and Sterrett (1931) and Horton et al. (1981) southwest of Gaffney, and as far north as the Kings Mountain Battlefield. These rocks are interpreted to be internal to the Kings Mountain terrane. In addition to the soapstone-serpentinites the Hammett Grove Metaigneous Suite comprises pyroxenites, including a high-Ca pyroxenite broken out geochemically, gabbros and an amphibolite. Mittwede interpreted these rocks to represent an ophiolite pseudostratigraphy; Dennis and Shervais (1991, 1992, 1996) disagreed sharply with this interpretation and included the Hammett Grove rocks with the zoned mafic-ultramafic plutonic-volcanic complexes they described from the Charlotte terrane.

Data presented on this trip, and that presented by Dennis (1988) Dennis and Baker (2012), Dennis et al. (2012), and Dennis and Miller (2013) complicate these relations somewhat, but we remain confident the HGMS rocks do not represent material formed at an oceanic spreading center. The Kings Mountain terrane probably accumulated closer to the Carolina slate terrane than to the Charlotte terrane based on the populations of Neoproterozoic grains that are preserved within the Dixon's Gap metaconglomerate member at Dixon's Gap and Stepp's Gap. The Tinsley Bridge fault juxtaposes the Charlotte terrane and the Kings Mountain terrane (Dennis, 1988). The thermal peak recorded by the Charlotte terrane (< 538 ± Ma, > 535 ± Ma) occurred well before the sedimentary section of the Kings Mountain terrane was deposited (ca. 522-518 Ma); the thermal peak recorded by the Kings Mountain terrane occurred ca. 323 Ma (Horton et al., 1987). Perhaps portions of the Hammett Grove Metaigneous Suite represent shreds of the subcrustal lithosphere preserved during rifting of Carolinia from Amazonia.



Geologic map from Nystrom (2000).



Stop 2-3: Hyder farm Bald Rock granite quarry (34°47'15"N 81°33'18"W): The "quarry" is located in a pasture approximately 300 m southwest of the house at the end of Hyder Road, off SC Highway 9. Hyder Road is 0.8 mile west of the intersection of SC 9 with S-44-57. This outcrop was visited on the 1995 CGS trip.

Purpose: To observe a large exposure of the Mississippian Bald Rock granite, as a representative of the western, undeformed Alleghanian granites.

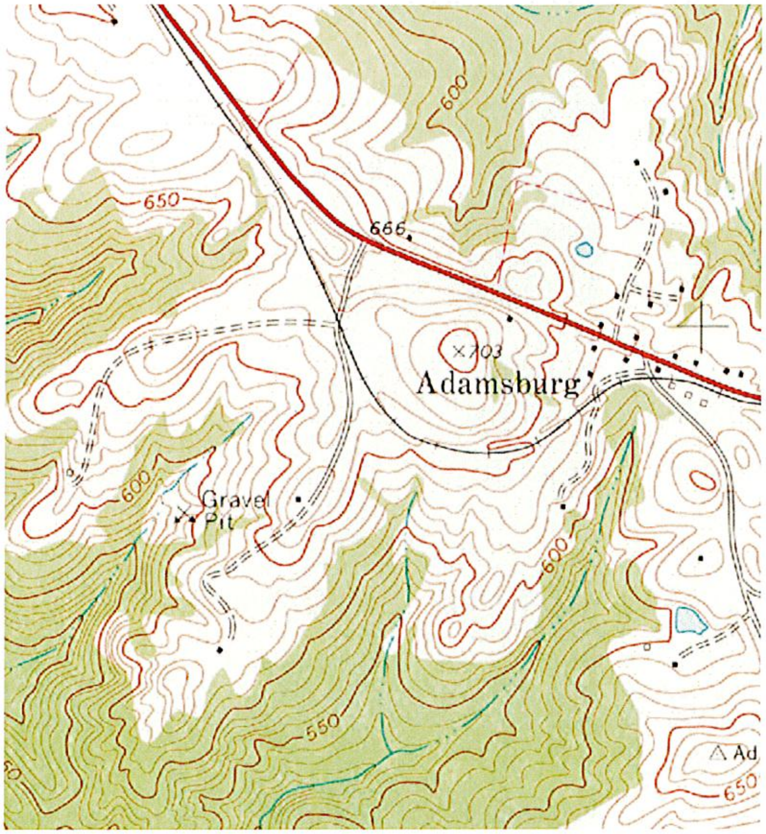
DESCRIPTION: This abandoned quarry illustrates the salient features of the Bald Rock granite: its megacrystic texture, the strong alignment of phenocrysts, and the parallel alignment of mafic enclaves. The megacrystic granite here is coarse-grained. The most common mafic phase here is biotite, but hornblende may also be found. The orientation of megacrysts and mafic enclaves here is about north-south.

Speer et al. (1986) and van Gelder and McSween (1981) present maps of the megacryst and mafic enclave fabric of the Bald Rock pluton. Generally the magmatic foliation is broadly concentric with the pluton margins, but tapered mafic enclaves define an asymmetric, counterclockwise pattern that Speer et al. (1986) suggested was a consequence of either irregularities in the magma chamber or emplacement in a left-lateral fault zone. Based on contrasts in metamorphic grade and structural style east and west of the pluton, it appears that the Bald Rock did intrude an existing fault zone, however, it has been difficult to evaluate the hypothesis of left-lateral shear along this zone ca. 320 Ma.

Dennis and Wright (1995) dated the Bald Rock granite by the U-Pb zircon method using a sample from this location. Three fractions of zircon yielded an upper intercept at 323±3 Ma (2σ) interpreted to be a crystallization age. Dallmeyer et al. (1986, p. 1331) report a 1985 personal communication from P.D. Fullagar that the Rb-Sr age of biotite from the Bald Rock pluton is ca. 290 Ma. Speer et al. (1986) reported mineral chemistry for biotite, amphibole and pyroxene from the Bald Rock granite, and compared their results to mineral chemistry of known Carboniferous plutons of the eastern Piedmont. Vhynal and McSween (1990) used the Al-in-hornblende (7 grains) barometer to estimate a crystallization pressure for the Bald Rock at 4.8±0.5 kbar or 18.5±2km. Vhynal and McSween (1990) prepared pressure estimates for 14 Carboniferous plutons from both the eastern Piedmont (Carolina slate belt: 10.8-11.6 km depth of emplacement) and central Piedmont (14.2-19.3 km depth of emplacement) and documented the Alleghanian-regional scale warping of isotherms suggested by regional reconnaissance $^{40}Ar/^{39}Ar$ ages and other mineral ages and proposed by Dallmeyer et al. (1986) and Secor et al. (1986a, b).

The Bald Rock granite is historically important in addition to its geologic significance. The Union Jail on West Main Street was designed and construction supervised by South Carolina architect Robert Mills (1781-1855) over the period 1822-1823. The original design called for brick construction; however after a problem with the quality of the brick was recognized, Mills ordered the brick torn down, and after learning of the existence of a nearby granite quarry (Humphries quarry west of town, as described by Sloan, 1908 and Wagener, 1977), elected to complete the outside walls with Bald Rock granite. Among

Mills' many later accomplishments were the US Treasury Building (1836, completed in 1842), Old Patent Office (now part of the Smithsonian Institution), and the Washington Monument (1836, completed 1884). The Union Jail is still in use, and it is the oldest functioning jail in the state and the oldest intact public building in the county.



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Inside back cover: Field trip stops drawn on a modified base of Hibbard et al. (2006). Meridians of longitude indicate north. A terrane-bounding fault has been drawn in separating Kings Mountain terrane from Charlotte terrane: this is called the Tinsley Bridge fault (TBF). Based on data and interpretations of Dennis & Baker (2012), Dennis et al. (2012) and presented on this field trip, area labeled (A) Battleground Formation and (B) Blacksburg Formation should be rekeyed on Hibbard et al (2006) map to reflect that they are the Rheic margin rift-drift (**18**: Passive margin: Mainly Cambrian to Lower Ordovician quartzose clastic slope and rise deposits; locally contains mafic dikes. presently under Ganderia (includes both A&B) **or 20**: Magmatic arc to rift: Upper Neoproterozoic volcanic rocks with marine to terrestrial clastic sedimentary rocks between older magmatic arc rocks and younger clastic rocks; **and 21**: Clastic shelf: Upper Neoproterozoic to Lower Devonian clastic sedimentary rocks with local carbonate rocks and mafic to felsic magmatic rocks . . . . Characterized by an "Avalonian" fauna) (Adapted from Dennis et al, 2012).
Inset: Appalachian orogen in eastern North America with locations of peri-Gondwanan terranes and Cambrian Rheic margin sections indicated. Several of the larger elements within Carolinia are indicated: i- Charlotte terrane; ii and iii make up the older (ca. 610-630 Ma) and younger portions (ca. 550 Ma) of the Carolina slate terrane respectively; iv- Alleghanian remobilized, high grade portions of older (610-630 Ma) arc; v- undifferentiated terranes east of Triassic basins and Goochland terrane. APF- Asbill Pond Formation; BBF- Bloody Bluff fault; BVBL- Baie Verte-Brompton Line; CF- Caledonia fault; CBF- Chedabucto fault; CPSZ- Central Piedmont shear zone; DHF- Dover-Hermitage Bay fault; HLPVF- Hollins Line- Pleasant Valley fault system; KMt- Kings Mountain terrane; M- Mesoproterozoic basement study; RIL- Red Indian Line. Adapted from Hibbard et al. (2006).

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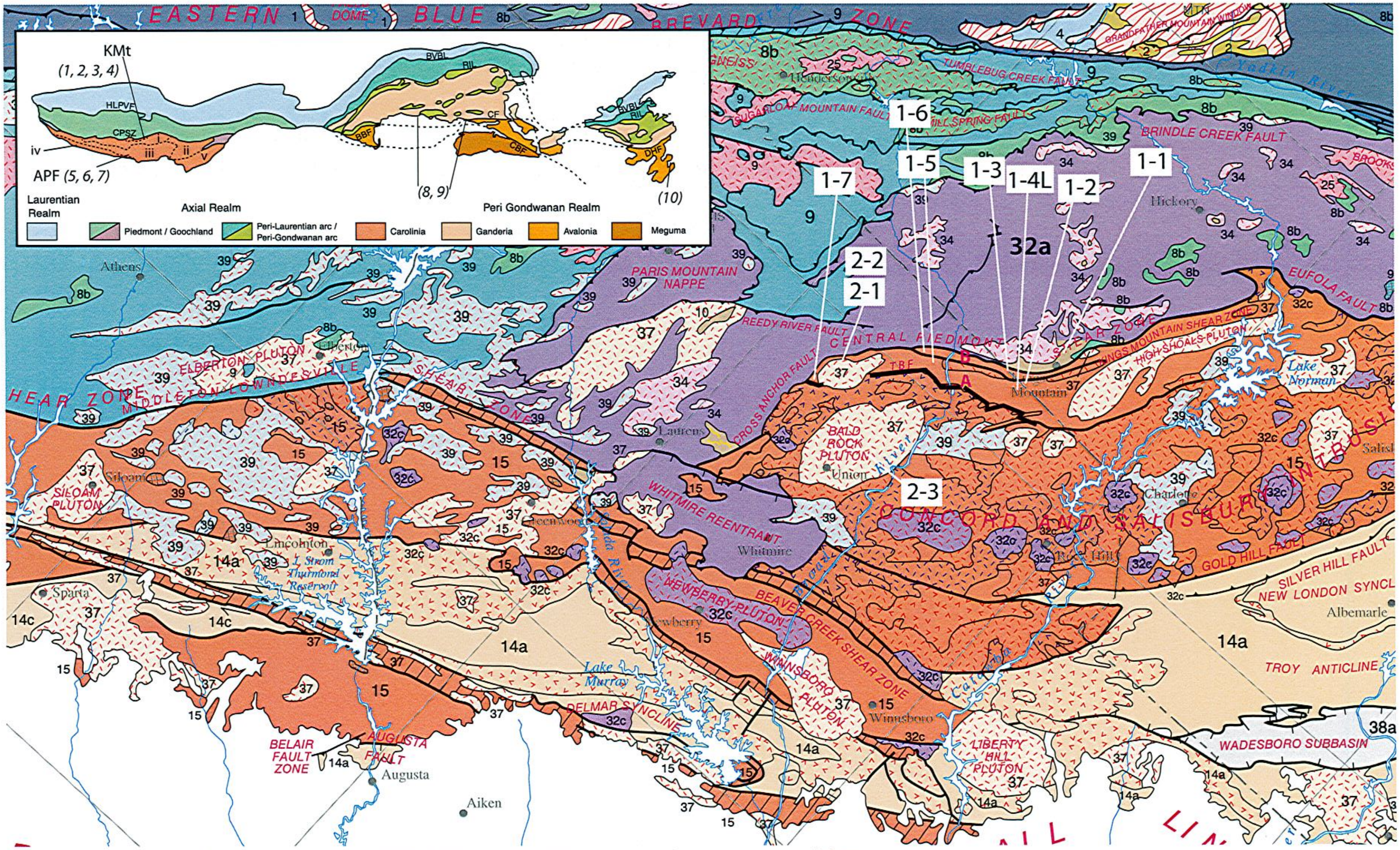
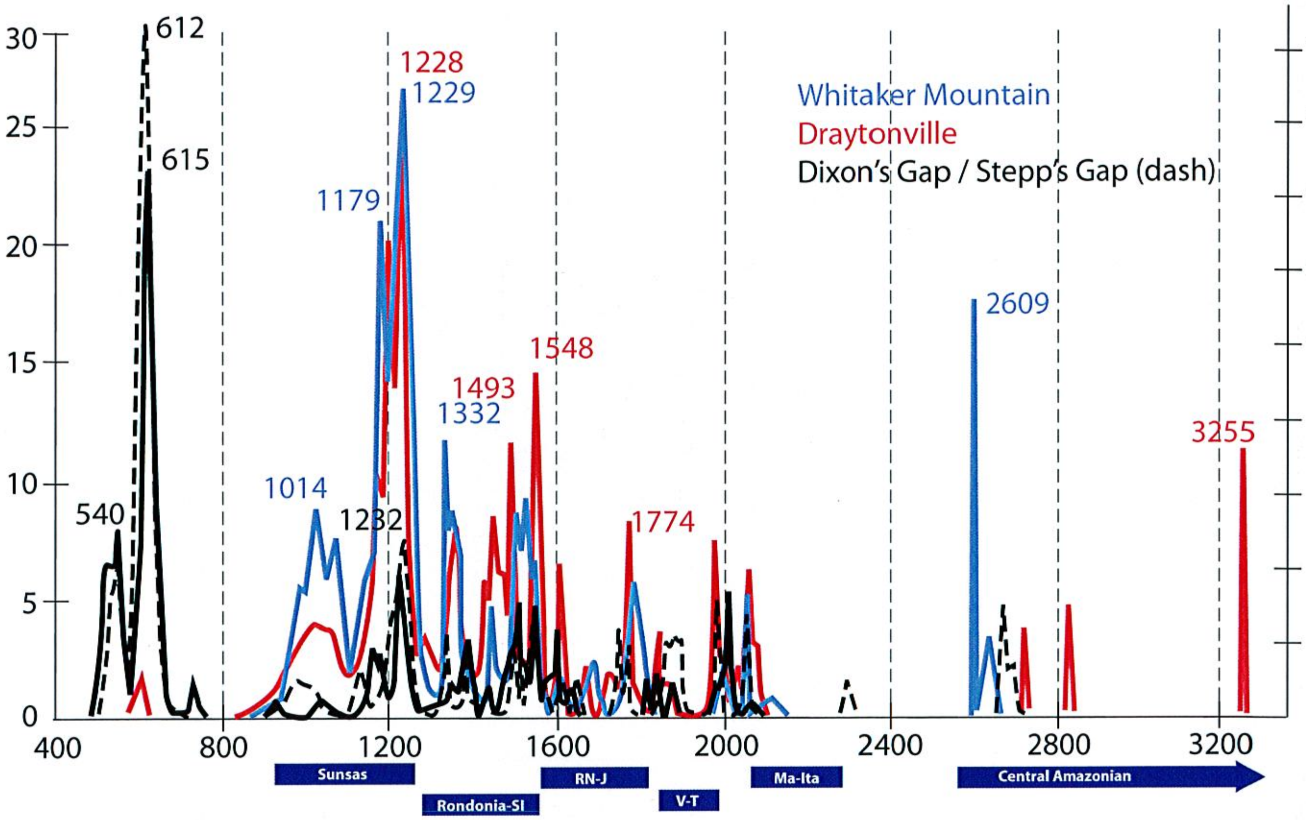


Index map to field trip stops 2014 Carolina Geological Society Field Trip:
Recognizing the Cambrian Rheic margin of Carolinia in the Kings Mountain terrane
drawn on a base modified from Hibbard et al., 2006.


Whitaker Mountain
Draytonville
Dixon's Gap / Stepp's Gap (dash)
612
615
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1229
1179
1014
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1493
1548
1774
2609
3255
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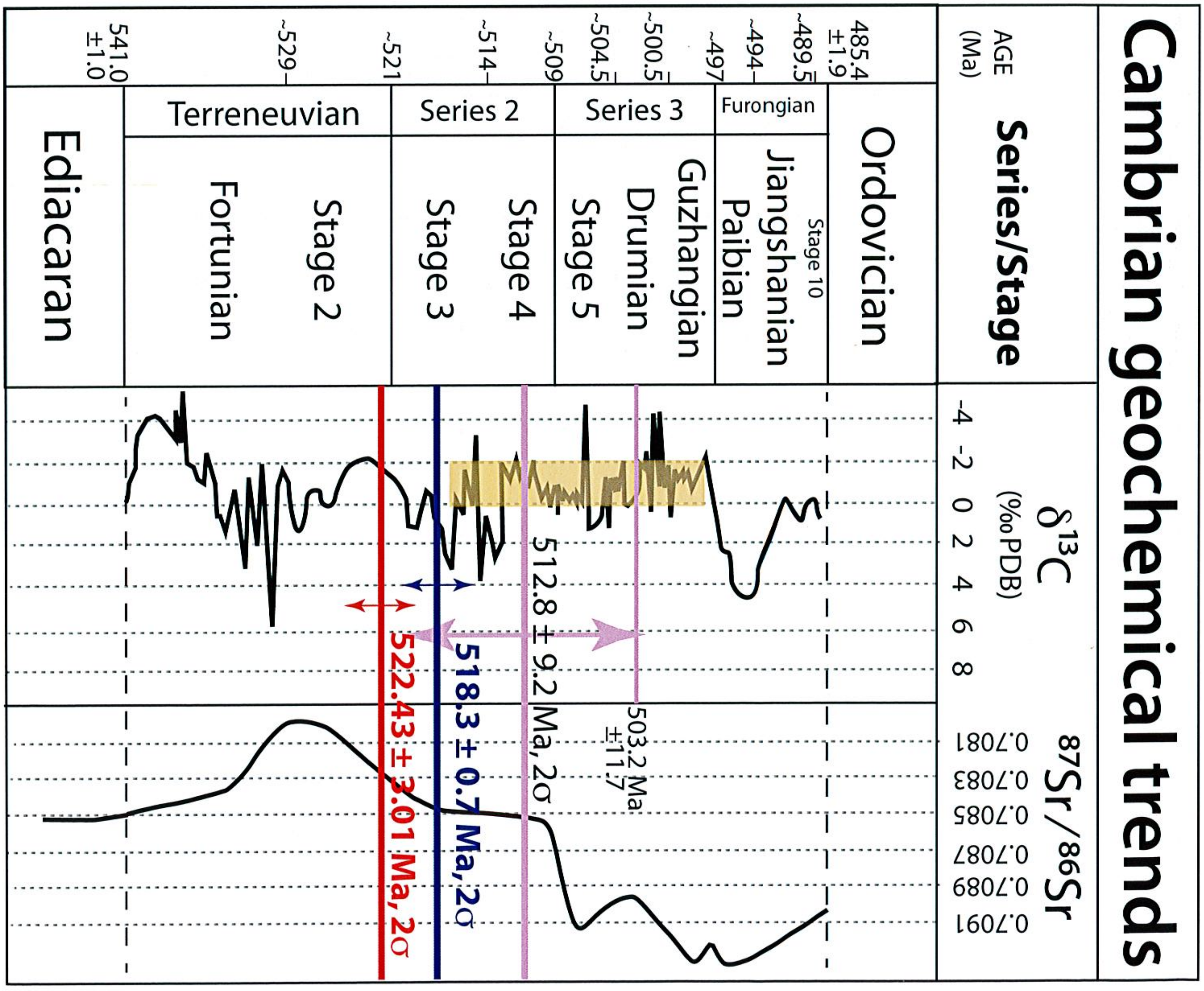
10
15
20
25
30
2
4
6
8
10
12
14
16
18
400
800
1200
1600
2000
2400
2800
3200
Sunsas
Rondonia-SI
RN-J
V-T
Ma-Ita
Central Amazonian


Cambrian geochemical trends
AGE (Ma)
541.0 ±1.0
~529
~521
~514
~509
~504.5
~500.5
~497
~494
~489.5
485.4 ±1.9
Series/Stage
Ediacaran
Terreneuvian
Fortunian
Stage 2
Series 2
Stage 3
Stage 4
Series 3
Stage 5
Drumian
Guzhangian
Furongian
Paibian
Jiangshanian
Stage 10
Ordovician
$\delta^{13}C$ (‰PDB)
-4
-2
0
2
4
6
8
$^{87}Sr/^{86}Sr$
0.7081
0.7083
0.7085
0.7087
0.7089
0.7091
522.43 ± 3.01 Ma, 2σ
518.3 ± 0.7 Ma, 2σ
512.8 ± 9.2 Ma, 2σ
503.2 Ma ±11.7