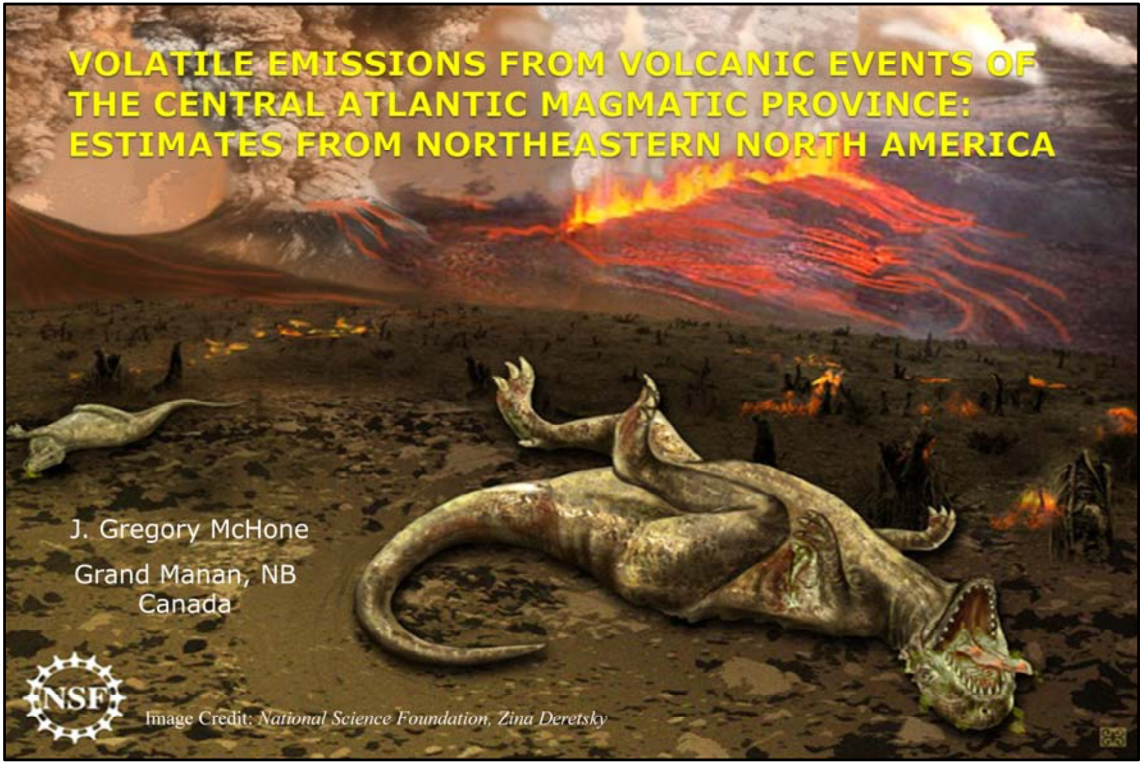
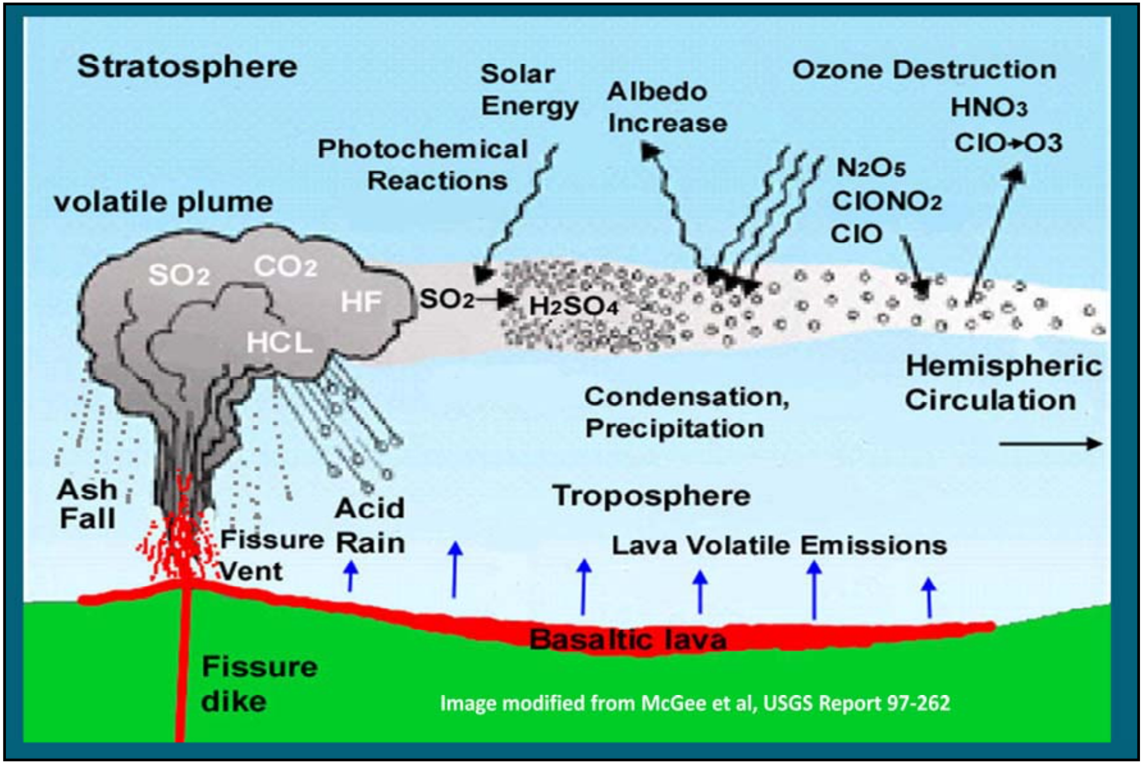
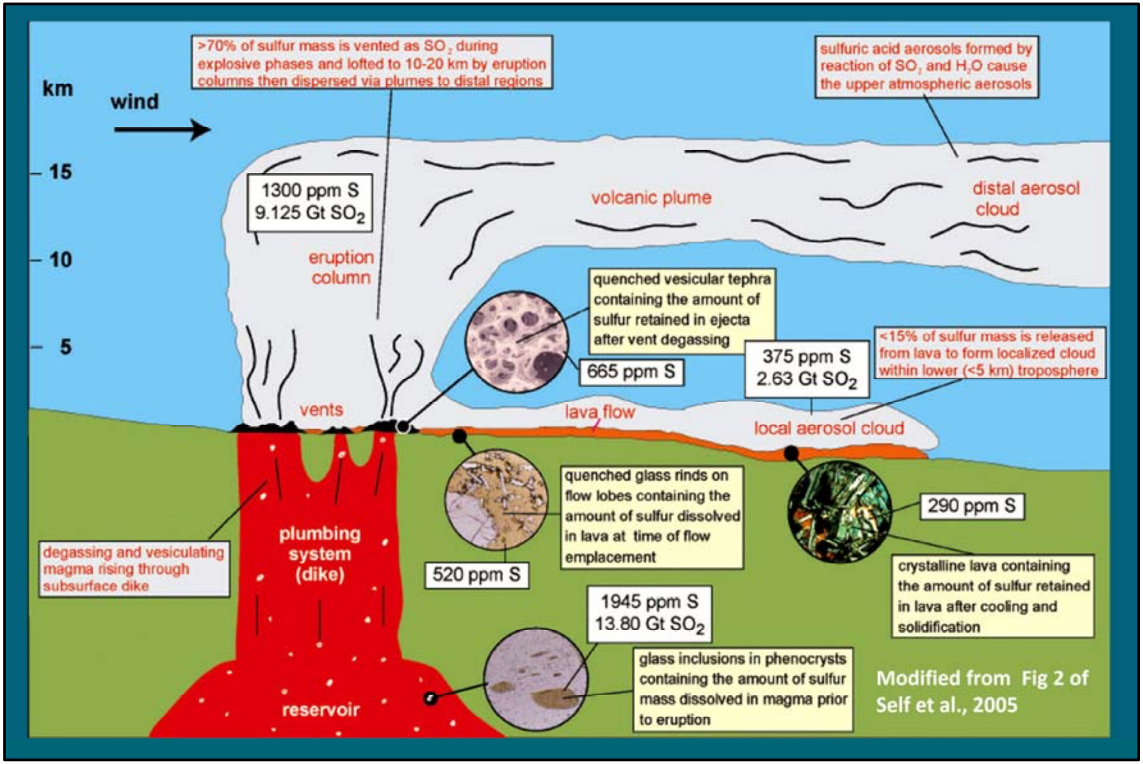


I know that dinosaurs were not very big at the time of the end-Triassic extinction, but this graphic from the National Science Foundation website sets the theme of mass extinction by fissure volcanism.

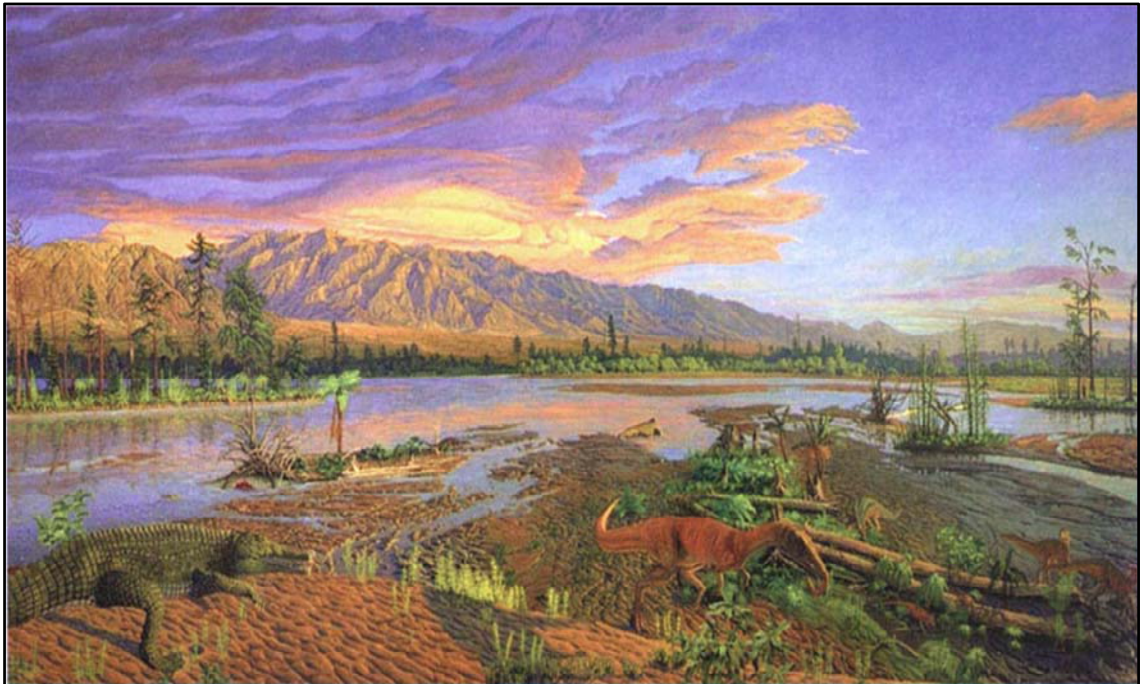
Fissure volcanoes produced massive flood basalts associated with the last 3 global mass extinctions. The eruptions probably looked like the Krafla Fires in Iceland, except they were much larger.



Fine ash and volatiles from vigorous eruptions can reach the stratosphere and enter into global circulation. Ash, chlorine, and fluorine are local killers of plants and animals, but mass extinctions are more likely due to global effects of sulfur and carbon dioxide. The sulfur forms a fog of sulfuric acid that blocks sunlight and creates brief dark cold periods, while CO2 makes a subsequent and longer-lasting greenhouse heat effect. Figure modified from Richard Turco in American Geophysical Union Special Report: Volcanism and Climate Change, May 1992.

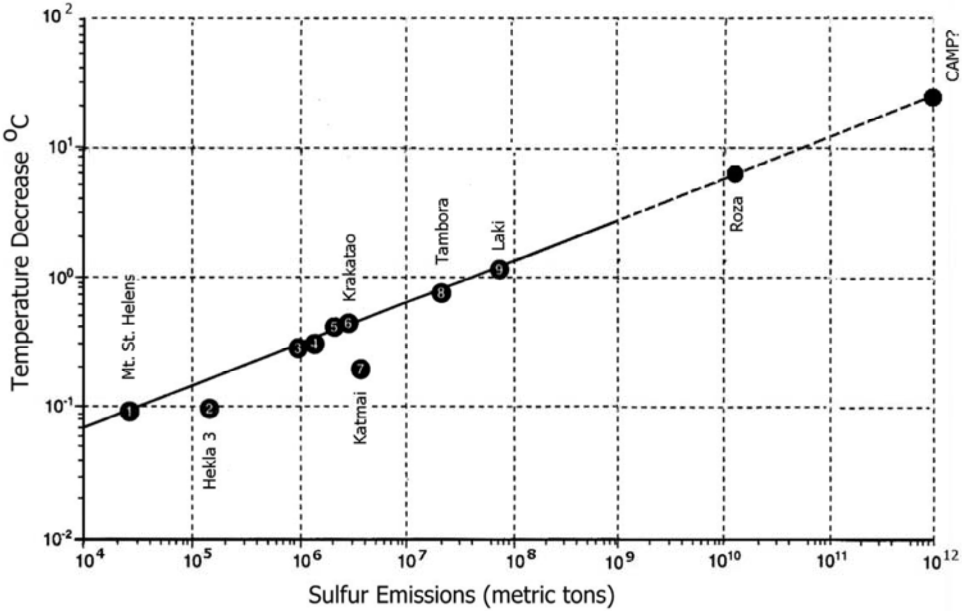


In addition to measuring volatiles in modern volcanic gas plumes, we can analyze volatile elements preserved in sub-surface dikes and compare them with their surface lavas. About 70% of SO2 and 90% of CO2 in the magma can escape, which are measurements that I am using to estimate CAMP magmatic volatiles (present in source dikes) that were injected into the atmosphere by fissure gas plumes and lava flows. Fig. 9 of Thordarson & Self (1996), illustrating methodology for estimating SO2 emissions for the Roza basalt flow.



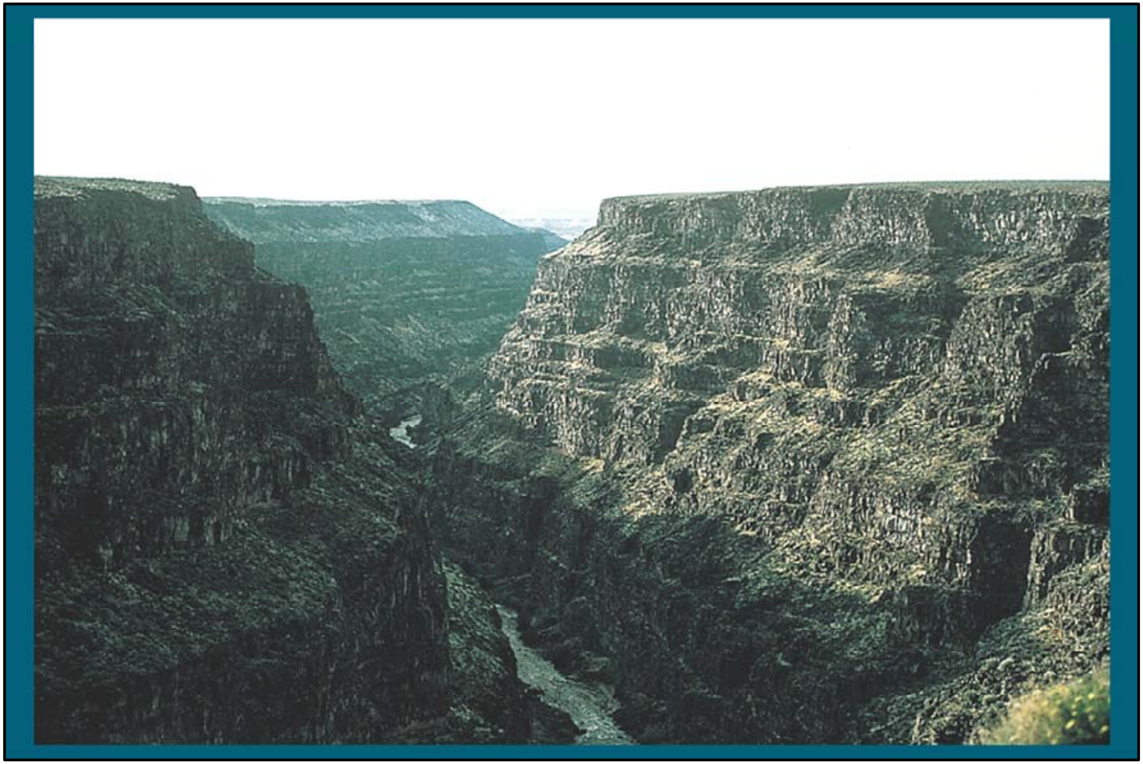
William Sillin's mural at Dinosaur State Park, Connecticut

Plants and animals were adapted to a very warm global climate at the end of the Triassic Period. This would make them vulnerable to cold periods that included sub-freezing temperatures, especially ones lasting for weeks or months. An increase in temperature, on the other hand, might not be effective in killing a large percentage of living things during this hot time. How much sulfur or carbon dioxide would have been emitted by our regional volcanic events, and did they contribute to the end-Triassic mass extinction?



Total sulfur load versus temperature decrease, after Palais and Sigurdsson, 1989

There have been attempts to calibrate cooling efffects of atmospheric sulfur using historic euptions, but no one is sure that the correlation is this linear (even on a log-log graph). But the best estimate as extrapolated is that the Roza flood basalt (one of the Columbia River plateau basalts) cooled the earth about 5 to 10 degrees C for up to 10 years. CAMP events, and especially the total CAMP volatiles, were much larger and might indicate 20 degrees, or more, of cooling.



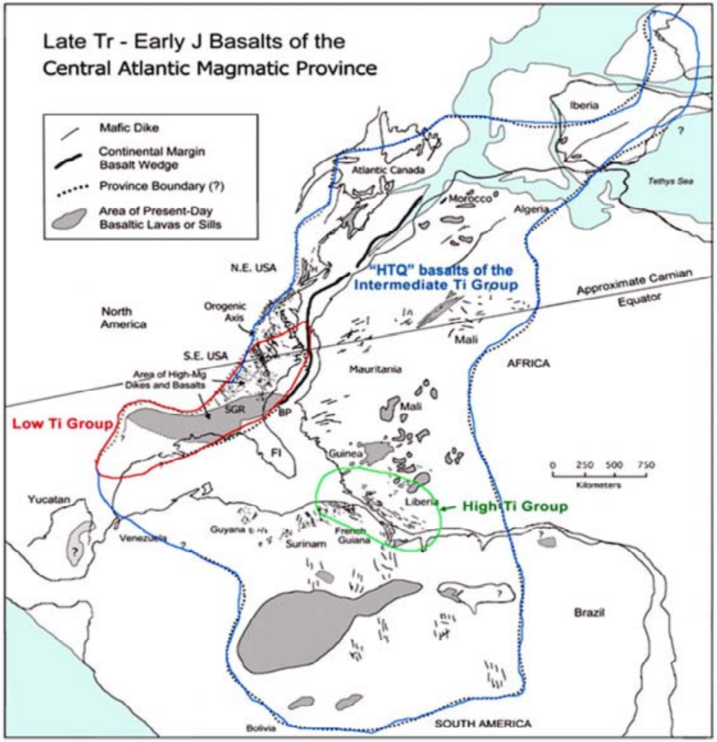
For an environmental effect big enough to cause global mass extinction, many relatively small flood basalt eruptions spread over a long period of time are not sufficient, because nature is working during the same time to remove problem gases (Columbia River Basalt).

You need big eruption events that produced high volumes of basalt in brief time periods, perhaps as represented in our northern part of the CAMP. For example, there are at least 6,600 km3 of HTQ North Mountain Basalt present today just in the Bay of Fundy. Only flows within the Siberian Traps at the Permian-Triassic boundary may be larger.

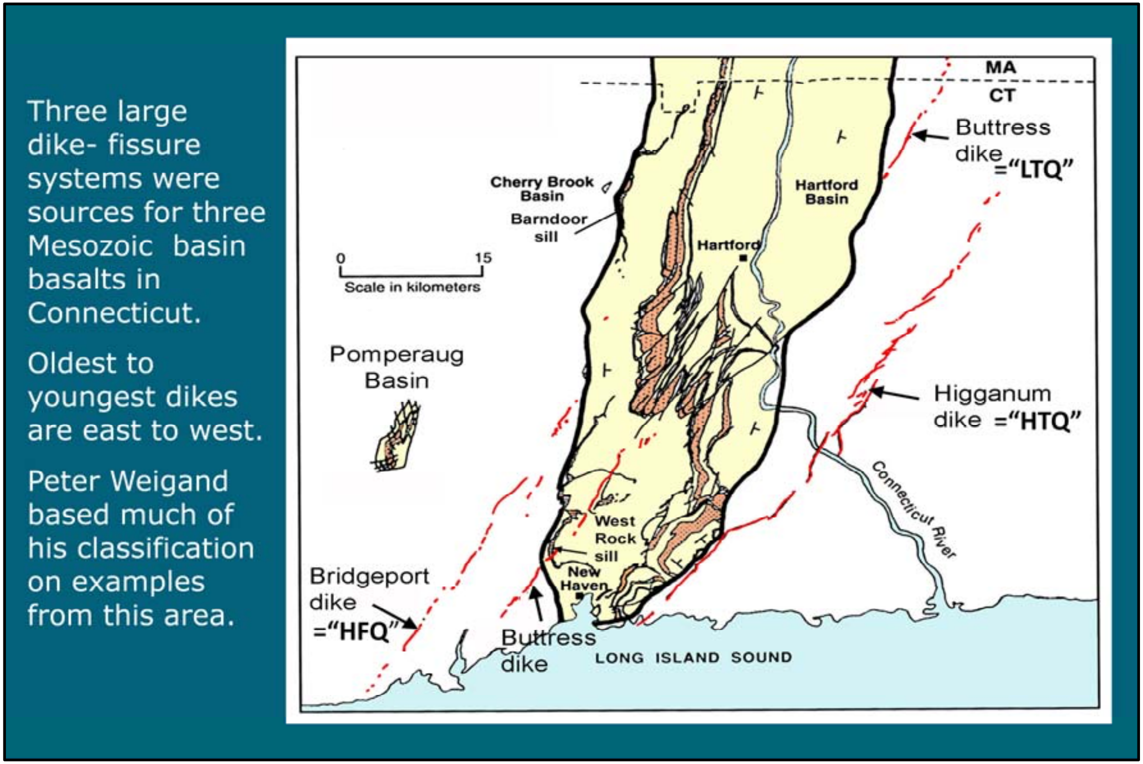
The CAMP extends over 11,000,000 km² of central Pangaea, in great dike swarms, sills, and surface flows of three magma groups, which can be distinguished by titanium.

Dikes and basalts within each magma group are slightly different in composition and age from one another.

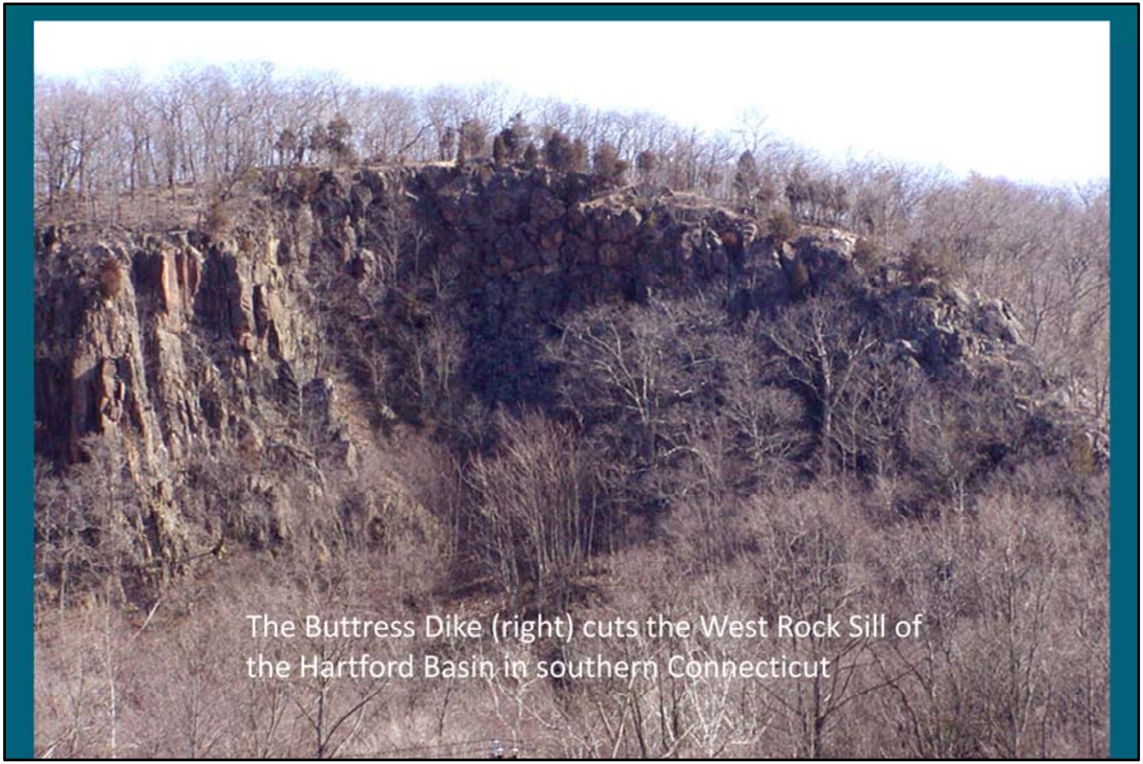
Most of the area of CAMP has dikes and basalts that are similar in age and composition, which in New England have been labeled as High Titanium Quartz Tholeiite or "**HTQ**."



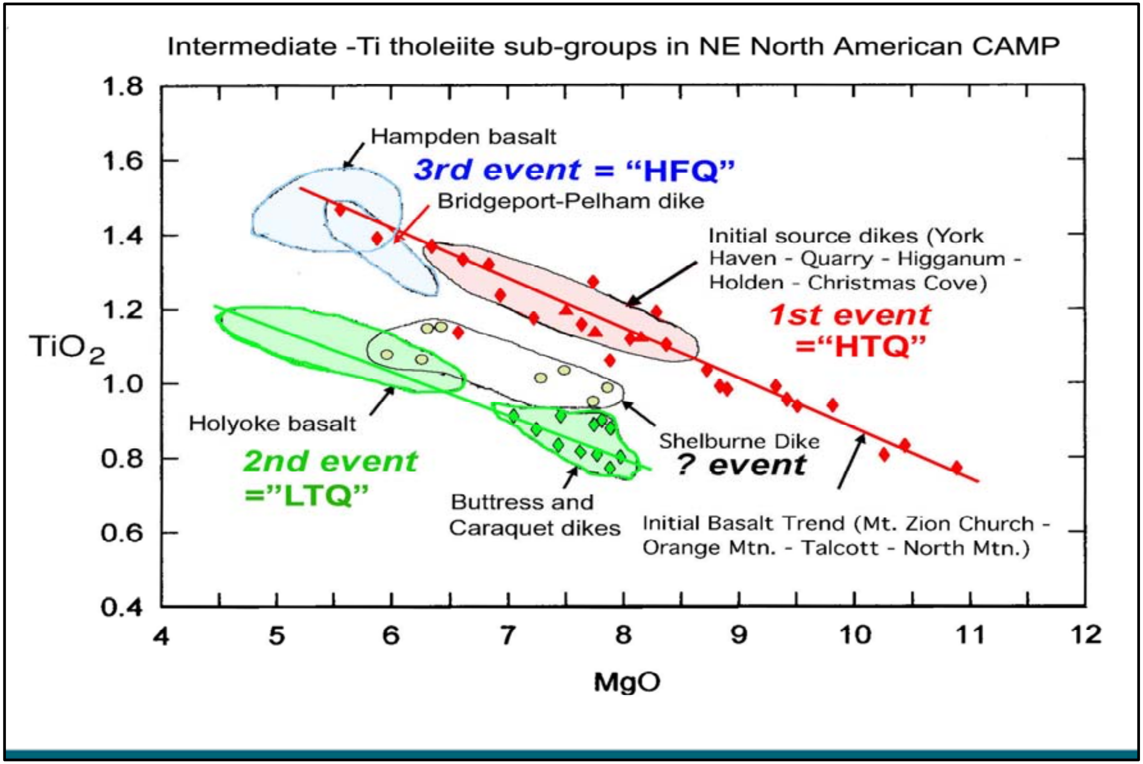
The Central Atlantic Magmatic Province or CAMP is the largest known Large Igneous Province, in area at least. Most of CAMP volcanism happened right around the Triassic-Jurassic boundary with its mass extinction, and it appears to be related to the initial rifting of Pangaea as well. The most widespread and abundant dikes and basalts are also very similar in age and composition, which in New England have been labeled as High Titanium Quartz Tholeiite or "HTQ."



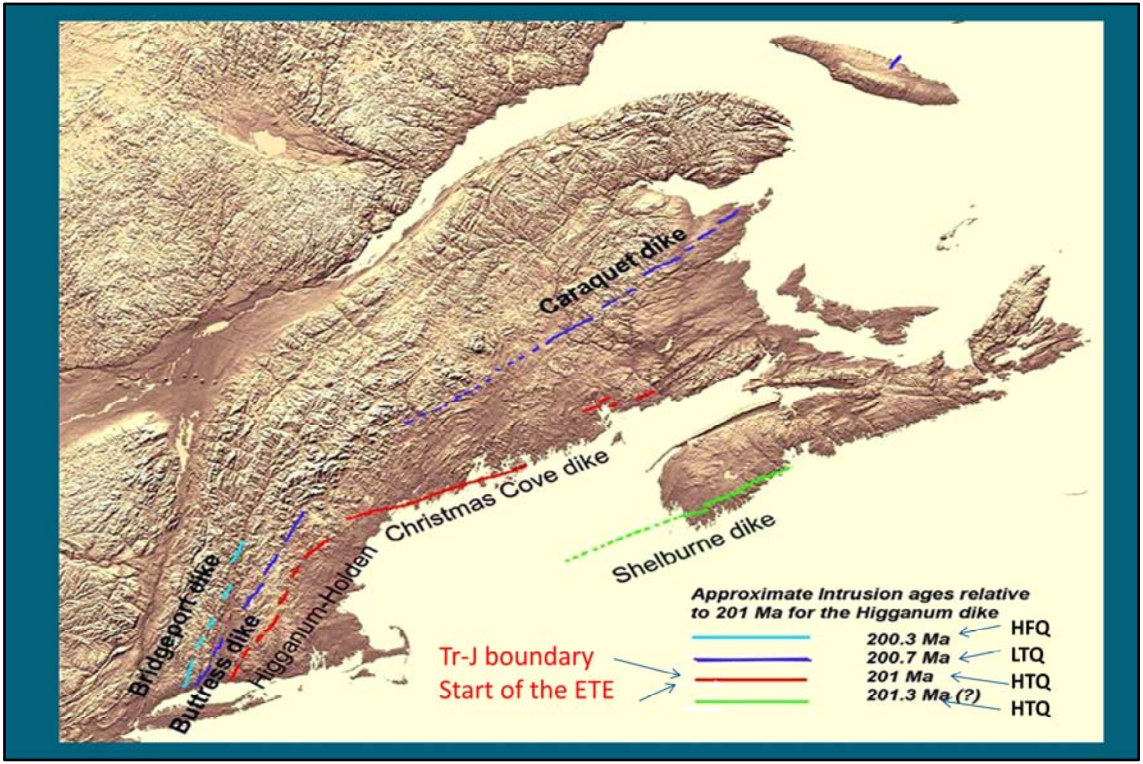
In northeastern North America, three basalt types that make large lava flows in Early Mesozoic basins appear to be derived from three dike systems that were fissure sources for the basalts. In Connecticut the oldest is an HTQ type called the Talcott Basalt, which was derived from the Higganum Dike. Dikes become younger from east to west, as shown by their basalt strata. I am still not sure of the significance of this age progression.



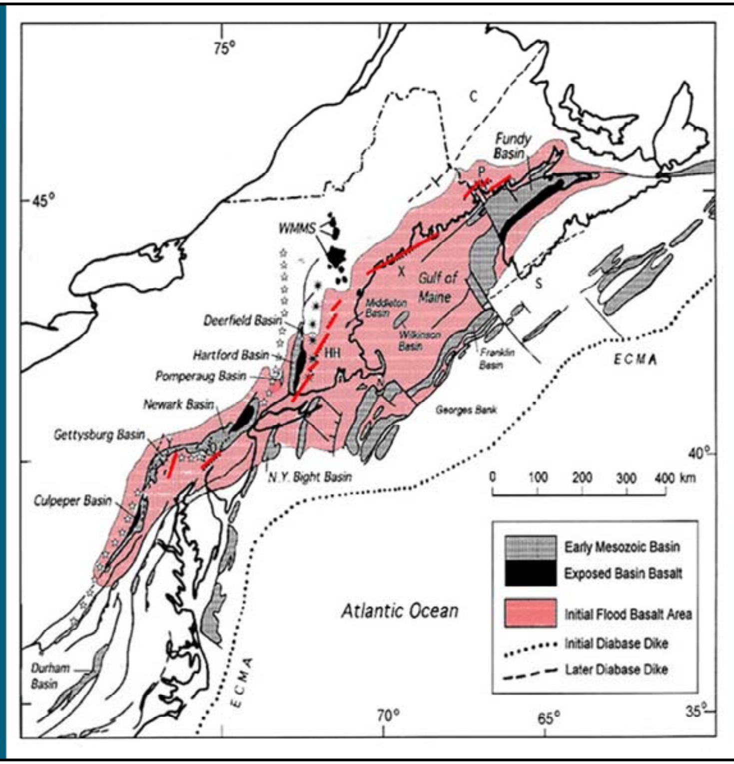
The Buttress dike (on the right) cuts across the slightly older HTQ West Rock sill west of Hamden, Connecticut. When these features formed, they were within Triassic sandstones of the New Haven formation and about 3 km beneath the surface. The dike is less than 10 meters wide while the sill is over 50 m thick. Intrusions like these provided samples for a large set of analyses made by the USGS (



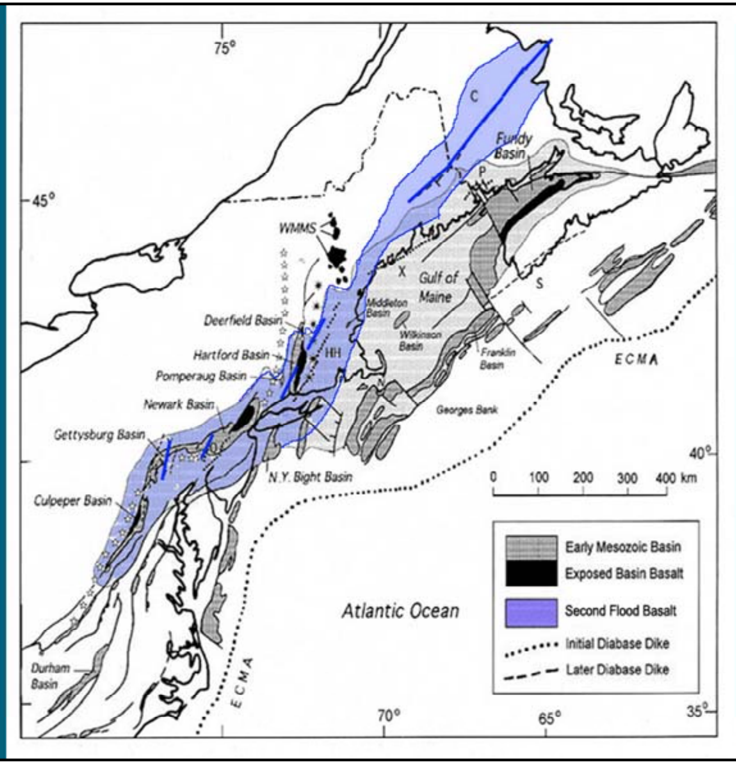
Peter Weigand's classification system (Weigand and Ragland, 1970) labels the three basalts as "High Titanium Quartz" (HTQ) tholeiite, "Low Titanium Quartz" (LTQ) tholeiite, and "High Iron Quartz" (HFQ) tholeiite , also sometimes called high iron-titanium quartz tholeiite. They are derived from the Higganum, Buttress, and Bridgeport dike systems, respectively. As shown by correlations of stratigraphy and U/Pb dates, the HTQ event in this region occurred around 201.3 million years ago, and the next two came in intervals about 300,000 years apart.



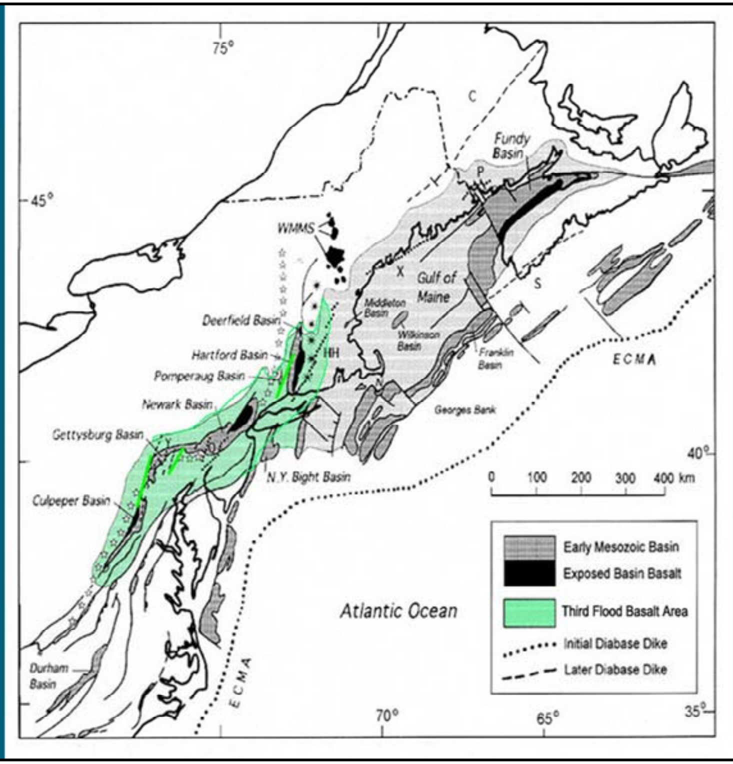
The three Connecticut fissure dike systems continue to the northeast of Connecticut for 250 to 700 km, or more. The Higganum dike coincides with the Christmas Cove dike, and the Buttress dike with the Caraquet dike, both of which run into New Brunswick, Canada. The Bridgeport Dike appears to die out in New Hampshire. There is a 4th large dike to the southeast in Nova Scotia, which is the Shelburne dike. Eastward = older(?), but it has no lava flows in exposed Mesozoic basins. The dikes continue to the southwest for an unknown distance beneath the Coastal Plain, and other dike sets of similar magma types occur in the mid-Atlantic and southeastern states.



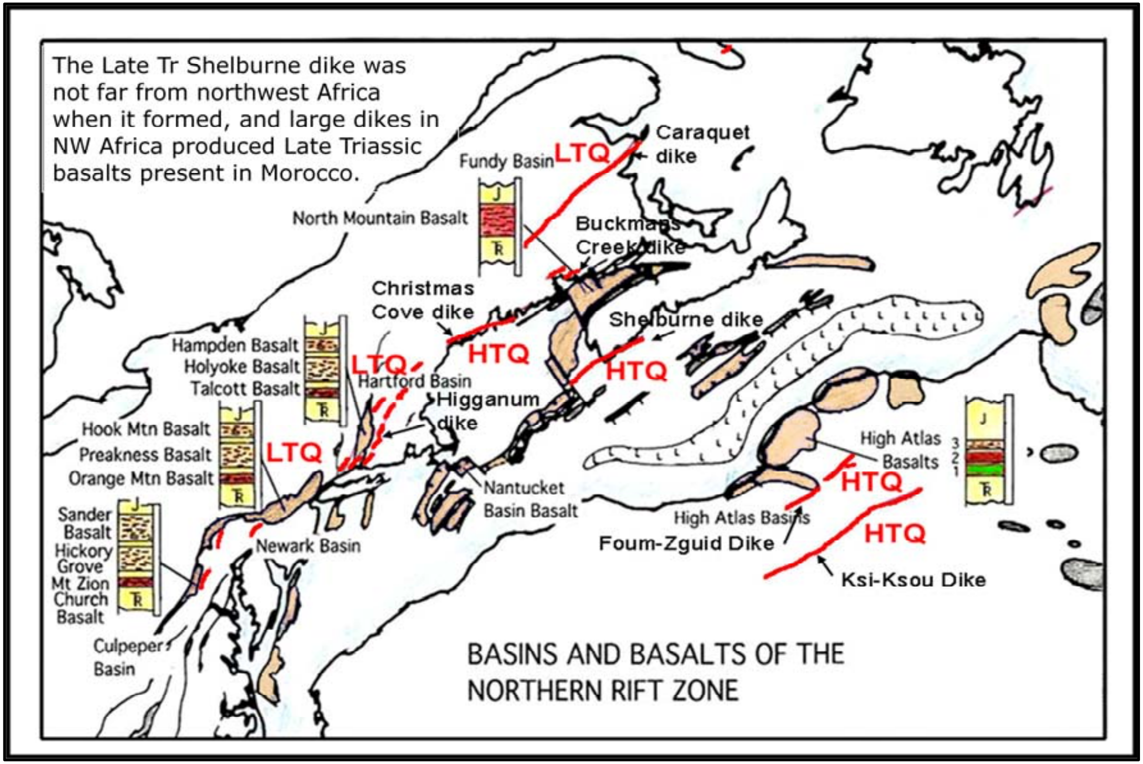
In 1996, I published in Geology (v. 24) an estimate of the area in northeastern North America that was likely to be mostly covered by basalts of the first or HTQ basalt type, based on the dike system and basalt remaining in basins both on-shore and off-shore. The volcanic area is around 500,000 km2 and at a conservative average of 100 m of basalt (more in the basins, less or none in highland areas), that makes 50,000 km3 of lava. It is a fantastic amount for a single volcanic event.



The second or "LTQ" basalt and dike system is just as long as the first, but its lava field could not be as wide as it has no lava in the big Fundy Basin. But it is very thick in the other land basins, so my estimate is 30,000 km3 of basalt.



The third or "HFQ" basalt and dike system area is much shorter and so I have estimated its basalt volume as 15,000 km3.



Variations of the HTQ basalt type are found in NW Africa and across most of the CAMP, but the LTQ and HFQ types appear to be confined to eastern North America. If the HTQ magmas are about the same age over this much larger area, as we suspect, their volcanic effect was greatly enhanced.

BASALT COMPOSITIONAL TYPES

	LTQ mean	LTQ n	HFQ mean	HFQ n	HTQ mean	HTQ n
SiO_2	51.12	35	52.74	14	52.61	560
TiO_2	0.78	35	1.05	14	1.26	560
Al_2O_3	15.06	35	13.81	14	14.06	560
FeO*	10.30	35	12.25	14	10.69	613
MgO	7.48	35	5.99	14	6.74	560
CO_2	0.076	27	0.024	5	0.125	530
S	0.060	35	0.067	14	0.032	414
F	0.017	21	0.019	14	0.030	397
Cl	0.043	21	0.013	14	0.069	398

Source: Grossman et al. (1991). FeO* = total Fe.
Major oxides and volatiles in weight %

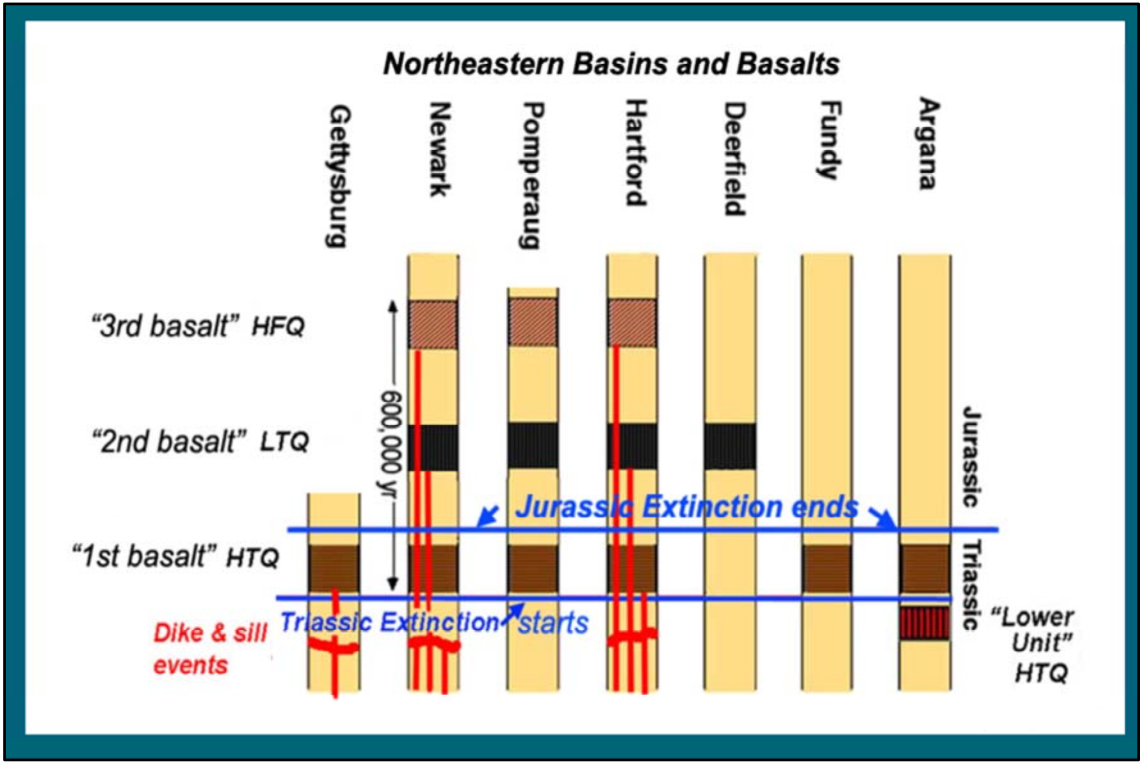
The LTQ and HFQ basalts have lower CO2 but higher contents of sulfur than the HTQ magma type in our region.

Volumes and Emission Estimates of CAMP Basalts in Northeastern North America (Pennsylvania to Nova Scotia)

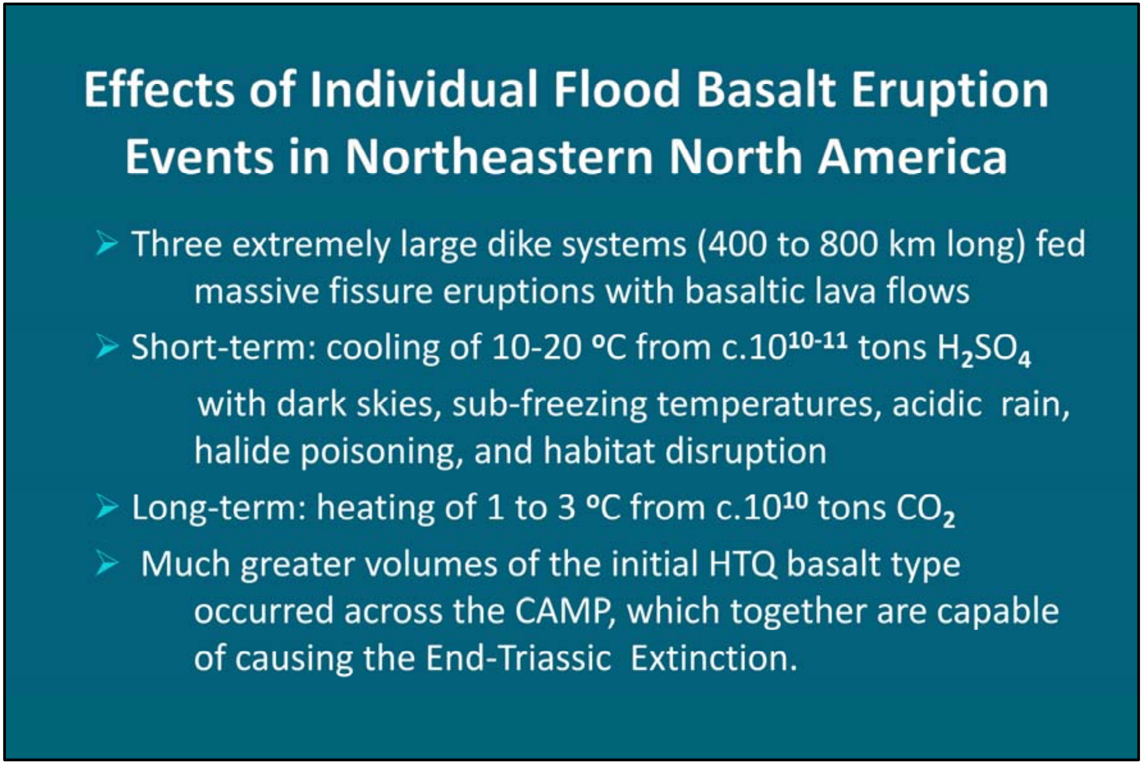
Basalt Type	Basin Basalts km3	Original Basalts km3	Original Basalt Mass megatons	H_2SO_4 Emiss. mt	CO_2 Emiss. mt	Temp Up estimated	Temp Dn estimated
HFQ	870	15,000	39,870,000	114,532	27,271	1-3°C	8-12°C
LTQ	1400	30,000	79,740,000	205,131	54,452	1-3°C	10-15°C
HTQ	9980	50,000	132,900,000	182,339	149,513	2-5°C	15-20°C
Laki	14.7	14.7	39,073	303	294	0.01°C	1.3°C for 1 year
Roza	700	1300	3,455,400	38519	24879	0.1°C	5-10°C for 10 years

Laki: Thordarson et al, Bull. Volcanology (1996) v. 58, p. 205-225
Roza: Thordarson & Self, J. Volcanology and Geothermal Research (1996) v. 74 p. 49-73

Although the HTQ basalt in northeastern North America was by far the largest in volume, the other two contain a lot more sulfur and so their sulfuric acid emissions were not greatly smaller. Measurements and estimates from Laki (Iceland) and Roza (Columbia River Basalt) fissure eruptions are shown for comparison. The cooling effects that could be caused by our volcanism are all extreme, yet there are no obvious extinction problems associated with the LTQ and HFQ. The reason must be that they are limited to our relatively small part of the CAMP, while the initial HTQ magmatism was spread across most of the huge province for a much higher total volume.



It appears that only the first basin basalt in northeastern North America can be linked to the end-Tr mass extinction. If the start of the Jurassic above this basalt marks the end of the extinction event, and the ETE commenced in the latest Triassic a little before it, then our regional HTQ basalt occurred during the event but did not start it. To the east, in the Argana Basin of Morocco, there is evidence for an older eruption of HTQ-type basalt, and much more HTQ fissure volcanism could be close to this age across the CAMP.



The three great CAMP basalts of northeastern North America must have made major environmental problems by their emissions of sulfur and carbon dioxide, yet as shown by the fossil record, by themselves they were not capable of causing mass extinctions. The earliest of the three basalts may have joined with others of similar type and age across most of the CAMP to cause the end-Triassic extinction.

Volcanism on a cold night in Iceland.