The Shatter Zone: A Physical Borderland from 420 Million Years Ago to Present and Conceptual Borderland from 1837 to Present

by Duane Braun

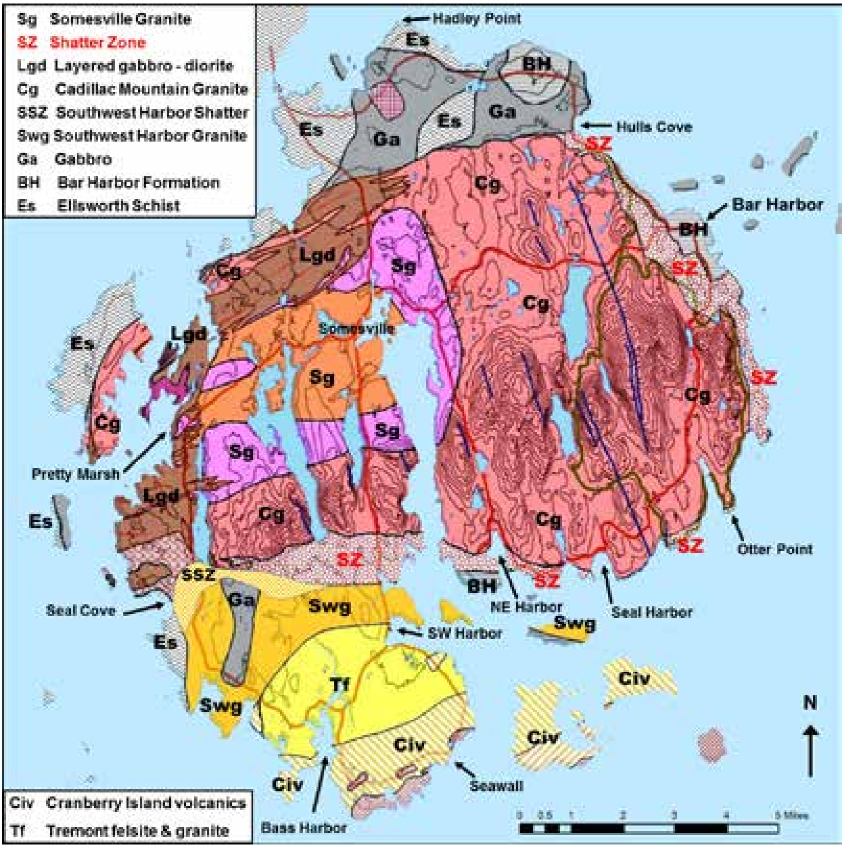
Today geologists recognize that the shatter zone on Mount Desert Island marks the edge of a large volcanic caldera that erupted 420 million years ago. This article will trace the evolution in geologic thinking about the shatter zone from 1837 to present. The shatter zone is an area where blocks of various types of rock are surrounded by light colored Cadillac Mountain granite (photo below). Granite is

Blocks of rusty colored Bar Harbor Formation and gray gabbro surrounded by lighter gray Cadillac Mountain granite at the east side of Sand Beach. *Photograph by the author*

This article is an offshoot of a 2011-2016 project to revise the bedrock geology map and surficial/glacial geology map of Mount Desert Island, to be published by the Maine Geologic Survey in a free digital format, and to produce a new geologic guidebook for Mount Desert Island, to be published in the summer of 2016. A number of Acadia National Park staff and students of our Acadia Senior College "Geology of Mount Desert Island" course have encouraged us to do this.

an igneous rock (crystalized from magma) composed mostly of pink potassium feldspar and gray quartz minerals (a felsic rock). The blocks of rock in the granite are mostly rusty red sea floor sandstones from the Bar Harbor Formation. Other blocks are dark colored gabbro, an igneous rock composed of gray calcium feldspar and iron-rich dark gray-green hornblende and pyroxene minerals (a mafic rock). Individual blocks range in size from a few inches to hundreds of feet across. The smaller blocks often have an inch-wide or so zone of recrystallized or metamorphosed material in contact with the granite.

The shatter zone forms an arcuate belt or borderland around the Cadillac Mountain granite on the eastern and southern parts of Mount Desert Island (SZ on map below). The Cadillac Mountain



Simplified geologic map showing the arcuate shatter zone (SZ) and the other major rock masses on Mount Desert Island. *Modified from Braun, "Bedrock Geology Map of Mount Desert Island, Maine," in preparation for 2016* granite (Cg) forms a semi-circular area to the west and north of the shatter zone. To the northeast, east, and south of the shatter zone are slightly metamorphosed sandstone and siltstone layers of the Bar Harbor Formation (BH) cut by vertical to horizontal strips of gabbro. To the south of the shatter zone lies the Southwest Harbor granite (Swg) and the volcanic ash and lava flow layers of the Cranberry Island Series (Civ). To the west and northwest of the Cadillac Mountain granite is the metamorphic rock of the Ellsworth schist (Es).

Charles Jackson, in 1837, was the first geologist to observe what is now called the shatter zone.[1] He noted that blocks of other rock types had the appearance of having sunk into the granite. That implied that the granite was "in a melted state" at the time the blocks sank into it. At that time, there was a major argument among geologists between the "Neptunist" and the "Plutonist" or "Vulcanist" schools of thought about the origin of granite. The Neptunists were lead by Abraham Werner, a prominent German geologist in the late eighteenth and early nineteenth century. They thought that all rocks, including granite, were precipitated from sea water, and that all volcanic activity was a recent phenomenon that cut across all the older rock. The Plutonists were lead by James Hutton and John Playfair, important English geologists of the late eighteenth and early nineteenth century. They noted that "great subterranean heat" was shown by volcanic activity. They contended that the crystalline rocks, like granite, were once hot molten material from "igneous fusion" and had cooled at depth. By the 1830s, the time of publication of Charles Lyell's Principles of Geology, the Plutonists were in ascendance, and Charles Jackson was one those geologists that from his own field observations agreed that granite had once been hot magma.

Nathaniel Shaler, in his 1889 "The Geology of the Island of Mount Desert, Maine,"[2] briefly described the shatter zone in these terms:

> At the contact of the central granite with the bounding walls the number of these divergent dikes [of granite] is extremely great. … The dikes extending from the central granitic mass are most plentiful near that mass and become

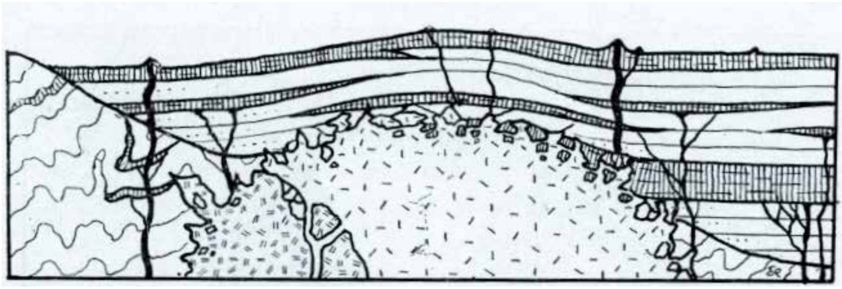
> less in size and of rarer occurrence as we go away from what we may call the contact wall.

His wording implies that he envisioned the molten granite being forcefully injected into fractures in the surrounding "country rock" rather than blocks of the country rock sinking into the fluid granite. He was the first to draw a map of the geology of the island and showed the central granitic area surrounded by older rocks that were cut by the granite. The older rocks were all stratified sedimentary rock or volcanic ash that had been metamorphosed, or recrystallized, by heat of varying intensity. The oldest rock, like that on Bartlett Island, was the most metamorphosed, forming a micaceous schist, while the somewhat younger rock around Bar Harbor was only metamorphosed to slate. At the end of the report, when discussing the origin and history of the rocks, he noted,

> This granite was evidently in a fluid condition, as is shown by the degree to which it penetrated into narrow crevices and the extent to which it has metamorphosed the rocks with which it came in contact, yet at no point is there any trace showing that it flowed superficially in the manner of lava. In fact, we nowhere know of any granitic rocks which have flowed over the surface of the earth. Thus theory, as well as fact, compels us to suppose that these granites were completely incased in deposits which once mantled high above the existing surface of the highest hills of the island.

These statements show the state of geologic knowledge at the time: Granite was certainly once molten, and it crystallized slowly deep below the ground surface. It also shows that no connection had yet been made between granite as the source magma for the eruption at the surface of fine-grained rapidly crystallized volcanic rock called rhyolite that has the same chemical composition and mineralogy as granite.

Erwin Raisz, in 1929, in his "The Scenery of Mount Desert Island: Its Origin and Development," drew a series of schematic side-view or cross-section illustrations of the successive geologic events that formed the different bedrock units on the island.[3] Just as



Raisz's conception of the granite pluton cutting across the Ellsworth schist (wavy line pattern) and intruding into the overlying Bar Harbor sediment layers and gabbro layers (vertical line with tick mark pattern). *Raisz, Figure 4, courtesy of John Wiley & Sons*

Shaler had described it, Raisz showed the granite as a mass that never reached the surface (diagram above). He noted that the contact of the granite with the surrounding rock was irregular, with blocks of that rock penetrating into and being incorporated into the granite. He visualized that some of the mafic gabbro dikes (near-vertical crack fillings) had cut across the granite to reach the surface as fine grained basalt to form small volcanoes. At this time, there was still little understanding by geologists of how the granite that cooled well below the surface may have been connected to volcanic activity at the surface.

George Chadwick, in 1939, in his "Geology of Mount Desert Island, Maine"[4] did not emphasize that the granite surrounded blocks of country rock in a shatter zone, but rather that the granite "forms a broad low dome rising (in some places very steeply) up into the older rocks that once roofed it over. Its failure to disturb notably these older rocks, where they rest against it, is evidence that the molten granite melted or engulfed the rock it has replaced." But then he went on to note that "The lower north half of the granite area … is so filled with inclusions of the older rocks for a long way back from its mapped boundary line as to make the drawing of that line often a matter of the personal equation."

These statements are part of his hypothesis that

> The granite mass of Mount Desert … is but recently unroofed and exhibits closely the original conformation of its roof. The cross-valleys in its mountain range are preglacial and were determined by roof-pendants [down

> dropped blocks of country rock] and by keystone faults [faults that bound the down dropped blocks].

Chadwick was following the geologic thinking of the time that the granite "engulfs" the surrounding rock without causing a volcanic eruption at the surface. What he added was that the present landscape is essentially the irregular top of the magma chamber that erosion had recently exposed or unroofed.

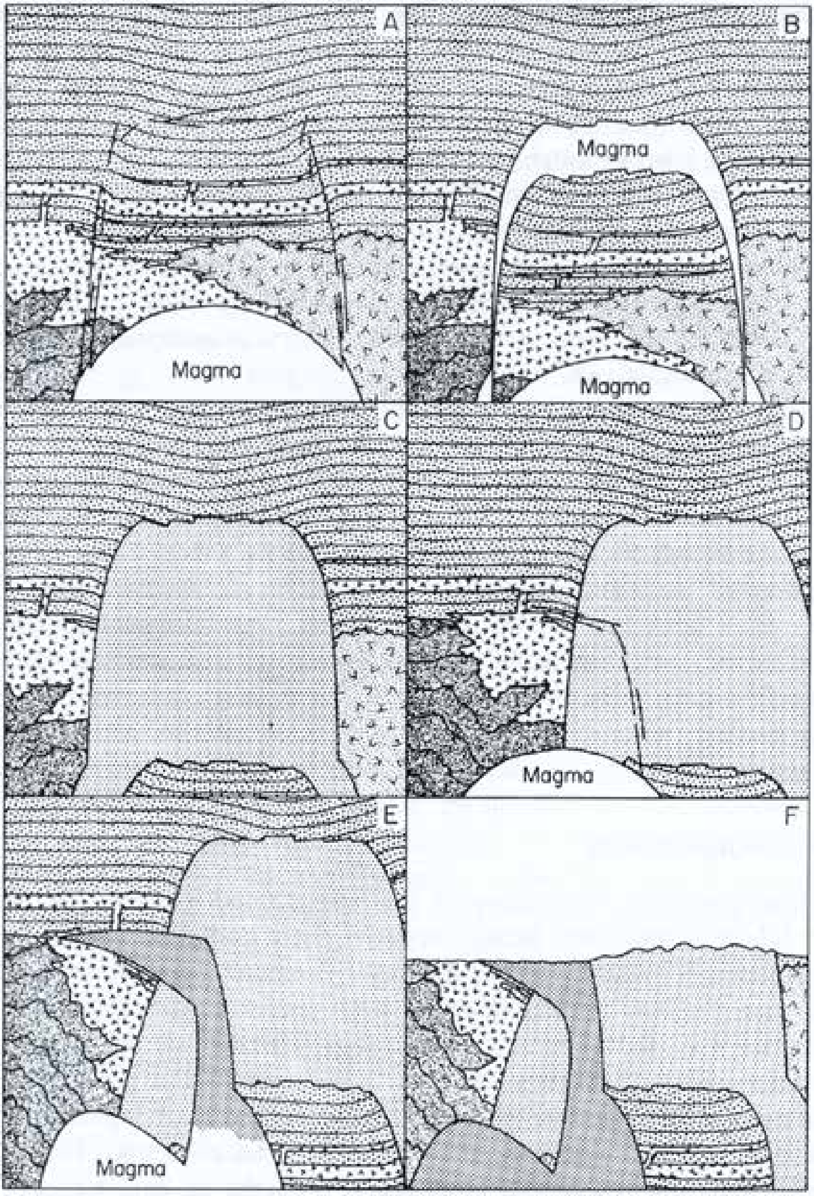
He was also the first to map an extensive area on the west side of the island of a light gray rock called diorite, intermediate in composition between granite and gabbro. This area of diorite would fifty years later become critical in understanding the connection between the granite, the shatter zone, and volcanic activity at the surface.

Carleton Chapman in 1953 in an abstract entitled "Cauldron Subsidence at Mount Desert Island, Maine" coined the term "shatter zone" for the contact or border zone of the granite with the surrounding country rock.[5] As he described it,

> A shell of intense shattering is conspicuous in the country rock along the entire extent of the intrusive [granite] contact. The shell is approximately half a mile wide. It grades inward from undisturbed country rock, through breccia without granitic material, to injected and granitized breccia [angular fragments surrounded by granite], to inclusion-rich granite, to inclusion-poor chill granite, and finally to normal granite.

In the 1950s and 1960s Chapman developed the concept of "cauldron subsidence" to explain the intrusion of both granite and gabbro, so-called bimodal intrusions, in eastern Maine. The theory involved the initial intrusion of gabbroic magma, granitic magma forming on top of the hotter but denser gabbro, and then one or more collapses (stoping events from mining terminology) of the magma chamber roof into the magma chamber. All this took place well below the ground surface.

Chapman applied the cauldron subsidence theory to Mount Desert Island in his 1962 and 1970 guidebooks to the geology of



Intrusion of the granites on Mount Desert Island by two cauldron subsidence events. A) Initial fracturing above the magma chamber. B) Initial subsidence. C) Intrusion of Cadillac Mountain granite. D) Second initial fracturing of only one side of the chamber. E) Intrusion of the Somesville granite. F) Post-intrusion erosion of overlying rock and the upper part of the old magma chamber to form the present landscape. *The image is from Carleton A. Chapman, The Geology of Acadia National Park (Old Greenwich: The Chatham Press, 1970), figure 2.*

the island. In his section on the "Great Invasions of Molten Rock," he proposed two separate collapse or stoping events to explain the intrusion of the Cadillac Mountain granite followed by a second intrusion of the Somesville granite (sequence of diagrams on the previous page).[6]

The geologic framework for Mount Desert Island that Chapman was working with during this period, supported by the earliest radiometric or numerical age dates for the different rock units, was not too different from that first developed by Shaler in 1889. Chapman was convinced the available evidence showed that the Ellsworth schist was the oldest rock unit followed by the extrusion of the Cranberry Island volcanic layers that in turn was followed by the deposition of the Bar Harbor sediments. The Cranberry Island volcanic material was thought to have a numerical age of 420 million years, while the Cadillac Mountain granite was forty-five million years younger with an age of 375 million years.

Gilman revised Chapman's work in the late 1970s to early 1980s, though it was not published until 1988 in an updated guidebook to the geology of Mount Desert Island.[7] He noted,

> Though details of its formation are not fully understood, the shatter zone is undoubtedly related to the intrusion of the Cadillac Mountain granite. Close to the main body of granite the light colored matrix that surrounds the angular pieces appears to be a mixture of ground-up and recrystallized country rock plus fine-grained Cadillac Mountain granite. Farther away, the light colored matrix is believed to be exclusively ground-up and recrystallized country rock. This suggests that the shatter zone resulted from severe fracturing of the country rock as the granite was intruded.

Gilman continued to use Chapman's cauldron subsidence theory to explain how the granites were intruded and formed the shatter zone.

The geologic framework or sequence of Mount Desert Island geologic events had also changed somewhat with the Cranberry Island volcanic layers now thought to be younger than the Bar

Mingling of blobs of dark gray mafic gabbro in light gray felsic granite along the shore of Stewart Head on the west side of Mount Desert Island. *Photograph by the author*

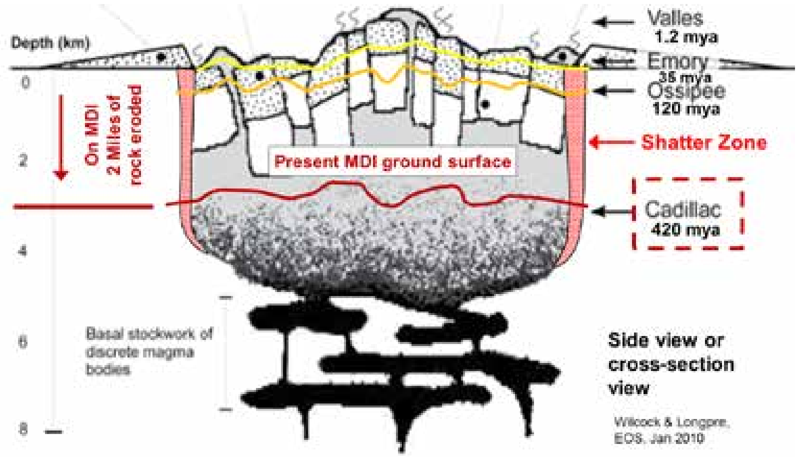
Harbor sediments. Still the Cranberry Island material was considered to be on the order of twenty million years older than the Cadillac Mountain granite.

From the 1970s through the 1990s, global geologic research, both in the field and in the laboratory, rapidly advanced knowledge on the connection of volcanic activity at the surface with magma chambers at depth. It was determined that highly explosive volcanism occurred when granitic magma approached the surface and eruptions deposited thick sequences of felsic ash and flows. Some modern day volcanoes were erupting both felsic and mafic material, so called bimodal volcanism. In the laboratory, it was discovered that felsic and mafic magmas didn't mix, but rather mingled as immiscible (unmixable) fluids, examples of which are common along the western shore of the island (photo above).

Since the 1970s, Robert Wiebe has specialized in research on bimodal magma chambers that had alternating episodes of felsic (granite-rhyolite) and mafic (gabbro-basalt) magma injection. In 1994 he published a research paper entitled "Silicic Magma Chambers as Traps for Basaltic Magmas: The Cadillac Mountain

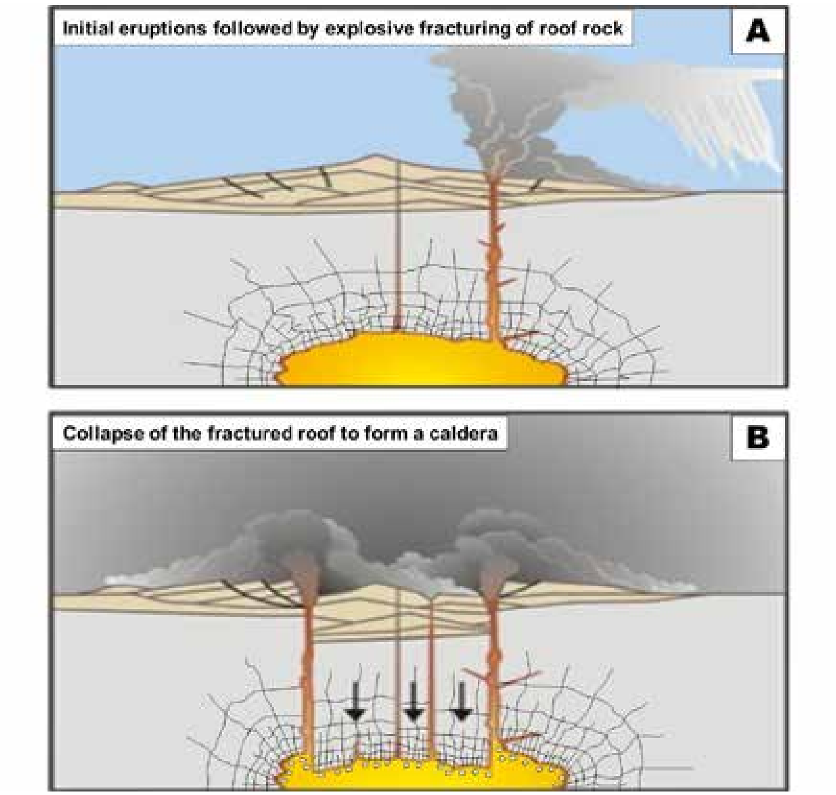
Intrusive Complex, (CMIC) Mount Desert Island, Maine."[8] For the first time, it was recognized that the gabbro and diorite on the west side of the island was not older than the Cadillac Mountain granite but rather contemporaneous with the granite. Hot dense gabbro magma was injected into the still molten Cadillac Mountain granite, adding a lot of heat and pressure to the Cadillac Mountain magma. Wiebe noted that other geologists thought such injection of gabbro magma into granite magma cause explosive caldera-forming volcanic eruptions where the rock around the top and sides of the magma chamber collapse into the chamber. Wiebe, though, did not directly call for the injection of gabbro into the Cadillac Mountain granite magma to cause a caldera-forming eruption and formation of the shatter zone around the edge of the magma chamber.

Sheila Seaman has specialized in research on volcanic activity since the 1980s. She and her students have studied the Cranberry Island volcanic series since the early 1990s. Seaman, Wiebe, and others, in 1995, noted that the CMIC and the Cranberry Island volcanics (Civ in the map on page 46) were geochemically similar.[9] Seaman and others, in 1999, noted that the radiometric age in years of CMIC and Civ were essentially the same.[10] Thus, the nine thousand-feet-thick tilted stack of volcanic ash beds, pyroclastic



Schematic cross-section view of a volcanic magma chamber and collapse caldera at the surface. The land surface during the erosion of the volcanic system is shown by the irregular lines labeled by the name and age of the volcanic caldera. *Modified from J. Wilcock et al., "Calderas Bottom to Top," Eos 91, (January 2010): 1-2* flows, and lava flows on the Cranberry Islands should have come from the CMIC intrusions. They went on to note that the thickness of the Civ layers indicated very large explosive eruptions that should have formed a caldera over the CMIC.

Jack Wilcock and others, in a 2010 article entitled "Calderas Bottom-to-Top," used Mount Desert Island as a prime example of an old, deeply eroded caldera.[11] The article was a synopsis of a field trip across the United States to examine the formation of a "supervolcano" caldera by visiting calderas of various ages. Mount Desert Island was used to show the deeper parts of a magma chamber under a caldera, while the younger sites showed the upper collapsed part of the caldera (diagram on previous page).



Shatter zone formation. A) Initial explosive fragmentation of the country rock. B) Subsidence of the fractured material into the magma chamber as the caldera forms. Modified from base diagram. *Courtesy of the US Geological Survey*

Samuel Roy and others, in 2012, examined the shape of the fragments in the shatter zone and concluded they were initially broken apart by a volcanic reservoir explosion (diagram A on previous page) and then immediately intruded by superheated magma.[12] After that, the shattered material sank into the magma chamber as pressure was reduced by the eruption of large amounts of ash and lava at the surface (diagram B on previous page).

Sheila Seaman in 2015 used the term supervolcano for CMIC and other nearby volcanoes of the Coastal Maine Supervolcano Field to emphasize the scale of the explosive caldera-forming eruptions.[13] Indeed, the ten-mile or more diameter caldera that once existed two miles above the present landscape, now outlined by the shatter zone, is twice the size of the Crater Lake caldera and one-fourth the size of the Yellowstone caldera. The shatter zone has now come to be considered key evidence for the scale and violence of the volcanic eruptions spawned by the intrusion of granite and gabbro under Mount Desert Island.

Duane Braun did field work in 2012–2014 to revise the geologic maps of Mount Desert Island.[14] During that work, he discovered that the previously mapped shatter zone on the southwest part of the island was a composite of two adjacent shatter zones. There is a strip of shattered material in the Southwest Harbor granite (Ssz on the geologic map, page 46) that is from the initial caldera-forming eruptions that deposited the Cranberry Island volcanic series (Civ on the geologic map, page 46). Next to it on the north is a strip of shattered material in the Cadillac Mountain granite that gets narrower until it disappears or "wedges out" along the south flank of Bernard Mountain, leaving just the Southwest Harbor granite shatter zone (Ssz) to continue westward to Seal Cove. Now, the shatter zone on the southwest side of the island is an integral part of a complete package from a single intrusive and extrusive igneous event—the intrusion of the Southwest Harbor granite, the shattering of the rock to form a collapse caldera, and the extrusion of nine thousand feet of volcanic material on the Cranberry Islands. In the Bar Harbor area where the "original" shatter zone in the Cadillac Mountain granite (now the second shatter zone) is at its widest, the zone shows alternating strips of granite with few fragments and granite packed full of large fragments marking the "keels" of down-dropped roof blocks.

So while the two-part shatter zone itself has simply been eroding away since its violent formation 420 million years ago, geologic thought about its origin has evolved a lot in the geologic instant of the last 178 years. Initially, in 1837, the shatter zone was used as evidence for the originally molten nature of granite. From the 1880s through the 1980s, it was pictured as part of the roof of a magma chamber, and the details of that roof and how it formed became more intricate with time. Then in the 1990s to present, due to the rapid expansion of knowledge about volcanic systems in general and the CMIC on Mount Desert Island, the shatter zone was recognized as the edge of a large volcanic caldera. The most recent work is simply adding more details to how the shatter zone formed around the edge of the caldera.

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