From Gondwanaland, With Love:
The Tale of How Boston Got Its Rocks

by

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ABSTRACT

The rocks on which the city of Boston was built did not form as part of North America. They formed about 600 million years ago, at the South Pole, as the northern coast of a supercontinent called Gondwanaland. Boston's journey from the South Pole to its current location traces the world's geologic history over that period of time, including the emergence of animal life as we know it, the formation and destruction of Pangaea, and the rise and fall of the dinosaurs. More than that, though: the history of our understanding of Boston's journey illustrates how geologists think about their world, and how their ideas have changed over the last 150 years in one of science's great revolutions.

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"The life of our city is rich in poetic and marvelous subjects. We are enveloped and steeped as though in an atmosphere of the marvelous; but we do not notice it."

Charles Baudelaire
"On the Heroism of Modern Life" *1845*

Pick a city - any city – and look. Really *look*. You'd be surprised by what you found: the whole spectacle of Earth history laid out, waiting to be read – slabs of ice that sculpted the mountains and then vanished, dizzying successions of animals, behemoths in violent collisions too subtle and slow to be noticed in a lifetime.

Los Angeles is the sheared, faulted convergence of two empires of rock. New Delhi is riding in the wake of the most violent mountain-building event of our time, as the Indian subcontinent plows headfirst into Asia. Manila straddles a tectonic intersection of nightmarish complexity. Tijuana is being pulled into the sea.

And so it is in Boston. The Hub of the Universe is an immigrant city, made of the shards of long-gone continents that collided with North America hundreds of millions of years ago. More than half a billion years of Earth history can be seen through the lens of Boston, if you peered under the skyscrapers, lifted Fenway Park, poked around through every subway.

Over the last 150 years, geologists have gradually come to understand how the rocks under Boston formed, and they have found something more: Boston does not belong to North America. Nor does it belong to Europe, Africa, or any other continent that left its mark on the United States.

From the earliest naturalists who studied with awe anything they could get their hands on, to the scientists who addressed the paradox presented by Boston's ancient fossils, each geologist approached Boston from within the intellectual landscape of their time. Their assumptions and ideas – sometimes sharp, often bizarre – form another kind of lens, which gathers all the minute details of their observations of this one small city, and projects a vision of how we have thought about the Earth, and how those thoughts have been transformed, in one of the science's great revolutions.

Today, dozens of geologists and students study Boston's rocks every year. But, in 1856, when our story begins, there were only three: the Swiss polymath Louis Agassiz, the eccentric – often maddening – Charles Thomas Jackson, and a tall, stately Virginian, named William Barton Rogers.

The Most Important Rock in Boston

If ever there was a place steeped in an atmosphere of the marvelous, it was the library of a Colonial-style building on Mason Street, on the east side of the Boston Common. The building is gone now, demolished to make way for a cineplex and a one-way alley, but, in 1856, the walls were lined with thousands of books, and the cabinets and tabletops bristled with mysterious objects: skeletons of mastodons and elephants, human skulls, gold from California, rocks from the Himalayas, 209 species of birds, 6,000 species of plants, the complete skeleton of an adult male moose[i].

This was the library of the Boston Society of Natural History, the heart of the city's scientific community. Once a month, the city's naturalists gathered there to celebrate the nature of their city. In that oil-lit room, Boston's science-minded citizens would hear of the first Neanderthals, discovered in a few months time. In two years, reports of speeches by a Mr. Darwin and Mr. Wallace of England would reach them. The ways in which they thought about the world were changing.

But on August 6th, 1856, as William Barton Rogers stood in that room on Mason Street, those changes were just beginning.

William Barton Rogers was a giant in both height and intellect. Towering, thin, and stately, with heavy eyelids and a fantastically large nose, Rogers might have been mistaken for Ichabod Crane, if it weren't for his famously sharp eyes[ii]. He had arrived in Boston three years earlier, after mapping vast portions of the Appalachians and developing a theory of mountain building that would ensure him a place in geology's history books. In five years, he would found the Massachusetts Institute of Technology. Genial and eloquent, he was one of the most influential geologists of his time. And he had come to announce a new discovery.

In the true spirit of Victorian naturalists, the Society members who gathered to hear him were curious about just about everything. Later at the same meeting they would hear presentations on the coal beds of North Carolina and theories on why birds' feathers change colors. Dr. Weinland would relate to them a case he had heard of where a cat caught a bird, whose feathers turned completely white with shock[iii]. Mr. Sprauge would present a rare fungus. "Its odor is intolerably strong and disagreeable," he would tell them. "But the strangeness as well as beauty of its structure will repay an examination, which may particularly offend the sense of smell."

William Barton Rogers's discovery counted as strange, beautiful, and, for a refreshing change, actually important. The Society members were taken aback.

He began by showing his audience a foot-long slab of rock, and described how he happened to find it:

That summer, Peter Wainwright of Quincy had written Rogers to report some fascinating rocks in the area. A Boston suburb that was home to several quarries, Quincy was famous for its granite. Its churches are granite, its walls are granite, its town hall, curbstones, and tombstones are granite. The stone is beautiful, gray, forming gently rolling hills amidst the otherwise featureless mudflats along the Weymouth River.

Quincy ends at a small industrial street called East Howard. The north side of East Howard Street is built on rugged gray granite, with broad hills, pine trees, and tall bushes. The south side of East Howard – the edge of the city of Braintree - is built on Cambridge Slate: flat land with tall grasses. On this subtle border, Mr. Elphias Hayward and his family ran a quarry – and it was this quarry that had excited Rogers's interest.

The Haywards quarried that slate, a rock made of compacted mud that is still commonly used for roofs and walkways. The quarry workers pulled up enormous slabs of the stone, and sent them to the wharves of Boston to be packed in the hulls of ships. For some years, Elphias Hayward had noticed what he called "images in the rock" – strange patterns which meant nothing to him, but seemed to startle Rogers when, just after he arrived, they began to sift through the slate. [iv]

The pit of Hayward's Quarry was a box of deep green slates: smooth, flat stones that had formed when mud precipitated out of a shallow sea, a formation that now underlies most of Boston, Cambridge, and parts of Roxbury and Braintree. Pyrite had stained the rock in places, creating glittering patches of rust against the green, and thin veins of quartz snaked their way through the walls.

Slate is a flakey rock, like sheets of paper stacked together. It begins life as a mudstone, made from fine sands and muds that precipitate out of a quiet sea. Over time, the weight of overlying sediments crushes and folds the mudstone, forming the metamorphic rock of slate. One hammers the ends of the sheets until they break, then, by hand, gently pulls them apart to reveal the pages within. The pages are the rock's autobiography: what was the ocean like when it formed? Was it shallow water or deep? Was it stormy or quiet? What animals lived there? The life history of the Earth has been pieced together by pages torn from quarries and outcrops all over the world – and now for the first time, in Boston. When William Barton Rogers pulled open a piece of slate at Hayward's Quarry, he was not disappointed: the rock held the fossilized imprint of a giant trilobite.

Rogers stared at the first fossil ever recognized in Boston. It was enormous: the size of a large cat. A smooth dome of a head crowned its box-shaped body, and two long, lobster-like antennae extended from the top. The seas once bristled with more species of trilobite than there are now species of birds, and they came in all manner of shapes, sizes, and styles. Some swam, some crawled, some floated like plankton. The trilobite that Rogers found had been a skillful predator along shallow beaches, a stingray-like creature that alternately swam and crawled. It had lived briefly, been buried in mud, and now gave William Barton Rogers something priceless: a relative age for his city.

In 1856, geologists did not know how old the Earth was, but they could guess at the ages of rocks based on the fossils they found in them. Usually, younger rocks are deposited on top of older ones. Starting in the early 1800s, geologists had used this basic insight to assign relative ages to the fossils found in these rocks. Fish started appearing in rocks long before insects did. Fossil corals start showing up in rocks long after insects, and mammals even later than that. Today, we know that many rocks are too old to hold fossils visible to the naked eye - more than 80 percent of Earth history left no animal-like fossils. But in 1856, the most ancient rocks that geologists knew contained fossilized trilobites. To William Barton Rogers, standing in a box of green slate in Quincy, Boston now appeared to be built on some of the oldest rocks on Earth.

"This is the most curious and important discovery ever made in the geology of this region," he wrote to his brother. [v]

The scientists at the Boston Society of Natural History could not have agreed more. As Rogers finished his story, a small flurry of polite exclamations ensued. A tall, broad-shouldered and bespectacled geologist named Charles Thomas Jackson leapt to his feet to declare that he had seen a similar fossil before, in the collection of one of his friends. A more mild-mannered patent clerk calmly observed that the trilobite had thrown "a clear light on what was obscure." And the great Louis Agassiz naturally wanted a plaster cast.

Louis Agassiz was a six-foot, burly, cigar-smoking zoologist from Switzerland, and Boston's most famous naturalist. Rogers, hoping for help in identifying the fossil's genus and species, readily allowed him to make a cast of it, and Agassiz retreated with the impression to his laboratory at Harvard. There, amidst a laboratory bristling with even more fantastic natural objects than even the Society's library, Agassiz set about identifying the genus of Rogers's trilobite.

To anyone but a zoologist, identifying an animal's genus and species is mind-numbingly dull work, but Louis Agassiz lived for these minute observations. He carefully measured the fossil's length and width, identified the deep rib-like indentations, and characterized its alien-sounding parts with equally alien-sounding adjectives: "an upstanding anterior cranidial border," "an ovate pygidium," "variously impressed glabellar furrows." Thus armed, Agassiz compared his description with those of other naturalists, trying to find a fit. However powerful his mind, Rogers did not have had the training or resources to carry out this tedious process of identification.

"My dear Sir," Agassiz wrote Rogers on August 13th, "The cast I took yesterday of your ... most interesting trilobite enables me at once to ascertain beyond doubt the genus to which it belongs. It is Paradoxides, all the known species of which are Lower Silurian," referring to a period of Earth history, which, at the time, was recognized as having the first fossils. The genus *Paradoxides,* means "the paradoxical."

"A more interesting and important discovery for the geology of Boston's vicinity," Agassiz continued, "could not have been made."

Coming from Agassiz, this was high praise, and all the confirmation Rogers needed. He wrote his brother: "I am preparing to take [the trilobite] to the Albany meeting," referring to the upcoming meeting of the American Association for the Advancement of Sciences (AAAS).

He continued: "Agassiz expresses great pleasure at this discovery and quite agrees with me as to the character of the fossil."

Not everyone did. At the AAAS meeting in Albany, the trilobite prompted such a debate that the easily-provoked Agassiz felt compelled to defend it - and a somewhat befuddled New York *Daily Times* reporter felt compelled to write about it:

> The proofs adduced by Prof. Rogers in his paper excited a sharp and vigorous discussion, in which the author, Mr. Agassiz, Prof. Hunt, Mr. Leslie, Sir Wm Logan, and Prof. Emmons joined. The opinion was expressed on the highest authority that the discoveries just announced to the Association would compel a reinvestigation of the whole subject. The opinion was by no means allowed, however, to pass unchallenged, especially on the part of the Canadian delegation.

Prof. Emmons did not coincide with the sentiments expressed as to the age of the rocks of New England. He was saying, 'We shall have to ignore all the principles of geology, if ----'

'Why not?' asked Mr. Agassiz ---- There was a little confusion about the desk.--- "Why not?" repeated Mr. Agassiz. "We construct our system of belief, why not reject it when"---

'I am not in the habit,' resumed Prof. Emmons, 'of interrupting gentlemen while speaking . . .'

'I beg to apologize,' said and immediately reiterated Mr. Agassiz: 'I am exceedingly sorry to interrupt any gentleman;' - and so the flurry subsided and Dr. Emmons proceeded.

Satisfied that he had covered the controversy, the reporter moved on to report that Major Emory had a throat infection, which had prevented him from giving his scheduled talk. [vi]

That was all the media coverage surrounding Rogers' announcement - what noted American naturalists were calling the most important find in the history of Boston geology: a few lines summarizing the moment when Louis Agassiz interrupted Ebenezer Emmons, then apologized.

Connecting Boston to the World

We will probably never know what principles of geology Professor Emmons was so upset about, but, whatever the issue, it was almost certainly beside the point. Early paleontologists were curious about every feature of Rogers's trilobite (legs, eyes, locomotion, food, ability to curl up into a ball) - except one. As it turned out, this was its most important attribute: the exact same trilobite had been found in Wales.

Today, Boston and Wales have almost nothing in common as far as flora and fauna are concerned. The plants and animals native to New England are distinctly different from those native to Old England, and for a very good reason: the Atlantic Ocean. Land and shallow-sea creatures cannot cross it, so they are found only in Old England or only in New. The trilobite, being a beach-loving creature, could never have made the journey.

But, as naturalists were discovering, trilobites seemed oblivious to the Atlantic Ocean, and not just in Boston. Identical species of trilobite had been found in Ohio, New York, Indiana, Virginia, and Canada, which was fine - but then they turned up in England, Spain, and Bohemia as well. Rogers's trilobite was different from the New Yorker trilobites, but identical to those of Wales.

"It is an interesting subject of inquiry," the naturalist James Ellsworth Dekay observed, "how far the fossil species of our continent agree with, or differ from those of Europe."

After all, he continued, North American animals and plants today are very different from Europe's - wouldn't one assume that the same would be true for past animals and plants? "This, however, does not appear to be the case," he told a gathering of naturalists in New York City. "For, in comparing American rocks that have hitherto been examined, and their fossil contents, with those of Europe, it would seem to be probable, that the remains they contain are identical." [vii]

Identical. The trilobite seemed to link all of North America to Europe in a way that no living plant or animal would dream of. But Dekay didn't ask why. He stated the problem, called it curious, and moved on to a description of the hunt for trilobite legs.

In fact, no one asked why. In all the collecting, cataloging, describing, and measuring that went on in the early years of trilobite science, many naturalists noted the similarities between European and American trilobites, but none asked why they should be so similar. They saw the matching fossils. They described them. If they asked "why", they did so privately. If they hypothesized, they never published. The catalogue of mysteries grew, and the more blatant it became, the more blatantly they ignored it. In the years before 1858, the naturalists - whose curiosity extended to just about everything - seemed to be not curious at all about the distribution of trilobites.

But why should they be curious? The first systematic naturalists had believed that God had created the Earth only a few million years before, populating it with creatures that did not change in shape or go extinct. Their purpose was to discover His plan, to celebrate Him by studying the world He had created. If He had created the same trilobite in Europe and Boston, then so be it.

By the mid-1800s, most investigators recognized that certain animals had gone extinct, and that others may have changed their shape through time; but they too still spoke of a moment of creation and of "the great Author of nature." Their purpose was not to question origins, but to celebrate the intricacies of God's plan. William Barton Rogers asked at William's College: "Who can fail to admire the sublime simplicity of the mechanism through which the Infinite Father fills all Nature with variety and beauty?" [viii]

So, when Rogers unearthed his paradoxical trilobite, there was no paradox for naturalists. An Infinite Father had created the trilobites, and had set them in both Europe and North America. [ix] That was all there was to it. That was 1856.

In 1858, Charles Darwin and Alfred Russel Wallace announced their theories of evolution by natural selection to the Linnaean Society of London. A year later, Darwin published *Origin of the Species.*

It set the world of natural history alight. William Barton Rogers first heard of it from his brother Henry, who was in Glasgow at the time.

"My Dear William," he wrote. "The only matter of any interest is the appearance of Charles Darwin's book 'On the Origin of the Species by Means of Natural Selection.' It is a suggestive book, full of ingenious arguments in favour of the Lamarckian hypothesis. Huxley . . . has reviewed this work in terms of high commendation." [x]

Thomas Henry Huxley, a British biologist, would be remembered by history as "Darwin's Bulldog," and it is quite obvious why. A few weeks after Rogers had heard the news from his brother, Huxley himself sent a letter:

"My Dear Rogers, My lectures begin in a month, and I must therefore beg you to let me have back my notes, etc. I hope you found them useful. Have you read Darwin?

There will be great fighting about his views for the next ten years, and great things will arise out of the combat." [xi]

Huxley's letters are almost giddy with enthusiasm at the thought of a fight. He wrote Rogers again a week later: "Darwin is the great subject at present, and everybody is talking about it. The thoroughly orthodox hold up their hands and lift up their eyes, but know not how to crush the enemy, barred as they are by finding all of us (whatever our views as to the truth of Darwin's opinions) fully agreed that the book shall not be hunted down but shall have fair play, on fair scientific grounds." [xii]

. . . and again three days later: "Darwin was with me yesterday, and we had a great conflabulation. I never met with his equal for intense candour and honesty." [xiii]

Rogers was himself quite impressed, and wrote Henry in January of 1860: "The more I look into Darwin's argument, the more I like it. The calmness and truth-loving spirit of the book are truly admirable." [xiv]

Not everyone in Boston was so enthusiastic. Louis Agassiz and his students set up camp in the anti-evolution ranks and resolved to stay there for the remainder of the campaign. And, as Huxley had predicted, it was indeed a battle.

In Boston, the Society of Natural History was the obvious place for a showdown, and Rogers and Agassiz debated Darwin's ideas at length. Their students were delighted by the debates and often provoked the two great naturalists. Nathanial Southgate Shaler wrote of Society meetings:

"Our particular aim was to set Agassiz and Rogers, who were chronic enemies, by the ears. When this could be accomplished, – and to that end there were many contrivings among the youngsters, - we were sure of good entertainment, often protracted over several successive meetings. Agassiz was admirable in discourse, - when at his best the most simply eloquent speaker I have ever heard, - but his capacity for debate was small. Rogers, on the other hand, was not only an able and learned geologist, but very skillful in argument, with a keen sense of the logic which should control statements." [xv]

"I can see before me now the noble shape and brilliant countenance of [Agassiz], as he eagerly, often incautiously, set forth his hypothesis, while Rogers, keen-faced and alert, prepared himself for his attack. When his turn came, with an odd gesture by which he seemed to turn his eagle eyes 'hard aport,' he would launch on a task of mingled criticism and construction, in both of which he was most effective. While it was on, the contrivers of the fracas would rejoice in the profit of it; it was always large. They were both game-cocks, so that on a higher plane I had once again the pleasure of my boyhood in watching their evolutions. Much came to us from these debates."

Curiously, one thing never mentioned in these confrontations was Rogers's trilobite. No expert in fossils, Rogers had not applied Darwin's theory to his own discovery. But others understood what natural selection meant for the strange distribution of trilobites: something wasn't right.

If God had created species, then each species would be found wherever God created it. If He created the *Paradoxides* trilobite in both Boston and Wales, then there they were. Not so with evolution by natural selection. If a species originated through natural selection, then it originated in *one* place at *one* time and migrated to other places. [xvi] Either *Paradoxides* originated in Boston or in Wales – or somewhere else – then somehow migrated to the other locations.

And here was the hitch. How could the beach-loving trilobite cross the Atlantic? Birds might transfer seeds from one land to the next; plants could float on currents to migrate to different continents. But birds did not exist in the day of the trilobite, and even a strong ocean current would take too long to deliver a trilobite to the other side of the Atlantic alive. There was something strange about Boston.

Connecting the Continents

Trilobites weren't the only problem. One year after Rogers visited Hayward's Quarry, Thomas Henry Huxley described a new Triassic reptile from South Africa, later named Lystrosaurus, literally "the shovel reptile." [xvii] Aptly named (its head looked like a shovel), the plant-eating reptile was about the size of a large pig. It lived around 220 million years ago, at the beginning of the age of dinosaurs.

Like trilobites, Lystrosaurs were turning up everywhere: in South America, in China, in India, Antarctica, and Russia. Here was an animal that could not swim, float, or fly from one continent to another. How did it come to live on so many different continents?

The situation only became more confusing. *Glossopteris*, the fern-like tree that had dominated continents around 200 million years ago, turned up in rocks in India in 1828[xviii] – then in Southern Africa, then Brazil, the Falkland Islands, the Argentine Republic, Australia, New Guinea, and, to the extreme consternation of geologists, Antarctica. That's a lot of oceans to cross, especially for a small tree.

Cynognathus, a land reptile, and *Mesosaurus*, a freshwater swimming reptile, followed the same pattern. The southern continents, which differ so obviously in their flora and fauna today, seemed to have shared nothing *but* the same flora and fauna from about 300 to 200 million years ago.

Darwin and Wallace had shifted biologists' views on the origin of species. Now their ideas forced geologists to change the way they thought. What could explain the strange distribution of trilobites, shovel reptiles, ancient ferns, and myriad other fossils?

Animals and plants could evolve, change their forms, migrate – but surely continents could not. Instead, thought early geologists, they must once have been connected by bridges of land.

In 1885, the Austrian geologist Edouard Suess proposed that land bridges had once linked South America, India, Australia, Africa, and Antarctica. The continents, thus joined, would form a "supercontinent," which Suess named "Gondwanaland," after the Gondwana province of India were *Glossopteris* was first found.[xix]

Land bridges, Suess argued, had formed as a result of the cooling of the Earth. Suess and most other geologists of the day believed that the early Earth had been molten, and that, as it cooled, the surface shrank. Mountain ranges formed where it buckled, like the crinkles on the surface of a balloon whose air is escaping. Erosion could then grind them down, and the land bridges would sink out of sight below the ocean.

Land bridges seemed to answer all the fossil distribution problems. Geologists could construct land bridges to explain all sorts of strange distribution patterns, including parallels between living animals on separate continents. Since they needed no geological evidence to propose a "sunken" land bridge, they could build one just about anywhere.

Soon enterprising geologists had woven the entire globe with strings of land bridges. [xx] Insectivores migrated between Haiti and western Africa via an Atlantic connection, which was cut diagonally by a bridge that allowed rodents to go from Brazil to northwest Africa. [xxi] Raccoons and bears made the jump from South America to Asia via a special Pacific Ocean bridge. [xxii] Two Atlantic bridges allowed the *Anchitherium* horse to go from Spain to the United States, and mastodons to travel between Africa and Florida. Aardvarks migrated from Mexico to Ethiopia, armadillos from Latin America to southern France, and saber-tooth tigers from Russia to Canada[xxiii]. Somehow, freshwater mussels migrated across a bridge between South America and Africa[xxiv].

As the century turned, Boston's trilobites added another tangle to the web. Geologists pointed out that Boston's trilobites were the same as those found in southeastern Newfoundland, Wales, southern England, and eastern Scandinavia – *but* vastly different from those found in New York, northwestern Newfoundland, northern England, and western Scandinavia. The Boston-type trilobites sat on slivers of land bordering the Atlantic on either side, sandwiched between realms of very different trilobites.

It wasn't just trilobites. The sliver of land that held Boston and southeastern Newfoundland had completely different species of brachipodos, gastropods, hyoliths, and conchostracoids than the rest of North America. It almost seemed as if Boston didn't belong to North America at all. In Europe, geologists noticed the same thing: Southern England's trilobites didn't match those of northern England - they matched Boston. Western Scandinavia did not match eastern Scandinavia - it matched Boston. It was almost as if northern England and western Scandinavia didn't belong to Europe at all.

What on Earth had gone on here? Naturalists, locked into the idea that continents were fixed and unchanging, scratched their heads and drew ever more complex systems of land bridges, spacing them with barriers like mountains that would prevent some species from ending up in the wrong places. It was, without a doubt, a big, rocky mess.

Unfortunately for land bridge enthusiasts, field geologists like rocks. They like physical evidence that they can hold in their hands, pound with their hammers, and kick with their boots. When they could not get their hands on any hard traces of "sunken" land bridges crisscrossing the globe, convenient superhighways for Earth's early commuters, many in the field began to look for alternatives.

Some turned to rafts, what some geologists called "the sweepstake route." [xxv] Through pure chance, an animal or plant "with tickets to the sweepstakes" might hitch a ride on a natural raft, land on a new continent, and proceed to populate it.

(The animal in question would obviously have to be female and pregnant at the time of the voyage.) Some geologists proposed that in this way ground sloths had voyaged from South America to the Caribbean and set up camp, [xxvi] and the Eocene wolf Tritemnodon sailed from North America to Europe and Africa. [xxvii] This idea, though, was so laced with holes that it was not widely accepted.

Others turned to even more fantastic explanations. The Italian naturalist Antonio Snider-Pellegrini proposed that all the questions surrounding earth's early history could be answered by turning to Genesis. The first "day" of Creation in the Bible was really a whole epoch, he argued, during which the cooling of the Earth produced such high pressures that all Earth's volcanoes exploded at once, spitting out the Moon. The Noachian Flood on the sixth "day" was so violent that it wrenched apart the formerly conjoined continents, carving out the Atlantic between them. [xxviii] Not surprisingly, few geologists took this seriously.

Land bridges, sea-faring species, and a Noachian Flood were just too *ad hoc*. They needed something simpler, an idea supported by the rocks, an idea that could explain how the same trilobites came to live in Boston and Wales and how a shovel-headed reptile could walk four widely separated continents.

There was one thought that had been proposed before – tentatively, half-heartedly, in bits and pieces. Some, like Sir Francis Bacon[xxix] and Benjamin Franklin, had simply noted that the continents on either side of the Atlantic seem to "fit" together. Others, like the Compte de Buffon[xxx] and Snider-Pellegrini, had proposed that the continents had once been joined, then split by the force of Noah's Flood. But not until 1912 did anyone make a serious attempt at demolishing the land bridges.

A Single Line

In that year, German meteorologist and Artic explorer Alfred Wegener proposed a theory that could explain how William Barton Rogers could find a European trilobite in Boston. He called it continental drift. The continents, he said, had once been united in a supercontinent called Pangaea ("All Land") - not connected by land bridges, but physically together. Then they had drifted apart.

Wegener suggested that the continents float on the surface of the Earth like ships. The mantle beneath them is solid, but can flow slowly, like glass. This idea, called isostacy, had been proposed decades earlier to explain how mountains form. Wegener argued that isostacy could also allow continents to move horizontally across the Earth's surface. If true, that stately progress could explain everything. Layers of rocks on either side of the Atlantic seemed to match because they had once been one solid layer. The lemurs of Madagascar looked exactly like those of India because Madagascar had once been part of India. Boston had once been joined with Europe. If the continents were free to move across the oceans, then reams of unsolved problems suddenly made sense.

"It is as if we were trying to repair the fragments of a newspaper by looking at the details of tearing and then confirming the accuracy of our fit with the printed text," wrote Wegener. "If the lines are re-constituted, we may assume that these fragments were originally part of the same sheet."

"A single line," he added, "would suffice to prove the likelihood of our reconstruction."

Alfred Wegener's theory of continental drift is now famous for two reasons: because it was - for the most part - right, and because it was - almost entirely - rejected.

The bit he got wrong was the mechanism. Wegener imagined that continents were moving across the oceans, literally plowing through the thick oceanic crust that makes up the sea floor. That crust is 3 miles thick. Geophysicists rightly guffawed at the thought. Wegener's drifting continents weren't at all like ships in the sea, pushing aside water to move smoothly across Earth's surface – they were more like beached sailboats trying to plow through an island. Even if they had some great wind to push them, they weren't going anywhere. Geophysicists muttered that meteorologists should stick to the weather and leave the continents to them. Then they retreated to their land bridges, weaving the planet in ever more complex paleo-highways.

Wegener went back to his Arctic expeditions. While attempting to establish climate observation posts in Greenland, several of Wegener's friends were cut off from supplies by unusually severe snow. Wegener and two others managed to reach them with dog sleds; on the return journey Wegener died of exhaustion and exposure. He was buried on the glacier in Greenland, where, as several authors have pointed out, he now lies a yard closer to North America than he was when he died. Greenland - and everything else, as we now know – does indeed drift.

"E Pur Si Muove!"

In its new home in an ornate building on Boylston Street, the Boston Society of Natural History paid no attention to thoughts of continental drift. The city's new scientists were slightly more analytical than the collecting and cataloging naturalists who had reigned in the days of Rogers and Agassiz, but as Wegener's ideas first reached North America, the Society went right along with its usual discussions of ascidians in the Gulf of Saint Lawrence, the development of a manual of orthoptera ("including locusts, grasshoppers, crickets, and their allies"), and classification schemes for New England fishes. The idea that could explain the origins of the ground under their feet simply sailed on by.

On its way, it also sailed past the Society's next-door neighbor: the Rogers Building, home to the Massachusetts Institute of Technology. As Wegener trekked across Greenland, the MIT geologists who followed in William Barton Rogers's footsteps busily applied themselves to earthquakes, volcanoes, and other serious geophysical phenomenon. They expressed little interest in continental drift.

There were exceptions. In 1921, Harvard professor Reginald Aldworth Daly met some staunch drift supporters while geologizing in Africa, and returned to Boston convinced that drift was a reality. In 1926, he published a book supporting the theory, quoting Galileo in his preface: *"E pur si muove!"* – and yet it moves.

"Every educated person cannot fail to be interested in this revolutionary conception," he wrote.

Daly became America's leading supporter of continental drift. In his office at Harvard, he typed furious, impassioned defenses of continental drift and instilled in his students a respect for its evidence. Yet despite his zeal, he convinced very few of his fellow American geologists of the validity of continental drift. Though drift supporters lingered on in Europe, most geologists either ignored the idea or dismissed it with an irritated wave of the hand.

And Daly himself, like most of the city's geologists, was uninterested in Boston, ignoring the rocks that surrounded him – rocks that all bore the imprint of the theory he so staunchly supported. His office at Harvard was built on top of the same slate that had harbored Rogers's trilobite: a muddy rock that was laid down while an ancient supercontinent was being torn apart by continental drift. On every side of his office ran parallel veins of dark basaltic rock that had bubbled up when continental drift disassembled another supercontinent 200 million years before. Reginald Aldworth Daly was literally surrounded by evidence that his theory was right, that it had worked, that it had shaped not only his city but the entire Earth – but like most geologists of his day, he did not see it.

By the late 1930s, it had become clear that land bridges couldn't explain the growing mountain of out-of-place fossils turning up in the field, and the world still could not explain how William Barton Rogers could find a Welsh trilobite in Boston.

An Essay in Geopoetry

And then came that day that lives in infamy: December 7, 1941. When the Japanese attacked Pearl Harbor, the United States called up thousands of Naval Reserve officers for duty. Among them: a 35-year-old geologist from Princeton named Harry Hess.

The National Academy of Sciences has described Harry Hess as "one of the truly remarkable earth scientists of this century." A mineralogist by training, Hess was fascinated by ocean crust, and had spent months in a submarine (the *Barracuda*) in the West Indies, taking gravity measurements of the ocean floor. When, in 1944, he was put in command of the *U.S.S. Cape Johnson*, he was not about to waste the opportunity to do some unscheduled research.

The *U.S.S. Cape Johnson* was an attack transport, designed to deliver more than 1,500 troops to the islands they were to assault. It carried a fathometer: a handy instrument that used sonar to measure the depth to the ocean floor. Hess was intrigued. He set up the fathometer to run almost constantly, producing reams of data on the topography of the ocean floor.

During the next two years, the *Cape Johnson* crisscrossed the Pacific, delivering troops and supplies to Guam, the Mariana Islands, and the Philippines. Between dodging frequent attacks by Japanese airplanes and delivering troops to the beaches of Iwo Jima, Leyte, and Lingayen, Hess left his fathometer running, and watched the previously unmapped ocean floor roll out under his ship.

He found a different world. The ocean floor was not flat and smooth, as geologists had long supposed. It wasn't just a little rough, with a few rocks here and there. It was mountainous and jagged, split by deep canyons and ringed by mountain ranges to rival those on land. Geologists had known since the mid-1930s that a strange mountain range ran down the center of the Atlantic Ocean, but Hess showed that the topography of the ocean floor was far more complicated and varied than anyone had imagined.

"Dear Mac," he wrote to his former student Lieutenant John C. Maxwell, who was also stationed in the Pacific. "We went up with the assault on Iwo Jima so this is about the first chance I've had since my short note to finish answering your letter of Nov. 15 . . . I'm trying to make the geology of a large area fit my preconceived opinion as to what it ought to be – and this even though I've never seen 90% of it. I'm aware that I am doing this, but would persist in it because I believe that regional geology always makes sense and fits together when you've got the story right. It doesn't fit at all now so in spite of the apparent facts I'm going to hold on for a while to my unwarranted hypotheses, and look upon the 'facts' with suspicion . . ." [xxxi]

When Hess returned to Princeton at the end of the War, he brought back a small mountain of data on the ocean floor. He continued working for the Office of Naval Research and studying the sea floor.

In 1960, after almost 15 years of studying the ocean floor he had unveiled, Harry Hess wrote what would become the most cited paper in the history of geology. He called it an essay in "geopoetry," and, in it, he proposed the explanation for continental drift that would become known as plate tectonics.

Wegener had thought that the continents plowed through the ocean floor, and geophysicists had been rightly appalled. Hess revised that idea. The continents did not move – the ocean crust did. The continents, embedded in the ocean crust, were merely dragged along with them.

Moving slabs of crust had some implications. When two segments of ocean crust – or plates – moved away from each other, they exposed the hot mantle beneath, and new magma rose up to fill the void, creating a chain of volcanoes running down the seam. Hess called this sea-floor spreading, and it explained the enormous mountain chain running down the middle of the Atlantic. It also explained why the oldest ocean crust was less than 200 million years old while the continents harbored billion-year-old rocks – Earth's oceans are constantly adding new crust.

But if ocean crust is constantly being created, then the old crust has to go somewhere. Hess suggested that when an oceanic plate hits the edge of a continent, it dives beneath the continental rock and sinks down into the mantle, in a process called subduction. This is what has dug the Marianas Trench: the oceanic Pacific Plate has crushed up against the stronger, continental Philippine Plate, and has been crushed beneath it, sinking into the Earth's interior.

To drive the engine of plate tectonics, Hess imagined that the Earth's interior – the mantle – could convect. Hot material from near the core would rise, and when it reached the surface, it could break through to form a new ocean ridge, or it might flow along the underbellies of the continents until it cooled and sank back down toward the core – towing the continents along with its stream. Today, geologists still think these convection cells are the most likely candidates to supply the power to plate tectonics.

Hess's proposal did not solve all of drift's problems – several decades would go into refining the idea of plate tectonics. But the crucial element Hess supplied – at last –

was a mechanism that worked, and it synthesized and explained a wider range of unanswered questions than continental drift alone.

Geologists since Hess have found dozens of other ways to test and verify plate tectonics: mapping the magnetic signatures of various rocks, measuring the crust with seismic tools, and re-examining Wegener's old evidence of parallel fossil, rock, and climate patterns. Of all these, one idea in particular would have special significance for the study of Boston

"Did the Atlantic Close and Re-Open?"

J. Tuzo Wilson was an early and strong supporter of plate tectonics. Wilson, a Canadian geophysicist from the University of Toronto, had studied at Cambridge with a Nobel Prize-winning physicist, and then at Princeton with the young lecturer Harry Hess. He had mapped glaciers, scaled mountains, discovered uncharted Artic islands, and was the second Canadian to fly over the North Pole. When Hess died suddenly of a heart attack in 1969, he was one of the most prominent geologists to inherit the torch.

In 1963, Wilson devised an elegant demonstration of plate tectonics - and, in the process, proposed a theory that would account for half of the planet's volcanoes. Hess's original idea could explain volcanoes along the edges of plates - the energy of the collisions powered eruptions along plate boundaries, like the Pacific Ring of Fire, but what about volcanoes in the middle of plates, like the Hawaiian Islands? Wilson suggested that the Hawaiian Islands had formed from what he called a "hotspot." Warm magma rises in a column from the mantle - we still don't know why - and erupts on ocean floor as lava. Over millions of years, the constant eruptions build a volcanic cone, which breaks the surface of the ocean as an island. Simple enough, perhaps, but here is the twist: if the ocean floor is being pulled along as part of an ocean plate, then the volcano is being pulled along too. Eventually, the island drifts all the way off the hotspot, and a new volcano starts to form. Given several million years, a whole chain of volcanic islands forms, pointing in the direction the plate is moving.

Geologists have compared the hotspot to a blowtorch under a conveyor belt. The belt moves over the torch, burning a long hole down its center. As ants on such a conveyor belt, we may not feel ourselves moving, but the scorched line from the torch certainly suggests that we are. The long chains of Earth's hotspot islands - the Hawaiians, Azores, Galapagos, and dozens more - map clearly how the plates are traveling.

Today, the hotspot concept appears in the introductory chapter of any geology textbook. It is a fundamental principle of how the Earth works. But, in 1963, it was geological heresy. Wilson's paper describing his theory was famously rejected by every major scientific journal, before being published in the obscure Canadian Journal of Physics.

Boston is nowhere near a hotspot today. But Wilson proposed that there had been a time, about 200 million years ago, when it might have been. In 1966, Wilson published another paper. Though his new idea sounded just as far-fetched as the blowtorch under the conveyor belt, the prestigious journal *Nature* took a chance and published it. Its short title summed up the entire idea: "Did the Atlantic close and then re-open?" Wilson's answer was a solid "Yes."

For support, Wilson turned to the trilobites. As geologists had recognized for almost a century, the trilobites in southeastern Newfoundland and Boston are completely different from those of the rest of North America. In fact, all the fossils are different. The sliver of land - running from the northern tip of Long Island, through Boston and Nova Scotia, up to the southeastern end of Newfoundland – looks more European than American. Alfred Wegener had used this fact in support of his idea that the continents had once been joined in a supercontinent he called Pangaea. Now Wilson went one step further.

Perhaps, he proposed, this sliver of strange land had not originated with Pangaea. If it had, then Boston's trilobites should match New York's. Perhaps instead, this sliver of land had formed on the European side of an ancient Atlantic Ocean. The ancient Atlantic had then closed, forming Pangaea and uniting Europe and North America: joining Boston with western Massachusetts. When Pangaea split apart, it split just east of Boston. Europe and Africa drifted away to the east, leaving behind a slab of land from the tip of Long Island to the southeastern region of Newfoundland.

Wilson's idea seemed to work – almost. When geologists compared the shapes of continental slopes, North America fit Europe and Africa quite nicely - except for a 100-mile gap between Boston/Nova Scotia and Morocco/Wales. When they compared the stripes on the seafloor, they fit perfectly – except for a 600-mile gap between Boston/Nova Scotia and Morocco/Wales. When they matched up faults, rocks, stripes, and fossils, all supported Wilson's theory for the rest of Europe, Africa, and North America - but nothing could make the strip of land from Long Island to Newfoundland match the strip from Morocco to England. One research team tried stuffing the Canary Islands into the gap, but had little success.

In 1971, geologist Paul Schenk finally figured out what was wrong. Schenk was a 34-year-old geologist at Dalhousie University in Halifax, Nova Scotia. Famously energetic, he ran marathons, climbed Mount Everest, and once circumnavigated the globe in a VW microbus – and in his 1971 paper, he managed to explain how Boston made its way to its current home.

As Schenk saw it, the Atlantic did not simply close and re-open like planet-sized elevator doors. The movements of the continents were far more complicated, and those of the slab of land from Long Island to Newfoundland were perhaps the most complicated of all.

That sliver of rock did not belong to North America. On that, everyone agreed. Schenk went one step further and said that it did not belong to Europe, either. It was its own strip of land – a microcontinent that had formed elsewhere, then had been plastered onto the side of North America, smashed by Europe and Africa when Wilson's original Atlantic closed, and ripped down the middle when the Atlantic re-opened.

The details of Schenk's idea have been modified slightly in the last 30 years, but the basics have remained, allowing us to finally put together a history of how Boston came to be.

The Story So Far

For William Barton Rogers, Boston was one piece of immovable land in a world designed by a great Author of nature. For Wegener, it was his single line, connecting the continents and validating his theory of drift. For J. Tuzo Wilson, it was an orphaned city, left behind as its parent continent drifted east. Each generation has redefined Boston in the image of their view of the Earth. We have too. They had their evidence, so do we. We hope ours is better. We hope our view is more insightful, better supported by the evidence, more useful for understanding this city we live in. Perhaps in another hundred years, our view of the Earth will change again and a new generation of geologists will set about establishing Boston's role in the world.

But for us, today, this is the story so far:

Once upon a time – about 650 million years ago, though geologists are perpetually revising that date – there was a supercontinent named Gondwana. It was basically the same supercontinent that Edward Suess had named Gondwanaland in 1885, but geologists have since corrected the redundant name (which literally means "Land Land") shortening it to Gondwana.

Gondwana was a vast continent, stretching from the Equator to the South Pole. It included the continents that today we call South America, Central America, Africa, Australia, India, and Antarctica. The alignment of tiny minerals in the rocks that formed the supercontinent tells us where each rock was relative to the North Pole, and geologists have used these minerals and fossils to piece together where each bit of modern land was within the giant. To us, these would look upside down. The modern-day Sahara marked the South Pole and the Cape of Good Hope extended up to the Equator. On the other side of the Earth, North America and Europe balanced on the Equator, just to the north of the supercontinent.

Earth was different then. The lands were bare. Plants would not ooze up out of the oceans for another 200 million years, and land animals would need another 250 million. In fact, 650 million years ago, animal life as we know it did not even exist. The seas were teaming cesspools, without even the ancestors of the fish, clams, and lobster on which Boston would come to rely. Spiny, microscopic creatures floated about with the algae, and mushroom-shaped microbial mats staked out the shallows. In both population and impact, the single-celled bacterium was king.

Along the southern edge of Gondwana, modern-day Venezuela met modern-day Morocco. Geologists have found 650-millon-year-old Venezuelan pebbles in Moroccan rocks – the two were literally united. This was the South Pole, but you would never recognize it. Earth had just emerged from the greatest, most devastating Ice Age of all time, and the climate all over the world was warming. Paleoclimatologists examine the sediments laid down in those ancient oceans to find where, when, and how the ocean's temperature has changed through time. Sediments from the coast of Gondwana show that by about 650 million years ago the ice at the poles had melted, and even the South Pole would have felt like autumn in Boston.

It was here, at this temperate South Pole, that the first rocks of Boston were forming. Rocks differ subtly in their chemical make-up, based on how they formed. The minerals trapped inside the first rocks of Boston illustrate that a powerful force was shaping the area when they formed. A slab of ocean crust had pushed its way under the edge of Gondwana, and sank slowly beneath it, dragging the muds that had caked the ocean bottom down into Earth's warm mantle. As it sank, the mud melted and bubbled up into the overlying continent. The mudflows formed a thick, quartz-ridden magma, which cooled slowly to form what today we call the Dedham Granite. This sparkling, pink granite now forms the basement of Boston, and built such modern landmarks as the Middlesex Fells seven miles north of the Boston Common.

Not all of the magma stayed underground. Much of it erupted onto the surface, forming volcanoes as explosive as Mount St. Helen's. They were explosive because their magmas had formed from mud, and mud is soaked with water. Buried under a continent with vast reservoirs of molten rock, the water was at intense temperatures and pressures. When it erupted, along with the magma, the sudden drop in pressure caused the water to explode. Over several million years, the fringe of volcanoes along Gondwana's south coast erupted so violently that many of them blew apart. Today, Boston hikers see the traces of these volcanoes every day along the ridge of Pine Hill, just north of Boston, and throughout Marblehead. The volcanoes themselves eroded away to nothing long ago, but the rocks of Pine Hill and Marblehead are embedded with angular shards of other rocks – shrapnel from explosions that rocked the southern coast of Gondwana, about 600 million years ago.

The ocean plate did more than melt some mud and provoke some volcanoes. Ocean plates are heavy, 3-mile-thick slabs of rock. If you were unlucky enough to be swimming next to the Titanic when it sank, you would have been sucked down with the ship. In the same way, the ocean plate was sucking Gondwana toward it, stretching the edge of the continent and ripping the land apart. The edge of the continent was thinning, stretching, cracking, forming a deep basin. The formation would have looked very much like the African Rift Valley, where anthropologists think humanity was born: steep walls surrounding a broad, flat bowl. This was the birth of the Boston Basin, and though millions of years of run-off from the surrounding mountains have filled in much of the valley, even today, Boston and its suburbs sit in a shallow bowl of land, the scar of an ancient supercontinent being pulled to pieces.

As the Boston Basin was deepening, something drastic was happening to the Earth. Between 542 and 530 million years ago, animals began to show up: complex organisms with shells and bones, features previously unknown to the soft-bodied creatures that had long dominated Earth's seas. Paleontologists call this period the Cambrian Explosion – "Cambrian" for the geologic era, and "Explosion" for the dizzying variety of animals that suddenly appeared on Earth. The trilobites emerged and evolved rapidly to dominate the oceans: the cone-shaped hyolithids appeared along with the primitive relatives of clams, fish, starfish, and sea cucumbers – though none of these looked remotely like their modern equivalents.

A shallow inlet of water had filled the Boston Basin, forming a muddy, silt-choked harbor where early trilobites scavenged for food. One of these was the foot-long trilobite that would – in 500 million years – cause such an uproar on Mason Street and in Albany. Other Cambrian-era animals must have lived alongside it, though we have yet to find their remains. The trilobite might have hunted the first tiny, jawless fishes, which darted in the muddy shallows. It probably hid from its chief predator: the enormous *Anomalocaris* – a hideous, stingray-type carnivore with a mouth like a pineapple ring, edged with rows of fangs. The earliest ancestors of today's clams dug into the mud.

This was Boston's first harbor, and it was probably calm and stagnant. Geologists find the mudstones it laid down stained with pyrite, a clue that the water was far from fresh. At some point, the trilobite died, and its body drifted down to the muddy sea floor. Over several million years, the muds would solidify into the dark gray mudstone that today underlies most of Cambridge, Boston, Braintree, and parts of Roxbury and other suburbs. The trilobite would solidify with it.

The Boston Basin wasn't the only basin to form on the edge of Gondwana – the subducting ocean plate stretched the land so badly that many basins were pulled open. Finally one of them became so deep that the continent snapped: magma from Earth's mantle bubbled up into the gap, and a new ocean began to form, just as Harry Hess would argue in a few hundred million years. If the continent had snapped farther to the north, the land where Boston now sits would have remained part of Morocco.

Of course, it was not just Boston that started drifting north. The rocks that now underlie the city rode on a long, slender spit of land that geologists call Avalon. From east to west, this sliver carried the rocks that would form the tip of Long Island, eastern Connecticut and Rhode Island, Boston, Nova Scotia, the southeastern rim of Newfoundland, the southwestern half of Ireland, most of southern Wales and England, a small corner of Spain, Portugal, and the western edge of Morocco. Together, these now remote places rode Avalon northward, as a new ocean opened behind them.

Avalon was not alone. Up and down the coast of Gondwana, similar processes were pulling slabs of land away, forming separate, smaller mini-continents that geologists call terranes. The Merrimack terrane, home of modern-day Worcester, broke away from Gondwana at about the same time – also the Meguma terrane (today's Cape Cod), the Cadomia terrane (today's northern France), and the Carolina terrane (today's coast of South Carolina). This small swarm of mini-continents drifted slowly northward while an ocean – J. Tuzo Wilson's ancient Atlantic – opened behind them.

For 200 million years, Avalon moved slowly up from the South Pole, carrying, among a million other things, the hardening imprint of a dead trilobite. On its way, Avalon collided with some of the other stray shards of continents. About 440 million years ago, the west coast of Avalon struck the Nashoba terrane, shearing and metamorphosing most of the rocks along the western edge. Geologists found the date by radioactive age dating the sheared rocks that now underlie Lexington and Concord. On April 19th, 1775, the colonial militia at Lexington fired the "shot heard 'round the world" and chased the British regulars back toward Boston. The regulars attempted to regroup and rally at a steep, blood-red cliff now known as the Bloody Bluff Fault. That cliff marks the boundary between Avalon and Nashoba, the place where two continents clashed 440 million years ago.

In that collision, the edge of Nashoba was smashed beneath Avalon and large chunks of it melted. The melt bubbled up into Avalon and cooled underground as a gray, quartz-rich granite. Today, that granite underlies all of Quincy, and parts of Cape Ann, Salem, Beverly, and Peabody. The Blue Hills Reservation, just south of Boston, is a mountain carved from the 440-million-year-old granite that formed when two tiny continents collided. This is the Quincy Granite, which Bostonians eagerly quarried in the late 1800s to build the Bunker Hill Monument, King's Chapel, and many other Boston buildings.

While the Quincy Granite cooled underground, life spread above ground. Fish with jaws had evolved and taken over the sea - we find their fossils emerging in rocks of this time period. Small, leafless, spiny plants oozed onto the land, and the first land amphibians followed close behind them. Once on land, plants could not be stopped - half the planet was available to those who could make use of it, and they evolved quickly. Ferns the size of houses appeared, followed by the woody plants that would become trees and the seed-bearing ancestors of modern flowers. Ancient insects evolved to capitalize on the new feeding opportunities that plants offered, and spiders came to hunt the insects.

Avalon and Nashoba continued north together, colliding with the Merrimack and the Meguma terranes along the way. When a geologist looks at a rock from Boston today, she sees the tiny deformations and strains that these collisions caused - and one particularly big strain from about 425 million years ago, when Avalon and the shards it had collected banged into North America. It was an agonizingly slow crash, requiring more than 50 million years. The collision pushed up the Berkshires of western Massachusetts and folded much of the land between today's Connecticut River Valley and Worcester into hills and valleys.

The remains of Gondwana were not far behind. Northwest Africa and southwest Europe collided with Boston (and the rest of North America) about 300 million years ago, driving up most of the Appalachians. South America, Australia, Antarctica, and all the rest had crossed paths in other areas, and, for the first time since Gondwana, all Earth's continents were again locked in a supercontinent. This was Alfred Wegener's Pangaea.

Pangaea was a tragedy for life on Earth. Most species still clustered in the shallow waters of the continental shelves, and when the continents merged, huge swaths of these shelves disappeared. More than 90 percent of life in the seas went extinct, including the very last of the trilobites. It was the worst mass extinction in Earth's history.

Reptiles, on the other hand, did very well. Since they were not dependant on shallow water environments, as most species were, and since they now had a vast continent to populate, the reptiles quickly became the dominant group of animals. The age of the dinosaurs began, and many colonized the Massachusetts area. In the Connecticut River Valley, footprints of the sleek, raptor-like predator *Grallator* have been found in mud, along with evidence of small relatives of *Apatosaurus*, a brontasaurous-like herbivore. The rocks of Boston were above sea level at this time - smack in the middle of the supercontinent, actually - and these and other dinosaurs doubtless roamed over it. At the time, a dinosaur could have stepped right out of Boston and into Morocco to the south or Wales to the north.

Supercontinents never last long. By the time the dinosaurs evolved, Pangaea was already breaking apart. Some geologists think that a plume of magma formed under what is now the eastern seaboard, creating a hotspot down the center of Pangaea and forcing the continent to split. This was J. Tuzo Wilson's idea, though he had not applied it to the breakup of Pangaea. Whatever the cause, ocean plates subducted along the margins of Pangaea, pulling Africa away from North America, and stretching and thinning the crust of New England. New England tried to break apart, many times. It almost snapped along the Connecticut River Valley to the west, and again along the Newark Basin to the south. But it finally broke directly through the middle of Avalon. Pieces of Avalon drifted east to become bits of England, Europe, and Africa. The pieces that stayed are now Boston and, far to the north, the southeastern tip of Newfoundland.

As the Atlantic grew, Boston's geologic activity slowed. No more bits of stray continents collided with it; no more volcanoes erupted; no more granites formed. More than 200 million years passed in geologic calm. Ice ages came and went; glaciers advanced and retreated; species evolved and died.

Glaciers crept down from Canada, carrying rocks and pebbles from the north, which they left all over Boston. These sheets of ice scraped the land and molded their debris into the smooth hills that now define the city's topography: Beacon Hill, Bunker Hill, the harbor islands. When the last glacier finally retreated, about 16,000 years ago, it left a few chunks of ice behind, buried under hills of glacial debris. When these chunks melted, the debris collapsed, forming deep pits known as kettle holes. Walden Pond is a kettle hole, left behind by the last glacier. So are Spy Pond, Fresh Water Pond, and most of the small lakes that make up Boston's Emerald Necklace.

The glaciers mark the end of Boston's geologic history, but not of its geologic story. The continents are still moving, and will continue to move until Earth has cooled to the point where the mantle can no longer convect.

The spreading centers of the Pacific Ocean are pushing the North American continent east – geophysicists now have such refined measurement devices that they can see the continent moving, little by little, year by year. They speculate that in about 50 million years, a subduction zone will again form along the east coast. Again, the sinking ocean slab will drag water-logged muds down into Earth's mantle. Again, they will melt and pool under Boston as new granite and erupt as explosive volcanoes. As more of the ocean crust dives beneath Boston and the east coast of the United States, the Atlantic will close until the Mid-Atlantic Ridge buries itself beneath the coast as well. Most of the east coast will already have buckled into mountain ranges when Europe and Africa hit, 250 million years in the future. The resulting collision will thrust up a new Appalachian chain to rival the Himalayas. Earth's continents will again be merged into one vast piece of land, which geologists delight in calling Pangaea Ultima.

The Most Important Rock in Boston

Hayward's Quarry was filled in and paved over in 1884 to make way for the Fore River Shipyard. Freighters, tankers, destroyers, and aircraft carriers were assembled over the Cambridge Slate, with its half-billion-year-old trilobites. The ships crossed the Atlantic and docked in England, underlain by the same slate and the same trilobites.

William Barton Rogers donated his trilobite to the Boston Society of Natural History. In 1946, the Society voted to become the Boston Museum of Science and to sell its fossil collection to Harvard. Rogers's trilobite, which began its short life in a warm sea by the South Pole, now sits in an aluminum tray in the Department of Invertebrate Paleontology at Harvard's Museum of Comparative Zoology.

The Department of Invertebrate Paleontology at the Museum of Comparative Zoology – the name inspires images of dark, cramped rooms, stuffed with all manner of unimaginable creatures: spiral-shelled ammonites, diatoms like intricate Christmas ornaments, and the billion-year-old worms that spawned animal life as we know it. One imagines vast, dusty tables, awash in fossils, microscopes, instruments, tools, and the occasional stuffed ostrich – in short, a room rich in the mysterious, like the one across the river where Rogers first announced his trilobite.

What one finds might be a surgical theatre: clean, whitewashed, and brilliantly lit.

A pair of bright blue double doors is neatly labeled: "Department of Invertebrate Paleontology." Through the doors are three large, white rooms, split by neat rows of tall, white cabinets. The cabinets are aluminum, spotlessly clean, and neatly labeled: "Ammonites," "Annelids", "Bivalves." The fluorescent lights cast no shadows, and the shelves are free of dust.

In one corner, the straight stub of an ammonite fossil supports a pinecone and a whitewashed human skull, but the scene itself is a fossil of the strangeness that a paleontology museum must once have been. One expects that, at any moment, the curator will notice the arrangement and whisk the ammonite, skull, and pinecone off to their respective cabinets. *How did you get here? Back you go.*

The trilobite cabinets house 46,000 of the spindly arthropods - all brilliantly lit, neatly labeled, and spotlessly clean. Aisle after aisle, tray after tray - trilobites in slate, sandstone, mudstone, plaster; white, grey, black, red, green; trilobites the size of a beetle, of a mouse, of a cat; trilobites from the Baltics, Quincy, Braintree, Maine, England, Canada; the delicate *Paradoxides gracilis* from Bohemia, the impressive *Paradoxides davidis* from Newfoundland.

And filed in the middle drawer of a cabinet near the back, the imprint in mud once called "the most curious and important discovery ever made in the geology of this region," the giant *Paradoxides harlani* that William Barton Rogers pulled from the wall of Hayward's Quarry in 1856.

An ancient, crumbly, brown scrap of paper is still glued to one edge, its loopy Victorian writing proclaiming it *Paradoxides harlani* Green 1856: Genus, species, first person to describe it, year found. In the next tray over are two smaller trilobites, which Charles Thomas Jackson pulled from the wall of Hayward's Quarry, three days after Roger's announcement.

William Barton Rogers did not live to be 630 million years old. He died at age 78, on his feet, addressing the graduating class of MIT, and his last words were "bituminous coal."

You won't live 630 million years either. You never saw a living trilobite, never walked on Pangaea, did not witness the collision of Avalon with North America. But you can pick up a single rock from a ballast quarry in Boston – and see it all. It's heavy, gritty, and unassuming. This is a rock that survived not one, but at least *seven* continental collisions and two supercontinents, then spent the last 150 years sitting in a cupboard.

It's still just sitting there, suspended in that moment when its armored body settled on the fine black mud of a Cambrian sea. More than 4 billion years of Earth history proceeded that moment. Another half-billion would pass before it would be pulled from the wall of a slate quarry, half-a-world away. It would take its finders one hundred years more to understand where it came from, and how it came to rest here, in what eventually became an immigrant city.

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