Thank you for coming to the Cutting Edge speaker series. I’m delighted to kick off the series with a historical perspective…
[on Earth Science Controversies, the Ice Ages and Mass Extinctions].

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Natural order is contingent order; scientific knowledge is contingent, open ended
Historical knowledge is contingent knowledge
Hist Science is not unreliable because it is contingent
Not a simplistic view of science as the key to a mc exam. Personal commitment to indwell reality is part of objective knowing in any field, sci or history.
To interweave the topics for tonight, I want to tell you a story about this man, Martin Rudwick. He encountered many controversies, both in the historical past and in the present era of his own lifetime, in his efforts to understand extinctions, mass extinctions, the ice ages, and how science develops.

- Martin began his career as a paleontologist at Cambridge University. This photo shows Martin holding a Scientific American issue from 1964 in which he argued for both continental drift and an Ice Age before the Cambrian period. On the basis of his study of living and fossil brachiopods, he also argued for a Permian mass extinction event, years before these controversial theories became accepted.
A few years later, Martin published this book as the culmination of his work on brachiopods.
Now Brachiopods are familiar to every fossil collector. They have shells above and below, hinged at the rear. The front opens for feeding and closes for protection. The word "Brachiopod" comes from the Greek brachion ("arm") and pod ("foot"). They are informally called "lamp shells", since the curved shells of some types resemble pottery oil-lamps.

https://en.wikipedia.org/wiki/Brachiopod
Here's Martin's sketch of a community of living brachiopods on a boulder located near Christchurch, New Zealand.

At the conclusion of his book, Martin charted the stratigraphical ranges of brachiopods, and their relative diversity, and offered a tentative phylogenetic interpretation.
Along the left side is the vertical scale of the modern geological column.

- The Lower Palaeozoic begins with the Cambrian, then the Ordovician and Silurian periods.
- The Upper Palaeozoic continues with the Devonian, Carboniferous, and Permian periods.
- The Mesozoic Era continues with the Triassic, Jurassic, and Cretaceous periods.
- Finally, the Cenozoic Era, or recent past, continues with the Tertiary period.
- Let’s look more closely at the boundary between the Upper Palaeozoic and the Mesozoic Eras, which lies at the border of the Permian and Triassic periods. (Take drink)
That Permian–Triassic boundary divides the history of the brachiopods as shown. Compare the large number of families of brachiopods which lie below the boundary with the much fewer number above the boundary.
This chart also shows the Permian boundary. Near the end of the Permian period there was a great falling off in the number of brachiopod families. At the time Martin was presenting arguments like these, the idea of a Permian mass extinction event was perceived as a “catastrophe” in Earth–history, and as such it was as deeply suspect and controversial, among geologists generally, as any idea of continental drift.
Yet Rudwick showed that the majority of families of brachiopods then in existence, had their last appearance in the Permian period. Brachiopods were not alone, and Rudwick was soon vindicated: The Permian mass extinction, often called the Great Dying, is now recognized as the most severe extinction event in the history of the Earth, with a loss of up to 96% of all marine species and 70% of all terrestrial species. Potential causes for several phases of extinction may include the double whammy of massive volcanic eruptions, and associated climate change.

https://en.wikipedia.org/wiki/Permian–Triassic_extinction_event
Martin was on the cutting edge of the earth sciences then, and all his life remained on the cutting edge of how science grows and changes over time.
The sections of this talk touch on the following controversies: Permian Mass Extinction, which was our brief introduction; the Reality of Extinction, the Directionalist Synthesis, the Devonian Controversy, and the Ice Ages.
In each section, we will focus narrowly on one particular individual to illustrate the controversy, with only minor asides for context and background.
And we’ll conclude with a few observations on science and an afterword.
- In every section, we’ll use the work of Martin Rudwick as a continuing point of reference to tie the vignettes together.
So let’s move on to Georges Cuvier and the reality of extinction.
Georges Cuvier joined the French Natural History Museum in Paris in 1795. He quickly became the world's leading expert on the reconstruction of large fossil quadrupeds, or creatures with four legs. These fossil bones were of unknown animals. What had happened to them? Were they still alive? How could one explain these fossils?

- In 1976, Rudwick published The Meaning of Fossils. It became a classic work in the history of geology, and contains a chapter devoted to Cuvier.
- More recently, Rudwick published Earth’s Deep History, which covers some of the same ground and is probably the first book I would recommend for anyone interested in the history of geology. For reasons that will become clear, Cuvier was the focus for Rudwick’s move from paleontology into the history of science.

https://en.wikipedia.org/wiki/Georges_Cuvier
Traditionally, the fundamental objectives of the field of Natural History had been to describe, identify, name and classify natural objects, which make up the furniture of the world. This reflects the classical meaning of history as "historia," in Latin. Oftentimes one may translate historia simply as "description." As a practitioner of this descriptive form of natural history in the 18th century, we might point to Carl von Linné, or Linneaus.

https://en.wikipedia.org/wiki/Carl_Linnaeus
But even by the time of Linnaeus, a momentous shift was in progress from natural history to the history of nature. Nature was gaining a temporal dimension. As an example of this shift, we might point to the Natural History of Linnaeus’ exact contemporary, Buffon.

Buffon brought to a focus the question of what changes have occurred with plant and animal life over time, in 1749 with the very first volume of his massive Natural History, and again in a 1778 supplement entitled Epochs of Nature.

In the Epochs, Buffon fashioned molten globes, of varying diameter and composition, and measured them as they cooled. From these measurements of cooling globes, Buffon derived chronological estimates of the cooling of the Earth. Changes in life on Earth must be correlated with physical changes in the Earth itself, including global temperatures and climate.

Lamarck, a contemporary of Cuvier, reflects this temporalizing of nature. In his Zoological Philosophy, Lamarck defended a view of the evolution of life on Earth in which forms of life are transmuted into other forms, tracking changes in their environment, and thereby avoiding extinction.

So this shift from descriptive natural history to the history of nature is the background for Cuvier’s interest in large fossil mammals. And with it comes the question whether, contrary to Lamarck, entire lineages of animals could ever become extinct.

In an early paper, Cuvier analyzed engravings of this large fossil quadruped, which had been reconstructed in Madrid from fossil bones found in Spanish South America. Cuvier named it the Megatherium, and sensationally claimed that it was a giant species of sloth. It was too large to be unknown, he argued, so it must be extinct. Thomas Jefferson, on the other hand, argued that the Megatherium and other large fossil quadrupeds necessarily could not be extinct, since the wisdom of the creator would fail if but one link in the great chain of being were lost. Maybe Lewis and Clark would find them on their journey westward, in the interior of the continent.
In another paper, Cuvier showed that fossil elephants were significantly different from living elephants. In this plate he shows that the Indian elephant and the mammoth are significantly different, as different as goats are from sheep, and therefore the two must be separate species. Cuvier argued, again, that mammoths were too large to be simply unknown; so they must have become extinct. This was a surprising and novel conclusion, for at this time, most naturalists believed, like Jefferson and Lamarck, that species did not become extinct.
The reality of extinction, as implied by Cuvier’s reconstructions of these and other large fossil quadrupeds, was a novel and controversial result for the time. To Cuvier, extinction seemed
● to “prove the existence of a world previous to ours, destroyed by some kind of catastrophe.”
● This concept of revolutions of the Earth soon became known pejoratively as “catastrophism.” But Cuvier established the reality of extinction as a fact that any future scientific theory of life had to explain. A half-century later, Darwin took extinction for granted, contrary to Lamarck. Yet Darwin had little place for mass extinctions, arguing that the extinction of species occurs piecemeal.
● In the last half century, “neo-catastrophist” geologists like Derek Ager and many others have argued that Cuvier was wrongly maligned, his actual views misrepresented in the Darwinian debates.
● The Permian mass extinction event seems quite consistent with Cuvier’s views. While Darwinian background extinction predominates, mass extinctions have occurred at the end of the Cretaceous, Triassic, Permian, Devonian and Ordovician periods, each one affecting perhaps half of the world’s living species.
● Rudwick’s paleontological work on the great dying of brachiopods at the end of the Permian motivated him to investigate Cuvier and to devote himself more and more to the history of geology. Instead of seeing early 19th century debates over the reality of extinction in terms of catastrophism vs. uniformitarianism –
words which carry so much baggage we are better off abandoning them today – Rudwick recasts the history of geology in this period in terms of...

‘Uniform’ (gradual) rates of geological change, versus variable (including sometimes ‘catastrophic’) rates
Cyclic-repetitive temporal scheme, versus linear-directional scheme
The reality of extinction confirmed the transition from natural history as descriptive, as historia, to a history of nature in which irreversible changes occur over time. Geohistory then refers to this new historical sensibility, that nature has a history that must be investigated if we are to understand the present natural order. Rudwick’s book is titled: not Earth’s Deep *TIME,* but rather Earth’s Deep *HISTORY,* for it is this historical character of the Earth, rather than its mere age or duration, that is most significant. But this is to get ahead of ourselves and into our next section...
To conclude this section, let’s define some terminology. This is Rachel.

- At her routine checkup, the pediatrician charts her development: is her length and weight appropriate for her age? Did she begin walking and talking at the expected times?
- That is biological development.
On a certain month last year, Rachel appeared in costume at a children’s hospital to inspire young people with hope and courage in the face of adversity. Is this biological development?
• Or personal biography? Did her pediatrician long ago predict this would happen?
The mark of personal biography is contingent history, that it could not have been predicted and might have been otherwise.
If Rachel were the Earth, we could speak of the Earth’s development, and of the Earth’s biography or contingent history.  
- Both are part of its “directionalist” history. If you were to step into a time machine, and travel back to any period of time, things would be different.
In contrast to directionalism,
- suppose that 5 years after this first picture was taken, she looked like this.
- And 5 years later, she still looked like this.
- If the Earth were Rachel, this would be
- the steady-state vision of its past. If you were to step into a time machine, and travel back to any period of
time, things would be roughly the same.
Or a third possibility:

- suppose that 5 years after this first picture was taken, she looked like this.
- And 5 years later, she looked like this again.
- And 5 years later, like this.
- And 5 years later, like this.
- If the Earth were Rachel, this would be a cyclical vision of its past. If you were to step into a time machine, and travel back to any period of time, you would find yourself at some point in a repeating cycle, like in the movie Groundhog Day.
Let’s go back to the Directionalist perspective. There may be some earlier instances of young Leia. A time machine will reveal cycles that recur over and over, but there is an overall directionalist trajectory that shapes subsequent cycles.

- If Rachel were the Earth, young Leia might stand for an earthquake, and older Leia a later earthquake, or any other recurring process. But the cyclical processes are carried forward in a sequence that makes each instance unique, that has an overall direction, and that may be reconstructed.
<table>
<thead>
<tr>
<th>Terminology</th>
<th>Time Machine</th>
<th>Example</th>
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<tr>
<td><strong>Directionalist</strong></td>
<td>Development:</td>
<td>Periods unique</td>
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<td></td>
<td>Contingent history:</td>
<td>Not predictable</td>
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<td><strong>Cyclic</strong></td>
<td></td>
<td>Periods recur</td>
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<tr>
<td><strong>Steady State</strong></td>
<td></td>
<td>Periods the same</td>
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To summarize our terms: Development means the periods are unique. An example would be Buffon’s cooling globe experiments. Contingent history means that they are not predictable, for they might have been otherwise. They must be reconstructed. Rudwick refers to this view of Earth’s contingent history as “geohistory,” as mentioned earlier. Both development and geohistory are encompassed under the term Directionalist.

- In a Cyclic view, periods recur. We’ll see an example with Lyell’s theory of climate.
- In a steady state system, everything continues much the same, as with Jefferson’s denial of extinction. Cuvier’s arguments for the reality of extinction took the steady state view off the table as no longer viable. The cyclic and steady state views were contrary to the Directionalist, although the Directionalist view will include phases that are cyclical or steady state within the overall Directionalist trajectory. Now, on to what Rudwick called the Directionalist synthesis, which was how there came to be a general consensus among earth scientists in support of Directionalist perspectives.
So let’s turn to the establishment of the directionalist synthesis, again using Cuvier as our focus.
In 2005, Rudwick published the first title of his two-volume magnum opus, Bursting the Limits of Time: The Reconstruction of Geohistory in the Age of Revolution. Both this volume and its sequel tell the story of the emergence and acceptance of this new concept of geohistory. Rudwick explains:
“I shall argue that what was involved in the reconstruction of geohistory, far more importantly than any occasional and local conflict with religious beliefs, was a new and surprising conception of the natural world. Rather than being essentially stable and bound by unchanging “laws of nature”—ever since an initial act of creation, or else from uncreated eternity—one major part of nature, the earth itself, came to be seen as a product of nature’s own history. Furthermore, geohistory turned out to be as contingent, as unrepeated, and as unpredictable (even in retrospect) as human history itself. This book, then, is about the historicization of the earth itself during the age of revolution. It can hardly be emphasized too strongly that this was a radically new feature on the conceptual landscape of the natural sciences: understanding and explaining the natural world began to be seen to entail its contingent past history as much as its directly observable present.”

Rudwick, Bursting the Limits of Time

READ.
Contingent order is that which might have been otherwise, could not be predicted in advance, and is reconstructed by the methods of the historical sciences.
As background, we can note Rudwick’s Scenes from Deep Time, a 1992 study of the development of artistic depictions of prehuman geological scenes.

- Rudwick begins with Scheuchzer’s Physica Sacra, and its role in establishing artistic conventions for depicting reconstructed landscapes in pre-human geological periods. Rudwick explains:
- READ. Scheuchzer is best known as a leading Swiss naturalist and an advocate for the organic origin of fossils in the 18th century. His 6-volume Physica Sacra was a popular encyclopedia of natural history organized as an illustrated companion for Bible reading.
Scheuchzer portrayed the sequential development of the Earth during the days of the creation week in depictions like these, arranged in linear sequence. These plates merged traditions of biblical illustration with conventions of natural history and provided an important framework for conceptualizing and representing pre–human worlds.
Take, for example, the third day, on which
- the waters below gathered together
- to form the sea, separate from the dry land with its mountains. Mountains thus predate the origin of humans.
The lower half of the global section represents the Earth at the start of the third day.
The top half depicts the Earth at the end of the third day.
Scheuchzer accompanied the global section with landscape depictions, corresponding to different stages during and at the end of the third day. A combination of global sections and landscape depictions represent each day of creation. Rudwick’s point is that the biblical sequence of days in works like Scheuchzer’s imparted a directionalist sensibility for a prehuman Earth history.

By Directionalist Synthesis, Rudwick refers to the idea that the Earth has some kind of irreversible temporal sequence like the days of creation, Buffon’s cooling molten globes, or Cuvier’s mass extinctions, that the Earth has some kind of real history, that there is a history of Nature. There were many streams that contributed to the Directionalist synthesis, but the Directionalist synthesis really crystallized in...
this map of the Paris basin, first published in 1810.
The title reads, Geognostical Map of the Environs of Paris, by Monsieurs Cuvier and Brongniart. Alexander Brongniart and Cuvier worked together to show how fossils were the key to unravelling the order of the strata in the Paris basin. Their fieldwork discoveries, and anatomical reconstructions of fossils of large quadrupeds, demonstrated the existence of former, pre–human worlds, even in levels of strata which to that point had widely been regarded as of quite recent origin. This is a map that changed the human conception of the age of the world.
Here’s a closeup of the Paris region. (Pause) The dark blue depicts a gypsum formation, outcropping on hilltops. • Stippled areas represent the Detrital Silt along the meandering valley of the Seine River.
I don’t know if you can see the solid straight lines radiating from the center of Paris? They are lines of traverse sections...
The traverse sections are shown here. Let’s zoom in on the section in the lower left.
Among the 9 formations are the blue gypsum noted earlier.

- And the stippled Detrital Silt.
- the Chalk formation was the lowest. Yet in typical geological maps, the Chalk was the highest of the regular formations. So this map began in the recent past right where others left off.
- The Course Limestone formation, which might be confused with the Chalk, was distinguished by the fact that it had a different fossil assemblage than the Chalk. So formations are to be defined by the fossils they contain, as well as – or in some cases even more so – than the type of rock.
- Notice that the Course Limestone contains different beds within it. Cuvier and Brongniart wrote that even these individual beds could be distinguished by the fossils they contain:
“The means we have used to recognize a bed ... amid such a large number of limestone strata, is drawn from the nature of the fossils enclosed in each bed. These fossils are always generally the same in the corresponding beds and show quite notable differences of species from one set [système] of beds to another set. This is a sign of recognition that so far has not misled us.” – Cuvier and Brongniart
“The geognostic pile of formations was simultaneously interpreted as a record of the geohistory of the Paris region; the formations, described in turn from lowest to highest, became the evidence of a temporal sequence of events from earliest to most recent. And the decisive evidence for constructing this geohistorical narrative came from the nature of the fossils.”

Rudwick summarizes: READ
Cuvier and Brongniart completed the geologic sequence, as one contemporary expressed it, “From granite to gravel.” Their map of the Paris basin represents the establishment of the Directionalist synthesis.
William Buckland was one of the many persons who took up the Cuverian directionalist synthesis in Britain. This original hand-colored print held in the History of Science Collections shows Buckland's inaugural address at Oxford University in 1823. He was a charismatic lecturer, who used a wealth of fossils, maps and artifacts to captivate his audience.
Notice the fossil elephant reconstruction on the back wall, for instance.
Buckland adopted Cuvier’s conceptions of the revolutions of the globe, and he baptized it for his English audience by identifying surface debris, left by the most recent revolution on the Earth, as the biblical deluge. (Cuvier did not explicitly make this connection.) But the reality of extinction and some version of the directional synthesis were now widely adopted among Cuvier’s contemporaries.
Let’s turn now to the Devonian controversy, using Louis Agassiz as our focus.
In 1988, Rudwick published *The Great Devonian Controversy*. You'll recall the Devonian period mentioned earlier in the modern geological column. This book explores how the Devonian period came to be recognized. The subtitle is: *The Shaping of Scientific Knowledge among Gentlemanly Specialists*. Rudwick here provides a fine-grained account, based on field notes and rapid-fire letter-writing practices, of how geologists debated and negotiated their contentious and contrary interpretations of the rocks and fossils making up the strata involved. When it appeared, this book was lauded as an important contribution to the sociology of knowledge, of how even lasting scientific knowledge is socially constructed, shaped by reality AND society in inextricable relation.
Louis Agassiz was at one point a student of Cuvier’s at the end of the latter’s career, and he carried forward the directionalist synthesis. A professor of natural history at Neuchâtel, Agassiz succeeded Cuvier as the preeminent authority on fossil fish with publication of a 5–volume treatise, Researches on Fossil Fish.

https://en.wikipedia.org/wiki/Louis_Agassiz
Great Britain’s Old Red Sandstone formation was at the heart of the Devonian controversy. It was regarded as devoid of fossils until the Scottish stone mason Hugh Miller discovered an abundance of spectacular bony fish. These were the same fossils described by Agassi in the Devonian formations of Switzerland. Miller had the opportunity to meet Agassi when the British Association for the Advancement of Science met in Edinburgh in 1835. Miller’s storytelling abilities and voluminous writing substantially heightened public interest in geology, and in the Old Red Sandstone fossil fish in particular.

https://en.wikipedia.org/wiki/Hugh_Miller
This is Agassiz' subsequent work on the Old Red Sandstone fossil fish of Great Britain, and also Russia, published 3 years after Miller's book.

Monographie des Poissons Fossiles du Vieux Grès-Rouge; ou, Système Devonien
Neuchâtel, 1844–45
The work included this monograph in which Agassiz described the fossil fish specimens.
The book was accompanied by 43 stunning, large, loose-leaf aqua-tint plates in a separate envelope. Let’s look at but two examples. These Devonian fish are spectacular, as are the plates that reproduce them. Agassiz found the same species of fossil fish in both Switzerland and Britain. In the Swiss Alps, they were found in a black slate formation.
In England, they were found in the Old Red Sandstone. Therefore he urged geologists to rely upon fossils rather than rock type to correlate formations. This was a particularly contentious issue in the debates over the Devonian period.
As we saw earlier, the Devonian is a recognized period in the modern geological column, no matter how controversial it was at that time. Just as with the reality of extinction, the Devonian controversy confirms the reality of the directionalist synthesis. Yet there were three important dissenters from a directionalist view...
We can pause to note that James Hutton’s Theory of the Earth was a cyclic system, with no vestige of a beginning, and no prospect of an end.

Hutton was explicitly concerned with the philosophical problem of understanding the Earth teleologically, as the product of design. Hutton’s system was premised on the twin propositions that perpetual habitability constitutes the overall purpose of the Earth and that continual renovation is required to ensure it. The cycle of continual renovation has the potential to recur perpetually, thus preventing any past or future decay of the Earth.

That the Earth has in fact endured long enough for the cycle to recur, Hutton concluded, is manifest in tilted formations such as those he described near Jedburgh, Scotland. Unconformities reveal recycling of former worlds.

https://en.wikipedia.org/wiki/James_Hutton
And William Smith would count as a second non-directionalist. Like Cuvier and Brongniart’s map of the Paris basin, Smith’s beautiful geological map was based on fossils to distinguish the strata. Yet Smith did not interpret the formations as different historical periods. For him, they were spatial but not temporal entities.

This is a small detail from one of sixteen large hand-colored sheets cover all of England and Wales in astonishing detail. Each copy of Smith’s atlas is unique, colored from start to finish, and updated with corrections from his latest travels. This copy dates from late 1816 or early 1817.

William Smith demonstrated that fossils were the key to unravelling the order of strata in Great Britain. Working a year or two before Cuvier and Brongniart, Smith insisted that strata are best correlated on the basis of their fossils. Although he did not assign strata to pre-human epochs, as did Cuvier and Brongniart, this spectacular atlas commemorates the discoveries of a working-class surveyor who was excluded from the gentlemanly circles of early English geology and only honored in retrospect. In fact, he went bankrupt because of the expense of this work.
Or, finally, Charles Lyell, the leading opponent of directional Earth history in the generation of Agassiz.
For that reason, Lyell’s Principles of Geology, published in three volumes beginning in 1830, was regarded by some contemporary geologists as a return to speculative Theories of the Earth. In the first volume, Lyell presented his theory of climate change. Here he waxed eloquent on the grandeur of a cyclic pattern of life, with purple prose conveying his utter opposition to a directionalist view:
“We might expect, therefore, in the summer of the ‘great year,’ which we are now considering, that there would be a great predominance of tree-ferns and plants allied to palms and arborescent grasses in the isles of the wide ocean, while the dicotyledonous plants and other forms now most common in temperate regions would almost disappear from the earth. Then might those genera of animals return, of which the memorials are preserved in the ancient rocks of our continents. The huge iguanodon might reappear in the woods, and the ichthyosaur in the sea, while the pterodactyle might flit again through umbrageous groves of tree-ferns....” (Pause) If this cyclical vision were true, I suppose we wouldn’t need to worry about climate change so much today.
In a classic article on caricature in the history of geology, Rudwick analyzed this drawing by contemporary geologist Henry de La Beche. An Ichthyosaur professor is holding forth. The title is “Awful Changes. Man only found in a fossil state. Reappearance of Ichthyosauri.”
Professor Ichthyosaur is lecturing on a fossil human skull. A caption beneath says, “You will at once perceive... that the skull before us belonged to some of the lower order of animals, the teeth are very insignificant, the power of the jaws trifling, and altogether it seems wonderful how the creature could have procured food.” De la Beche, caricaturing Lyell, was himself in the mainstream of directionalist geology.
Now let’s look at the Ice Ages, again using Agassiz as our focus.
In 2010, Rudwick published the sequel to Bursting the Limits of Time, the second volume of his magnum opus: Worlds Before Adam: The Reconstruction of Geohistory in the Age of Reform. Here Rudwick carries on his theme of geohistory into the generation of Lyell and Agassiz.
Here is another major work by Agassiz, the Studies on Glaciers, published in 1840. Many scientists had studied glacial phenomena, including the ability of glaciers in the Alps to carry boulders long distances.
In numerous beautiful engravings, Agassiz detailed the characteristic features of glaciers.
Each plate has a translucent paper overlay to label the features.
The work is simply stunning. I feel that I am on a virtual tour, there in the Swiss Alps,
with Agassiz right beside me to explain everything and teach me how to look.
The effects of glaciers — creating scratches and grooves on underlying rock, dumping and shaping moraines, transporting erratic boulders, and carving out U-shaped valleys...
become clear through the field evidence presented in this paper exhibit.
Agassiz' collaborators provide corroborating witness. The surprising point is that Agassiz observed evidence of glacial action far from existing glaciers. Therefore, in previous times, he concluded, glaciers must have occupied a much larger area than they do now. The world is not just cooling down, but has warmed up in the recent past.
The History of Science Collections also holds this manuscript of lectures on glaciers which Agassiz presented in Boston a few years later.
After Studies on Glaciers was published, later that same year, Agassiz met William Buckland and together they toured the highlands of Scotland. Together they found the same evidence of glacial action which Agassiz knew so well from Switzerland. Buckland realized that the evidence he had previously interpreted in terms of the deluge of Noah was better understood as the result of glacial action. Buckland dramatically recanted his flood theory, and publicly affirmed the theory of Agassiz that, indeed, the globe must have endured an Ice Age in the recent past during which time a gigantic ice sheet must have covered nearly the entire European continent. (Pause) Even the Scottish lowlands must have been covered by ice...
Sensationally, Agassiz claimed, for example, that the Old Town or city center of Edinburgh topped by its castle had once been a rocky island (in modern terms, a nunatak) surrounded by a sheet of ice.

Rudwick explains: “Sensationally, Agassiz claimed, for example, that the Old Town or city center of Edinburgh topped by its castle had once been a rocky island (in modern terms, a nunatak) surrounded by a sheet of ice.”

- So contingency prevails: where does an Ice Age in the recent past leave Buffon’s models of the Earth as a cooling globe? With an Ice Age, the Earth must have suddenly cooled off and then warmed up again, in the recent past. After all, the glaciers are gone from Scotland now. While a generally directional change in global temperatures might still be affirmed, the Ice Age required that major exceptions sometimes occur abruptly, interrupting long term trends. The contingency of the Earth’s history is more pronounced than anticipated. Geohistory is full of surprises.
Where does all this leave our understanding of historical sciences, such as geology and climate change, today?
The face of places, and their forms decay;
And that is solid earth, that once was sea;
Seas, in their turn, retreating from the shore,
Make solid land, what ocean was before.

Ovid, Metamorphoses, XV

The Roman poet Ovid wrote:
Is our knowledge of the past doomed to similar metamorphoses? Is there any solid ground for the historical sciences to stand on?
“O Earth, what changes hast thou seen!
There where the long street roars, hath been
The stillness of a central sea.
The hills are shadows, and they flow
From form to form, and nothing stands;
They melt like mist, the solid lands,
Like clouds they shape themselves and go.”

Alfred, Lord Tennyson, In Memoriam, VII

Alfred Lord Tennyson wrote:
Are we chasing clouds in trying to understand the Earth? or can attempts to reconstruct geohistory succeed? Are the conclusions of the historical sciences reliable and warranted?
Rudwick left paleontology for history of science in order to grapple with such questions. He would remind us, I think, of the following five considerations:

- First, Knowledge is socially constructed. But this does not mean endless subjectivity. Rather, reality is also an actor. Both shape the outcome. We search for fidelity to reality as a community of knowers. This is the meaning of the subtitle: “The Shaping of Scientific Knowledge…”
Second, much knowledge that is now firmly and uncontroversially accepted as solid, was nevertheless controversial in the past. Each episode we have reviewed here is an example of an irreversible addition to our stock of warranted knowledge today: the reality of extinction, and mass extinctions, the directionalist synthesis, even down to the level of periods like the Devonian, and the unexpected contingency of geohistory as represented by the Ice Age. Knowledge grows like a mosaic, piece by piece, through episodes like these. It may not be wise to bet against the advance of knowledge.
Reflections

There is no universal scientific method. Rather, the method must fit the problem. New problems call for new methods. Therefore, science on the cutting edge is normally controversial.

Third, the study of actual scientific practice, in history or in the present, shows that there is no such thing as a universal scientific method. Rather, the method must fit the problem. New problems call for new methods. Therefore, by nature, science on the cutting edge is normally controversial. We do scientists and the public no favors by repeating simplistic accounts of the nature of science, nor by assuming that consensus is always the mark of true science.
Fourth, the natural order is contingent, which means it cannot be predicted, because it might have been otherwise, and must be reconstructed. Expect nature to be intelligible, but full of surprises. Often it just doesn’t turn out the way we expect.

Fifth, this is particularly evident for the historical sciences. They reconstruct sequences of particular events, more like solving a crime than determining unchanging physical laws. But contrary to what one might expect, in practice, the history of science shows that the conclusions of historical science are no less warranted than the conclusions of experimental science. That this is the case may seem counterintuitive or misguided. If it is true, perhaps it illustrates the remarkable resourcefulness of scientists, or the surprising intelligibility of nature, or both. That it IS the case is part of what Martin Rudwick turned to the history of science in order to show.

On this point he has a current defender, the philosopher of science Adrian Currie: Rock, Bone and Ruin, An Optimist’s Guide to the Historical Sciences. With Rudwick and Currie as our guides, these are some observations on science we may take from the history of geology.
Finally, a brief afterword.
As we have seen, Martin moved from paleontology to the history of geology. In doing so, he shaped the development for the last half century not only of the field of the history of geology but also of the history of science more generally.

Back in 1955, Martin was Cambridge’s youngest don. His switch from geology to the history of science became formalized in 1967, much to the dismay of his scientific colleagues. After distinguished sojourns at the Free University in Amsterdam, the Hebrew University in Tel Aviv, Princeton University (multiple times), and the University of California San Diego, he returned to England in “retirement” and produced his magnum opus.
We began with this photo. It shows Martin in his study the morning of June 20, last year, in Bishop’s Castle, a town of about 2,000 people in Shropshire, located in western England about 2 miles from the Welsh border, smack dab in Devonian territory. I’m pleased to announce that on this occasion, we were sorting through his papers to add them to a new History of Geology Archive in the History of Science Collections at the University of Oklahoma.
To launch this archive, we have acquired the papers of three eminent historians of geology: Martin J. S. Rudwick, Kenneth L. Taylor, and Hugh Torrens. Martin has received coveted awards for lifetime achievement in the history of geology, from the Geological Societies of London, of America, of France, and the International Union of Geological Sciences. Remarkably, Taylor and Torrens have each received three of the four medals as well, a quite unusual achievement. One could argue that these are the three most decorated scholars in the field, worldwide.

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Last June we shipped 35 boxes of Rudwick’s papers from Bishop’s Castle to Norman. They are being processed now.
While waiting for the papers to be processed, you can read his books. All but the brachiopods are still in print from the University of Chicago Press, and rightly so. And these are not all of them.
Ken Taylor is the OU Hudson/Torchmark Presidential Professor, Emeritus. His archive pertains to Nicholas Desmarest, 18th-century science, and the French earth sciences. He is my mentor in the field. I would have chosen no other.
Here is Hugh Torrens, with his wife Shirley, at a canal near their home in Madeley, Shropshire. Torrens is the foremost historian of William Smith and of Mary Anning. Mary Anning was the working-class fossil collector who made a lot of Rudwick’s gentlemen geologists famous. Torrens’ expertise is the historical relations between geology and the British Industrial Revolution. In October 2018, we shipped 35 boxes from their home to Norman. Last June, we shipped another 34 boxes. As with the others, they are being processed now.
These three collections are not alone:

- David Kitts is the late OU professor of Geology and History of Science. His papers deal with geology, the philosophy of geology, Charles Darwin, and other topics in the history of science.
- The late Alexander Ospovat was an OU History of Geology alumnus, and a professor at Oklahoma State University. His papers are mainly on Abraham Werner, the most influential 18th century German geologist.
- Léo Laporte is a renowned geologist, and historian of geology. In 2019 we received several boxes of papers, mainly on the life of paleontologist George Gaylord Simpson. So that’s the launch of the history of geology archive.
Finally, I introduced Earth’s Deep History as the first book I would recommend to someone interested in reading in the history of geology.

- As we have seen, Rudwick’s magisterial account of the development of “geohistory” is a two-volume work, *Bursting the Limits of Time* (on the generation of Cuvier) and *Worlds Before Adam* (on the generation of Lyell and Agassiz).
- In addition, I highly commend Adrian Currie’s book, *Rock, Bone and Ruin*, as a study of present practices in the historical sciences that complements Rudwick’s Great Devonian Controversy.
- If anyone would be interested in joining a reading group for one or more of these titles, let me know. I imagine a format of meeting once each month for three months, covering a single book in those three meetings, one book per semester, beginning with Earth’s Deep History. I have a clipboard with sign-up sheets here if you’re interested, no obligation, or let me know by email.
- The slides and script for this presentation are available at kerrymagruder.com/Rudwick.pdf.
- Thank you.