**The Earth Through Time**

# Chapter 2—Early Geologists Tackle History’s

**I. Founders of Historical Geology—European and English Geologists**

 **A. Nicolaus Steno or Niels Stensen (Danish, 1638–1687)**

 1. Studies of Italian geology

 2. Developed basic geologic principles

 a. Superposition

 b. Original horizontality

 c. Original lateral continuity

 3. First to study stratigraphy in an organized way

 **B. John Strachey (English, 1671–1743)**

 1. Used principles of superposition and lateral continuity

2. Studied coal beds in England

 3. Described first angular unconformity

 4. Pioneer in study of local stratigraphy

 **C. Giovanni Arduino (Italian, 1713–1795)**

 1. Classification of mountains according to type of rock

 a. Primary (oldest)

 b. Secondary

 c. Tertiary (youngest)

2. Classification used by others, including Pallas

 **D. Abraham Gottlob Werner (German, 1749–1817)**

 1. Professor of mineralogy, Freiberg Mining Academy

 2. Internationally known - first great synthesizer of geologicknowledge

 3. Advocated "Neptunist" theory and a “universal sea" to explain stratigraphy

 4. Developed a four-fold classification of rock ages

 **E. James Hutton (Scottish, 1726–1797)**

 1. Dynamic/cyclic concept of Earth history

 2. Champion of the “Plutonist” theory that challenged Werner’s concepts

 3. Used principle of uniformitarianism (actualism)

 4. First great geology text: *Theory of the Earth* (1785)

 5. Concept of immense length of geologic time

 6. Explained the significance of geologic unconformities

 7. His ideas were popularized after his death by John Playfair

**F. William Smith (English, 1769–1839)**

 1. Civil engineer and surveyor for coal company

 2. Recorded detail of stratigraphy in Britain and Wales

 3. First to publish a geologic map (1815)

 4. Noted fossil succession in stratigraphy; his book was titled *Strata Identified by Organized Fossils*

 5.Principle of fossil succession

 6. His observations were used extensively by later workers: Lyell and Darwin; Is considered the “father of English geology”

 **G. George Léopold Cuvier (French, 1769–1832)**

 1. Validated Smith's observations on fossil succession

 2. Attributed unconformities to catastrophes

 3. Advocated ‘catastrophism’ as a view of Earth history

 4. Advocated young age for Earth

 **H. Charles Lyell (English, 1797–1875)**

 1. Advocate and author exposing views of ancient Earth history and uniformitarianism

 2. Author of important text: *Principles of Geology* (1830)

 3. Synthesizer of stratigraphy who developed the first geologic time scale

 4. Principles of cross-cutting relationships and inclusions

 5. Developed concept of relative age dating and sequence of events

 **I. Charles Darwin (English, 1809–1882)**

1. Learned geology in the field from Adam Sedgwick, a prominent geology of the day at Cambridge University

 2. Read and embraced Lyell’s *Principles of Geology*

 3. Learned much about geology and biology on five year voyage of the *H.M.S. Beagle* (1831-1836)

 4. Wrote a general theory of evolution to account for fossil succession; proposed natural selection theory

 5. Reviewed the work of Wallace, who had similar findings

 6. Author of several key books, including *Origin of Species* (1859)

**II. Founders of Historical Geology—American Geologists**

 **A. Louis Agassiz (1807–1873)**

 1. Swiss immigrant to U.S. in 1846; Harvard professor

 2. In *Studies of Glaciers* (1840), proposed that immense ice sheets once covered North America

 3. Studied glacial striations, erratics, and moraines

 4. Wrote about the “Ice Age,” which ended about 8,000 to 10,000 years ago

 **B. James Hall (1811–1898)**

 1. Director of New York’s first Geologic Survey

 2. Studied over 40,000 feet of strata in New York

 3. First to theorize about the subsidence of the seafloor and its effect on stratal accumulation

 4. Author of *The Paleontology of New York*

 **C. Ferdinand V. Hayden (1829–1887)**

 1. Studied the badlands of South Dakota and the Black Hills

 2. Lobbied for creation of Yellowstone Park

 3. Conducted geologic surveys of western territories

 **D. John Powell (1834–1902)**

 1. Director of geological surveys of the western territories

 2. Director, U.S. Geological Survey

 3. Pioneer explorer of the Colorado River

 **E. Othniel C. Marsh (1831–1899)**

 1. Professor of paleontology at Yale

 2. Founded Peabody Museum of Natural History

 3. Led famous dinosaur explorations of the western U.S.

 **F. Edwin D. Cope (1850–1897)**

 1. Well-known fossil expert at the University of Pennsylvania

 2. Led famous dinosaur explorations of the western U.S.

 3. Bitter rival of Marsh in the “dinosaur rush”

**Answers to Discussion Questions**

1. Steno’s principles were superposition, initial horizontality, and original lateral continuity. Mainly the first and third principles of Steno were used by William Smith, who intuitively rediscovered them. Where Smith studied the succession of strata, he used superposition. Where Smith traced or correlated layers, he used the principle of original lateral continuity.

2. One reason that the fossils would differ is that if the layers are different ages, organic evolution would have produced a different fauna or flora entombed in the respective rock formations. Another reason is that the layers may have been formed under different environmental conditions and therefore the fauna or flora living where the rock formed would be different for environmental reasons.

3. Steno reasoned that sedimentary layers form from settling of particles and that typically forms a horizontal layer. Thus, he said that all sedimentary layers are initially horizontal. If such layers are found in any position other than horizontal, they must have been changed since deposition by geologic forces. If older strata are found on top of younger strata, this violates Steno’s principle of superposition, which says that younger always occurs on top of older. The logical conclusion is that the strata were overturned (turned upside down) by geologic forces.

4. In observing this cross-cutting relationship, Hutton might have looked for evidence that the heat of the igneous rock affected the minerals in the adjacent sedimentary rock or melted some of the sedimentary rock.

5. These are the proper matches.

John Powell – Explorer of Grand Canyon

Charles Lyell – Cross-cutting relationships

Abraham Werner – Pioneer mineralogist and Neptunist

Georges Cuvier – Proponent of catastrophism

Louis Agassiz – Recognition of Ice Age

William Smith –

James Hutton – Uniformitarianism

Charles Darwin – Natural selection

Nicholas Steno – Original horizontality

James Hall – From depositional basins to mountains

Othniel Marsh – Fossil vertebrates of western U.S.

6. The “cross sections” will show the following:

1. Flat-lying Silurian strata on the seafloor.
2. Silurian strata being squeezed and tilted upward by compression.
3. Near vertical Silurian strata being eroded to a nearly flat surface.
4. Devonian strata being deposited horizontally over the Silurian erosional surface.
5. Silurian and overlying Devonian strata being tilted by compression.

7. The only way to explain having 40,000 feet of sedimentary rock that showed evidence of only forming in shallow water was to have the basin in which these layers accumulated subside slowly over time.

8. According to the principle of cross-cutting relationships, the previously molten rock must be younger to have cut across older, therefore pre-existing rock.

**CHAPTER ACTIVITIES**

**Student activities for in-depth learning**

1. Recently (2009), Charles Darwin’s 200th birthday passed and so did the 150th anniversary of the publication of his masterwork, *Origin of Species*. Learn more about Darwin by visiting this extensive page on his life and work: AboutDarwin.com (http://www.aboutdarwin.com/index.html). Read about his voyage on the *Beagle* and write an account of the places visited on the voyage (see the “Timeline” section of AboutDarwin.com). Also comment on how these sorts of observations may have profoundly influenced the way of thinking of Darwin after he returned from the voyage.

2. The paleontological “bone wars” of Cope and Marsh are legendary. Using the web, (for example - http://www.wyomingtalesandtrails.com/bonewars2.html) read more about the battles between these two dinosaur hunters of the past. Write a short summary of what they were competing over, who they were, and make a list of their separate and joint finds and discoveries.

**CHAPTER OVERVIEW**

This chapter introduces the concept of fossils and demonstrates how important they are to the study of geology. This chapter also examines in detail the contributions of some of the founders of historical geology. The work of European scientists such as Nicholas Steno, Giovanni Arduino, Peter Simon Pallas, Abraham Werner, James Hutton, William Smith, Georges Cuvier, Charles Lyell, and Charles Darwin is discussed in terms of modern day geology. In addition, American geologists such as Louis Agassiz, James Hall, Ferdinand Hayden, and Othniel C. Marsh and their contributions to the development of historical geology are also presented. The three basic principles of historical geology formulated by Nicholas Steno—superposition, original horizontality, and original lateral continuity—are discussed in detail. Background information is provided outlining the controversy and conflict that developed among these and other early scientists as geology and its principles were developed.

**LEARNING OBJECTIVES**

By reading and completing information within this chapter, you should gain an understanding of the following concepts:

* Explain the contributions to the field of geology made by Nicolaus Steno, Giovanni Arduino, Peter Simon Pallas, Abraham Werner, James Hutton, William Smith, Georges Cuvier, Charles Lyell, Charles Darwin, Louis Agassiz, James Hall, Ferdinand Hayden, Othniel C. Marsh, and others.
* Define and apply the principles of superposition, original horizontality, and original lateral continuity.
* Describe the controversy between Neptunists and Plutonists.
* Discuss uniformitarianism.
* Describe the principle of cross-cutting relationships.
* Describe the relationship between Charles Darwin’s Theory of Evolution and historical geology.

**CHAPTER OUTLINE**

1. The Intrigue of Fossils

A. How Do Fossils Form?

1. An Early Scientists Discovers Some Basic Rules
	1. Principle of Superposition
	2. Principle of Original Horizontality
	3. Principle of Original Lateral Continuity

1. European Researchers Unravel the Succession of Strata
2. Neptunists and Plutonists Clash
3. Uniformitarianism: James Hutton Recognizes That “The Present Is Key to the Past”
	1. Uniformitarianism
	2. Uniform, But . . .
	3. Actualism
	4. Unconformities
4. The Principle of Fossil Succession
5. The Great Uniformitarianism – Catastrophism Controversy

1. The Principle of Cross-Cutting Relationships
2. Evolution: How Organisms Change Through Time
3. Earth History in America
	1. Louis Agassiz on Glaciers
	2. James Hall’s 7.5 Miles of Strata
	3. Western Geology
	4. The Dinosaur Rush

**Key Terms** (*page numbers in parenthesis*)

**actualism (19):** The principle that natural laws governing both past and present processes on Earth have been the same.

**catastrophism (21):** The theory that most features in the Earth were produced by the occurrence of sudden, short-lived, worldwide events.

**inclusions (23):** Fragments within larger rock masses are older than the rock masses in which they are enclosed. Whenever two rock masses are in contact, the one containing pieces of the other will be the younger of the two.

**principle of cross-cutting relationships (22):** This principle states that geologic features such as faults, veins, and dikes must be younger than the rocks or features across which they cut.

**principle of fossil succession (20):**  This principle stipulates that the life forms of each age in Earth’s long history are unique for particular periods, that fossils permit geologists to recognize contemporaneous deposits worldwide, and that fossils can be used to assemble scattered fragments in the rock record into a chronologic sequence.

**principle of original lateral continuity (15):** Steno’s principle which states that as originally deposited, strata extend in all directions until they terminate by thinning at the margin of the basin, end abruptly against some former barrier to deposition, or grade laterally into a different kind of sediment.

**principle of original horizontality (15):** Steno’s principle which states that most sedimentary particles settle from fluids under the influence of gravity. The sediment must then be deposited in layers that are nearly horizontal and parallel to the surface on which it is accumulating.

**principle of superposition (15):** Steno’s principle which states that in any sequence of undisturbed strata, the oldest layer is at the bottom and successively higher layers are successively younger.

**stratigraphy (17):** The study of layered rocks, including their texture, composition, arrangement, and correlation from place to place.

**unconformity (20):** A surface separating an overlying younger rock formation from an underlying formation and representing an episode of erosion or nondeposition. Because unconformities represent a lack of continuity in deposition, we know that there are gaps in the geologic record.

**CHAPTER 2**

**Early Geologists Tackle History's Mysteries**



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**NICOLAUS STENO & HIS LAWS**

•**Danish Physician (lived in Italy); 1638-1687**

•**Developed basic principles (laws) regarding age** **relationships of sedimentary strata**

•**These Principles are referred to as Steno’s Laws**

**STENO'S LAWS**

1. **Principle of Superposition -** Oldest layers are onthe bottom and younger layers on top (unless they are overturned).
2. **Principle of Original Horizontality -** Sediments aredeposited in horizontal or nearly horizontal layers**.**
3. **Principle of Original Lateral Continuity -**Sedimentsare deposited over a large area in a continuous layer that may be traced laterally.

**STRATIGRAPHY**

**Stratigraphy** is the study of layered rockswhich includes their texture, composition, arrangement, and correlation.

Stratigraphy allows geologists place rock formations into a sequence (order), and this is key to interpreting Earth history.

**HISTORICAL GEOLOGY IN EUROPE**

1. **John Strachey** (1671-1743) used superposition andlateral continuity to interpret the stratigraphy of coal-bearing rocks in England. He also described an **unconformity** for the first time.
2. In Italy, **Giovanni Arduino** (1713-1795) classified mountains according to rock type:
	* "Primary mountains" composed of crystalline rocks. These were interpreted to be oldest.
	* "Secondary mountains" composed of fossiliferous sedimentary rocks.
	* "Tertiary mountains" composed of beds of gravel, sand,

and clay; the youngest materials.

**NEPTUNISM**

Professor **Abraham Gottlob Werner** (1749-1817) Insisted that all rocks formed from a great ocean. For this reason, he and his followers were called **Neptunists**, after Neptune, the Roman god of the sea.

Primitive rocks è Transition rocks è Alluvium

* "Primitive rocks”. He thought these rocks were deposited by a hot, mineral-rich ocean. They formed the cores of mountain ranges.
* "Transition rocks" - Flat-lying sandstones, shales, coals, limestones, and old lava flows. He thought these rocks were deposited when Earth became suitable for life.
* "Alluvium", - loose gravel, sand, clay, and young lava flows that overlie his transition rocks.

**NEPTUNISM VS. PLUTONISM**

* Werner's ideas were criticized because he could not explain what had happened to such an immense volume of water needed to form all "primitive rocks," and because he insisted that lava flows were precipitated from water.
* Other geologists showed the volcanic origin of lava flows. These were the **Plutonists**, named for the Roman god of the underworld. Plutonists said that "fire" or heat, rather than water, was involved in the origin of "primitive" igneous rocks.
* James Hutton (1726-1797) was a prominent Plutonist who disagreed with Werner.

**UNCONFORMITIES**

An **unconformity** is an ancient surface of erosion (or non-deposition), separating older rocks from younger rocks.

If the older rocks are folded or tilted, the unconformity is referred to as an angular unconformity.

James Hutton recognized the

significance of the

unconformity at Siccar Point

in Scotland.

**HUTTON'S UNIFORMITARIANISM**

1. Saw Earth as a dynamic, ever changing place where rocks and mountains form slowly, and are slowly weathered and eroded.

2.

3.

Recognized that **"the present is the key to the past."**

Recognized uniform natural laws (physical & chemical laws) govern geologic processes, later this

view was called **uniformitarianism**.

1. Uniform natural laws govern weathering, erosion, glacial movement, earthquakes, volcanic eruptions, and the transport of sediment by moving water.

**UNIFORMITARIANISM**

Limitations on uniformitarianism: Some events which occurred in the past, and left a record in the rocks, ARE NOT OCCURRING TODAY, or have not occurred during human history.

These include:

* Huge meteorite impacts
* Extensive volcanism
* Large glacial ice sheets accompanied by much lower sea levels
* Differences in atmospheric chemistry - Earth's original atmosphere lacked oxygen, so chemical process acting in the weathering environment did not include oxidation

**ACTUALISM**

* Many geologists prefer to use the term **actualism**, to emphasize the importance ofnatural laws to the concept of uniformitarianism.
* Actualism is the principle that natural laws (physical and chemical laws) governing past and present processes on Earth have been the same.

**PRINCIPLE OF FOSSIL SUCCESSION**

* **William Smith** (1769–1839) was an Englishsurveyor and civil engineer who was working to site canals to transport coal in England.
* He saw that layers of rocks occurred in a definite order, and that rock units could be differentiated on the basis of the unique set of fossils they contain.

**PRINCIPLE OF FOSSIL SUCCESSION**

* Fossils occur in a consistent vertical order in sedimentary rocks all over the world.
* This is the **Principle of Fossil Succession**.

Life found at each stage of Earth’s history is unique to a specific time interval.

* Geologists interpret fossil succession to be the result of evolution—the natural appearance and disappearance of species through time.

**CATASTROPHISM**

* **Cuvier** observed a striking change in the fossilsacross unconformities
* Cuvier concluded that the only way to explain change in fossils was a global catastrophe.
* He concluded that there had been a series of catastrophic floods and crustal upheavals that changed the history of life on Earth.
* This doctrine became known as **catastrophism**.

**UNIFORMITARIANISM VS. CATASTROPHISM**

English geologist, Sir Charles Lyell (1797–1875) held the opposing viewpoint to **catastrophism**, that

of **uniformitarianism**.

Seemingly abrupt changes in the fossil record were

interpreted to result from *missing strata* *that were* *eroded along the unconformity*.

The ancestors of the "new" fossil groups were actually present in the underlying strata.

**PRINCIPLE OF CROSS-CUTTING**

**RELATIONSHIPS**

The Principle of Cross-Cutting Relationships establishes that a geologic feature is older than the feature that does

the cutting.

FIGURE 2-11 Determining the sequence of geologic events from cross-cutting relationships and

superposition.

1. Where a fault cuts across a sequence of sedimentary rock, the fault is younger.
2. Where an igneous intrusion cuts across a sequence of sedimentary rock, the sedimentary rocks are older.
3. The unconformity is younger than the rocks that have been eroded.

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**PRINCIPLE OF INCLUSIONS**

Fragments (or clasts) of rock within a larger mass of host rock are called **inclusions**. These inclusions are older than the rock hosting them.



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| FIGURE 2-12 |  |  |
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This diagram illustrates two possible situations involving the principle of inclusions.

**INTERPRETING A SEQUENCE OF EVENTS**

FIGURE 2-11 Determining the sequence of geologic events from cross-cutting relationships and superposition.

Lyell pioneered the use of cross sections like this to determine the order in which the geologic events occurred.

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**EVOLUTION OR CHANGE THROUGH TIME**

English biologist and geologist, **Charles Darwin** (1809– 1882) provided a hypothesis to account for the observed fossil succession.

He served as a naturalist on a scientific voyage around the world aboard the *H.M.S. Beagle* (1831–1836). He gathered volumes of data to support his hypothesis of the evolution of organisms by **natural selection**, which he published in 1859 (*Origin of Species*).

Alfred Russel Wallace was a contemporary to Darwin and independently developed the same ideas as Darwin

**NATURAL SELECTION**

1.

2.

3.

4.

5.

A given species produces more offspring than can survive to maturity.

Variations in morphology (form and structure) and physiology (organs and functions) exist among individuals of a species.

The individuals of a species must compete with one another for food and habitat.

Individuals with the most favorable traits are more likely to survive to reproduce.

Beneficial traits are passed on to the next generation.

**CAUSE OF VARIATION**

Darwin did not know the cause of the variations among individuals in a species.

Many years after Darwin's death, scientists determined that variations within a species are caused by **new gene combinations** that occur during reproduction, and from **genetic mutation**.

**HISTORICAL GEOLOGY IN AMERICA**

**ICE AGE HYPOTHESIS**

**Louis Agassiz** (1807–1873) was a Swiss paleontologistwho arrived in North America in 1846.

He studied glaciers and proposed that ice sheets once covered much of North America & Europe.

Evidence includes:

* Glacial striations (scratches on rock)
* Glacial erratics (huge boulders transported by ice)
* Glacial moraines (mounds of rock debris deposited by melting glaciers)
* Lakes scoured by glacial erosion

**ANCIENT SEDIMENTS AND THE**

**APPALACHIAN MOUNTAINS**

James Hall (1811–1898) was the director of New York's first geological survey.

He recognized that fossils in 40,000 ft (7.5 mi) thick sedimentary rock sequence in NY were deposited in shallow water, and concluded that the seafloor had subsided during deposition.

The Appalachian Mountains, he concluded, were later raised from that marine basin.

**GEOLOGY IN THE WESTERN US**

Ferdinand V. Hayden (1829–1887)—mapped geology of Badlands of South Dakota and other areas in the west

Hayden helped convince Congress to establish Yellowstone National Park, the oldest national park in the US.

 **GEOLOGY IN THE WESTERN US**

John Wesley Powell (1834–1902)—journeyed by boat through Grand Canyon on Colorado River to describe the many formations of the canyon area despite having lost an arm in Civil War.

Powell directed the U.S. Geological Survey.

**THE DINOSAUR RUSH**

* Cope and Marsh were rivals who competed to hire professional collectors to discover, describe, and name dinosaur fossils from the western U.S.
* O.C. Marsh (1831–1899)—first professor of paleontology at Yale University, and later founded the Peabody Museum of Natural History.
* Edwin D. Cope (1850–1897)—wealthy Quaker who taught at the University of Pennsylvania.

**THE DINOSAUR RUSH**

Results of the work of Cope and Marsh:

* Thousands of specimens of dinosaurs were collected for study and museum exhibits.
* Enhanced our understanding of life during Mesozoic.
* Provided evidence for evolution.
* Established paleontology as a science with a spirit of discovery.

The Hayden field party in the summer of 1870.

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Extensive volcanism

Large glacial ice sheets accompanied by much lower sea levels

Differences in atmospheric chemistry - Earth's original atmosphere lacked oxygen, so chemical process acting in the weathering environment did not include oxidation

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CAUSE OF VARIATION

Darwin did not know the cause of the variations among individuals in a species.

Many years after Darwin's death, scientists determined that variations within a species are caused by new gene combinations that occur during reproduction, and from genetic mutation

HISTORICAL GEOLOGY IN AMERICA

 ICE AGE HYPOTHESIS

Louis Agassiz (1807–1873) was a Swiss paleontologist who arrived in North America in 1846.

He studied glaciers and proposed that ice sheets once covered much of North America & Europe. Evidence includes:

Glacial striations (scratches on rock)

Glacial erratics (huge boulders transported by ice)

Glacial moraines (mounds of rock debris deposited by melting glaciers)

Lakes scoured by glacial erosion

ANCIENT SEDIMENTS AND THE APPALACHIAN MOUNTAINS

James Hall (1811–1898) was the director of New York's first geological survey.

He recognized that fossils in 40,000 ft (7.5 mi) thick sedimentary rock sequence in NY were deposited in shallow water, and concluded that the seafloor had subsided during deposition.

The Appalachian Mountains, he concluded, were later raised from that marine basin.

GEOLOGY IN THE WESTERN US

Ferdinand V. Hayden (1829–1887)—mapped geology of Badlands of South Dakota and other areas in the west

Hayden helped convince Congress to establish Yellowstone National Park, the oldest national park in the US.

GEOLOGY IN THE WESTERN US

John Wesley Powell (1834–1902)—journeyed by boat through Grand Canyon on Colorado River to describe the many formations of the canyon area despite having lost an arm in Civil War.

Powell directed the U.S. Geological Survey.

THE DINOSAUR RUSH

Cope and Marsh were rivals who competed to hire professional collectors to discover, describe, and name dinosaur fossils from the western U.S.

O.C. Marsh (1831–1899)—first professor of paleontology at Yale University, and later founded the Peabody Museum of Natural History.

Edwin D. Cope (1850–1897)—wealthy Quaker who taught at the University of Pennsylvania.

THE DINOSAUR RUSH

Results of the work of Cope and Marsh:

Thousands of specimens of dinosaurs were collected for study and museum exhibits.

Enhanced our understanding of life during Mesozoic.

Provided evidence for evolution.

Established paleontology as a science with a spirit of discovery.

THE DINOSAUR RUSH The Hayden field party in the summer of 1870. 30

**IMAGE CREDITS**

• FIGURE 2-11 Determining the sequence of geologic events from cross-cutting relationships and superposition. Source: Harold Levin.

• FIGURE 2-12 Inclusions. (A) Granite inclusions in sandstone indicate that granite is the older unit. (B) Inclusions of sandstone in the granite indicate that sandstone is the older unit. Source: Harold Levin.