Geosynclinal theory proposed 150 years ago

JAMES DWIGHT DANA AND THE CONCEPT OF GEOSYNCLINES

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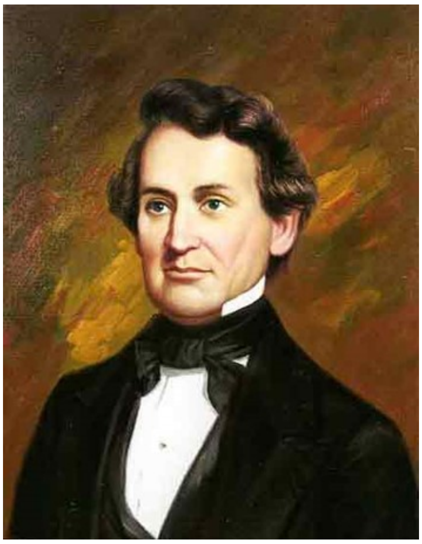

Figure 1. James Dwight Dana. Source: U.S. Geological Survey.

In June 1873, James Dwight Dana (1813–1895) (Fig. 1)—America's pre-eminent, native-born natural historian of the nineteenth century—introduced the terms *geosynclinal* and *geoanticlinal* into the lexicon of geology (later converted to the more familiar noun forms, *geosyncline* and *geanticline*). For the following 90 years the concept of geosynclines dominated geologists' attempts to understand mountain-building processes, especially in North America.

Dana was a professor at Yale, co-editor of the *American Journal of Science and Arts*, and, in 1855, president of the American Association for the Advancement of Science. These professional positions, together with his widely used textbooks (*Manual of Geology*, *Textbook of Geology*, and *Manual of Mineralogy*) provided a high-profile platform for Dana to influence students, colleagues, and the geological community globally.

Dana's early work on tectonic theory was greatly influenced by James Hall, State Paleontologist of New York (not to be confused with the Scottish geologist, Sir James Hall). In the late 1850s, Hall had pointed out that Paleozoic strata in the Appalachian Mountains of eastern North America are about ten times thicker, and also more highly deformed, than correlative strata in the interior of the continent. Hall had suggested that these two phenomena—greater thickness and greater deformation—were directly related. This led him to propose a cause-and-effect model for mountain belts in which a heavy sedimentary load depresses the underlying crust. Eventually, Hall suggested, the depressed crust fails, causing the strata to crumple into folds.

Dana rejected the cause-and-effect aspect of Hall's orogenic model. He did not accept the concept that low-density sediments could depress the higher-density crust enough to create a mountain range of folded strata. But Hall's fundamental observations were insightful, and they focused Dana's attention on the question of the origin of folded mountain belts, such as the Appalachians. He proposed that large-scale down-warping of the crust was not caused by a heavy sedimentary load, but rather that it was an inherent aspect of the structural instability of mountain belts. In Dana's model the driving mechanism was the cooling and global contraction of the Earth. As the interior of the Earth cooled and contracted, Dana reasoned, large downward folds—which he called geosynclines—had formed along continental margins, while large upward folds—which he called geanticlines—developed seaward of the geosynclines. Erosion of the geanticlines provided sediment to the adjacent geosynclines. Ultimately, the crust failed, and a fold-belt mountain range formed. Such a mountain range was thus accreted onto the continent, and a new geosyncline-geanticline couplet developed on the seaward margin of the expanding continent (Fig. 2).

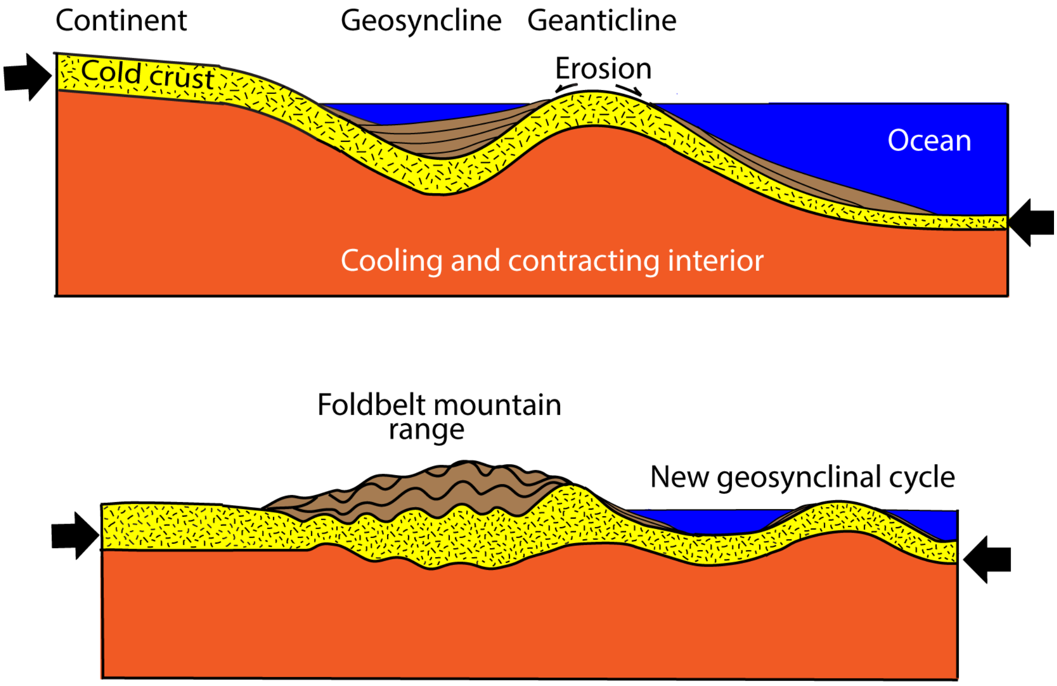

Figure 2. Diagrammatic synthesis of Dana's geosynclinal theory, showing the bending of the crust as the Earth's interior cools and contracts. Bending is shown to occur along the margin of the continent. Erosion of the upraised geanticline contributed sediment to the adjacent geosyncline, together with sediment eroding off the continent. Ultimately, the crust fails, causing the strata to be folded and uplifted as a mountain range which is accreted onto the margin of the continent. A new geosyncline and geanticline then develops outboard of the fold belt, causing the continent to expand seaward. Adapted from Dott and Prothero (1994).

North America was Dana's archetypical continent, with mountain belts occurring on both margins, between the continents and ocean basins (Fig. 3). However, this model didn't fit the occurrence of many mountain ranges elsewhere in the world. In Europe, for example, the Alpine geosyncline had apparently formed *between* two continents, rather than on the margin of a single continent. Austrian tectonicist Eduard Suess was favorably influenced by some of Dana's ideas, but he rejected the concept that a "preparatory geosyncline" was a prerequisite for mountain-making. German geologist Hans Stille also embraced aspects of the geosynclinal paradigm. It was Stille who, in 1941, coined the terms eugeosyncline and miogeosyncline, for distinctly different zones of a geosyncline.

The discovery of heat-generating radioactivity in 1896 began to cast doubt on Dana's thermal contraction mechanism for creating fold belts. This mechanism was further discredited in the early 20th century when long-distance overthrusting was recognized in some mountain ranges, such as the Alps. Huge amounts of crustal shortening was required, making thermal contraction an implausible mechanism.

But the concept of geosynclines continued to thrive, reaching its zenith in the 1950s. In 1951, Columbia University professor Marshall Kay published a monograph titled *North American Geosynclines*, in which he expanded the anatomical terminology associated with these features. Building on Stille's subdivision—eugeosynclines and miogeosynclines—Kay defined exogeosynclines, autogeosynclines, and zeugogeosynclines, among others. As late as 1960, in their book *The Geological Evolution of North America*, Canadians Thomas Clark and Colin Stern—both professors at McGill University—leaned heavily on geosynclinal theory in their reconstruction of the geologic history of the North American continent. "The geosynclinal theory," they wrote, "is of fundamental importance to sedimentation, petrology, geomorphology, ore deposits, structural geology, geophysics, and practically all the minor branches of geological science."

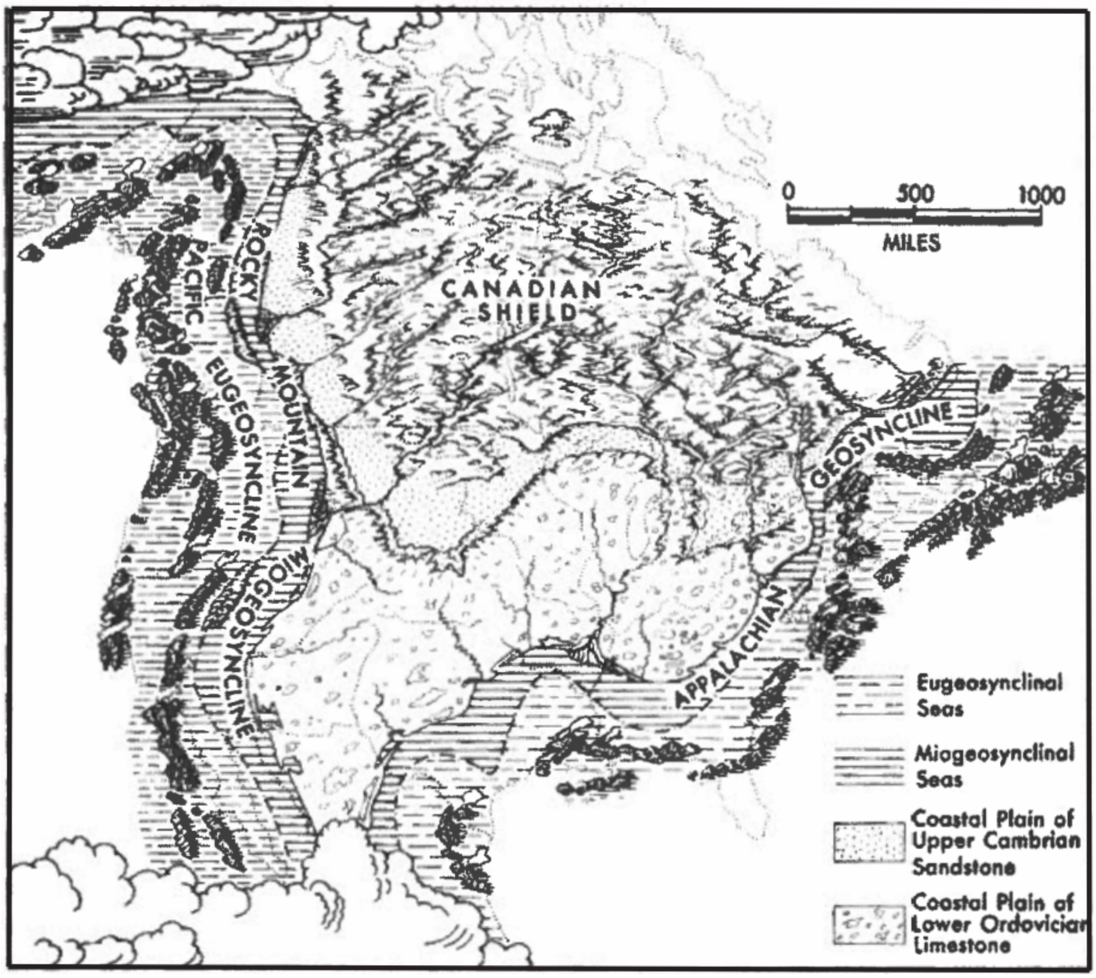

Figure 3. Reconstruction of North America in mid-Ordovician time, showing interior lowlands, bordering miogeosynclines, eugeosynclines, and island arcs. The geosynclines and island arcs are restored to the positions they occupied before being squeezed and accreted onto the margin of the continent. From Clark and Stern (1960), adapted from Kay (1951).

Hardly had Clark and Stern written those words when geosynclinal theory began to become outdated. Of course, it was the processes and terminology associated with continental-drift and plate-tectonics that pushed geosynclinal theory out of the geology textbooks and grant proposals. Although proposed by Alfred Wegener in 1915, the concept of drifting continents had been very slow to gain traction among mainstream geologists, especially in North America, the birthplace of geosynclinal theory. Finally, in the 1960s, the bold new plate-tectonic model of mountain-building gained wide acceptance, causing geosynclines to disappear into the mantle of lexicological obsolescence.

In the 1977 edition of his book *The Evolution of North America*, originally published in 1959, the prominent American geologist P. B. King provided this explanation for why North American geologists were so slow to jump on the continental-drift bandwagon. "Most of us geologists engaged in study of North America and other Northern Hemisphere continents," King wrote, "were not so much hostile to the theory as indifferent, for it did not concern our local problems that could be explained by other means."

Scientists need conceptual models to guide their research. For ninety years geosynclinal theory served as the leading conceptual model for the origin of mountain belts. It is indeed appropriate for us to celebrate the 150-year anniversary of this venerable concept. Cheers to James Dwight Dana and geosynclinal theory!

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