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Invited review

The valuation of unconformities

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ABSTRACT

Eliot Blackwelder published a paper with this title in 1909. He was the first to demonstrate that the Phanerozoic record of North America contains continent-wide regional unconformities that divide the stratigraphy into what we would now call sequences. Subsequent studies by Grabau, Barrell, Wheeler, Ager, Dott, Sadler, and others have helped to clarify the issue of missing time in the rock record, and unconformities now play a key role in the definition and mapping of sequences. Calculated sedimentation rates for the ancient record indicate that as little as 10% of elapsed time is recorded by rock at measured time scales in the 10^6-year range, the remainder being missing at sedimentary breaks.

Recent refinements in chronostratigraphic methods and the availability of a reliable Global Time Scale permit a more detailed evaluation of the nature of unconformities and other sedimentary breaks. They may be grouped into four broad classes.

1) Major breaks spanning 10^6–10^7 years. These are generated by five distinct processes: a) orogenic tectonism. Hutton's classic unconformity at Siccar Point in northern England is of this type. b) Dynamic topography. This is the term for the slow elevation and subsidence of the craton in response to changing thermal properties of the underlying mantle. Example: the great basal Phanerozoic unconformity overlying the Canadian Shield. c) Dynamic unconformities associated with basin formation, including breakup unconformities and flexural onlap in extensional basins, and the onlap/offlap stratigraphy of foreland-basin forebulges. d) Global eustasy, caused by changing rates of seafloor spreading and its effect on the total global volume of the ocean basins. The resulting breaks are the basis for the definition of what have come to be called Sloss sequences. e) Long-term environmental change, including eolian supersurfaces, and drowning unconformities in carbonates.
2) Breaks of two distinct types that span 10^4–10^5 years: a) Unconformities generated by high-frequency tectonism, including the regional propagation of such breaks by intraplate stresses. Sequences of regional extent may be bounded by breaks of this type. b) Glacioeustatic sea-level changes generated by orbital forcing of global climate change. Example: Cyclothem boundaries in the late Paleozoic record of the US Midcontinent.
3) Hiatuses of 10^0–10^3-year duration, the product of autogenic, seasonal to long-term geomorphic processes, which drive the migration and switching of depositional systems, including shelf clinoforms and deltas.
4) Minor breaks of 10^{-6}–10^{-1}-year duration (minutes to months), the breaks generated by bedform and bar migration. The product of diurnal, monthly (lunar) and normal meteorological changes in runoff; tidal cycles.

Identification and classification of unconformities and other sedimentary breaks is an essential component of high-resolution stratigraphic mapping.

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1. Introduction

The title of this paper is the title Eliot Blackwelder used for what became a landmark study that he published in 1909. The purpose of the present paper is firstly, to provide a brief review of the progress made in understanding unconformities and other sedimentary breaks in the century since this publication appeared, and, secondly, to present a modern classification of sedimentary breaks, based on our current understanding of the range of geological processes at work in forming the sedimentary record. A clarification of stratigraphic time scales and rates of allogenic processes is central to this new classification. The review focuses primarily on the stratigraphy of clastic rocks, reflecting the author's primary experience, but some examples from the carbonate record are also included.

2. An evaluation of missing time in the sedimentary record, from Blackwelder (1909) to Aubry (1991)

Blackwelder (1909, p. 289) classified unconformities in the following way:

> (a) eroded surface separating parallel strata; (b) contact between rocks of wholly unlike origin (for example, sandstone resting upon granite); and (c) angular discordance of beds with or without difference in lithologic character.

Blackwelder discussed at length the significance of these various types of unconformity, including the diachronous nature of the surfaces marking the beginning and end of an unconformity. He presented a stratigraphic chart showing the "principal periods and areas of sedimentation" in North America (Fig. 1). This is a precursor of the classic North American sequences diagram of Sloss (1963).

Grabau (1913, p. 821–826) coined the term *disconformity* for Blackwelder's type (a) unconformity, structurally conformable sedimentary breaks.

Barrell (1917, p. 748) introduced the term *diastem* for breaks in sedimentation "in which the beds above and below lie parallel, and, except for some changes in fauna or flora, give little or no indication of the great lapse of time which occurred between their deposition." His intent was to distinguish local breaks, which he described using his new term, from the more regional breaks that Grabau had included in his term disconformity. The term *paraconformity* is also used for sedimentary breaks that lack structural angularity.

Barrell (1917, his Figure 5), in a development that was decades ahead of its time, constructed a diagram showing the "Sedimentary Record made by Harmonic Oscillation in Baselevel" (Fig. 2). This is remarkably similar to diagrams that have appeared in some of the Exxon sequence model publications since the 1980s, and represents a thoroughly modern deductive model of the way in which "time" is stored in the rock record. Curve A-A simulates the record of long-term subsidence and the corresponding rise of the sea. Curve B-B simulates an oscillation of sea levels brought about by other causes. He discussed diastrophic and climatic causes, including glacial processes, and applied these ideas to the rhythmic stratigraphic record of the "upper Paleozoic formation of the Appalachian geosyncline" in a discussion that would appear to have provided the foundation for the interpretations of *cyclothems* that appeared in the 1930s. Barrell showed that when the long-term and short-term curves of sea-level change are combined, the oscillations of base level provide only limited time periods when sea-level is rising and sediments can accumulate. "Only one-sixth of time is recorded" by sediments (Barrell, 1917, p. 797). This demonstration of the significance of missing time in the geological record has largely been ignored until recently. Modern stratigraphic charts show the major, recognized breaks, based on paleontological or structural data, although commonly these charts are drawn using an arbitrary and variable scale for the time axis, which under-represents the significance of the missing time. The pervasive nature of minor breaks, and the generally fragmentary nature of the sedimentary record is typically not part of the description or interpretation of stratigraphic sections.

The petroleum geologist A. I. Levorsen was one of the first to describe in detail some examples of the "natural groupings of strata on the North American craton:"

> A second principle of geology which has a wide application to petroleum geology is the concept of successive layers of geology in the earth, each separated by an unconformity. They are present in most of the sedimentary regions of the United States and will probably be found to prevail the world over (Levorsen, 1943, p. 907).

This principle appears to have been arrived at on the basis of practical experience in the field rather than on the basis of theoretical model building. These unconformity-bounded successions can now be classified into several of the groups identified in this paper, including some that are the bounding surfaces between what are now commonly called "Sloss sequences," for reasons which we mention below and, we now know, represent tens to hundreds of millions of years of geologic time. Other examples cited by Levorsen may be categorized as dynamic unconformities related to changes in plate-tectonic configurations.

Wheeler (1958) developed the concept of the chronostratigraphic cross-section, in which the vertical dimension in a stratigraphic cross-section is drawn with a time scale instead of a thickness scale (Fig. 3). In this way, time gaps (unconformities) become readily apparent, and the nature of time correlation may be accurately indicated. Such diagrams have come to be termed "Wheeler plots."