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# Episodic accumulation and the origin of formation boundaries in the Helderberg Group of New York State

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**ABSTRACT**

**At any single locality in the Helderberg Group of New York State, most formation and member boundaries coincide with boundaries of punctuated aggradational cycles. In each case of coincidence, the boundary is a discontinuity that was produced by a rapid rise of relative base level, rather than a facies contact representing gradual migration of contiguous paleoenvironments. Apparently diachronous formation boundaries in the sequence are *not* single continuous surfaces; instead, each diachronous boundary is actually a stratigraphic series of isochronous surfaces that are separate punctuated aggradational cycles (PAC) boundaries produced by distinct geologically instantaneous base-level rises. These conclusions about the origin of formation boundaries suggest that the concept of the formation as a fundamental unit of stratigraphic description and interpretation may need revision if the stratigraphic record accumulated episodically on a small scale.**

## INTRODUCTION

Traditional gradualistic interpretations (e.g., Rickard, 1962; Laporte, 1969) of the origin of formation boundaries in the Helderberg Group of New York State are in conflict with detailed observations of the nature of most formational contacts in the sequence. This paper demonstrates that the nature of these boundaries is consistent with an episodic model of stratigraphic accumulation, the hypothesis of punctuated aggradational cycles (Goodwin and Anderson, 1980).

The American Commission on Stratigraphic Nomenclature (1961), the International Subcommission on Stratigraphic Classification (Hedberg, 1976), and recently the North American Commission on Stratigraphic Nomenclature (1983) have gone to great lengths to define rock-stratigraphic units in an objective and utilitarian manner independent of genetic interpretations. Using criteria such as "lithologic homogeneity, mappability, practical utility, and independence from inferred geologic history," the American Commission (1961, p. 649–650) has established rock-stratigraphic units, especially formations, as descriptive entities that can be recognized precisely and objectively without reference to process or mode of origin. Presumably, these efforts to establish objectivity were based on the need for a practical classification that could be applied regardless of current theories of origin, because interpretations of genesis are likely to change. However desirable this goal may be, it is essentially unattainable, because practicing stratigraphers use the formation as the fundamental unit for interpretation as well as description of the geology of a region. In other words, genesis and description are inextricably linked despite our efforts to maintain separation and independence.

In the Helderberg Group the formation has been the fundamental unit of paleoenvironmental and stratigraphic interpretation in essentially all efforts to interpret the sedimentary history of the interval. Modern investigations (e.g., Rickard, 1962; Laporte, 1969) have utilized a concept of the formation very similar to that of Shaw (1964, p. 51), in which the formation is viewed as the stratigraphic expression of a migrating depositional environment or environmental mosaic. In this view, formation boundaries at any single locality represent the passage of an environmental boundary through that geographic point. In agreement with Shaw (1964, p. 56), such boundaries in the Helderberg sequence have generally been considered diachronous perpendicular to depositional strike. For example, both Rickard (1962) and Laporte (1969) have interpreted the Helderberg Group as a fundamentally transgressive sequence in which diachronous paleoenvironmental units (formations) accumulated as a result of gradual lateral migration accompanied by gradual relative base-level rise. In these studies, most formation boundaries have been drawn and interpreted as actual diachronous surfaces separating paleoenvironmental units.

Detailed investigation of formation boundaries in the Helderberg sequence yields observations that are incompatible with these gradualistic interpretations. Most formation boundaries mark sharp contacts between very different facies, facies that do not represent laterally contiguous environments and therefore could not have been superimposed by gradual lateral migration accompanied by gradual base-level rise. However, such sharp contacts separating distinct facies *are* compatible with the hypothesis of punctuated aggradational cycles (PACs), a model of episodic accumulation that predicts abrupt facies changes at stratigraphic discontinuities (Goodwin and Anderson, 1980). According to the PAC hypothesis, the stratigraphic record consists of thin shallowing-upward cycles separated by sharp nondepositional surfaces produced by geologically instantaneous base-level rises. Each PAC boundary is at an abrupt facies change, from relatively shallow facies below to markedly deeper facies above.

The fundamental incompatibility of stratigraphic gradualism and detailed observation of formation boundaries in the Helderberg Group at single localities casts serious doubt on the actuality of diachronous formation boundaries. This incompatibility and the lateral traceability

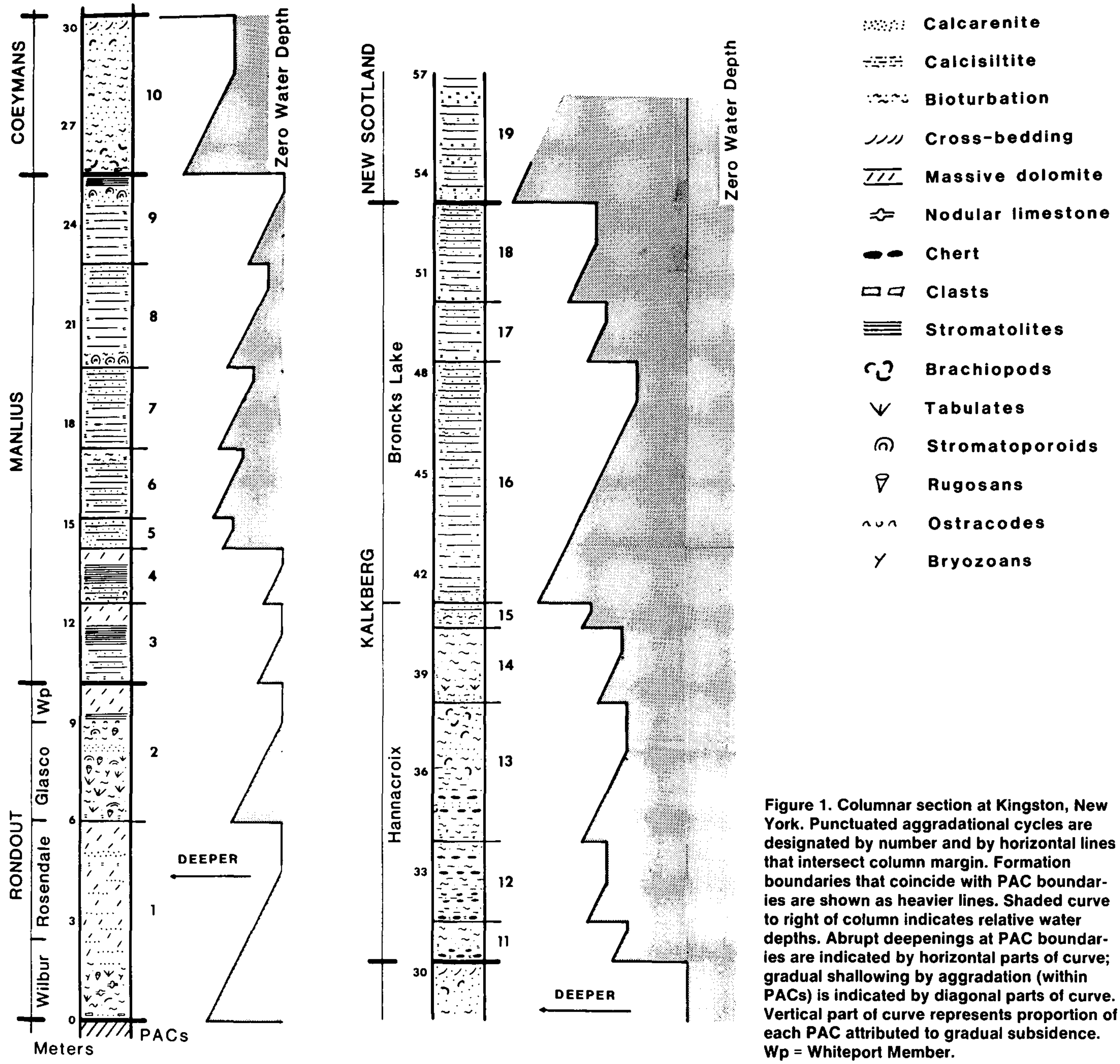


**Figure 1. Columnar section at Kingston, New York. Punctuated aggradational cycles are designated by number and by horizontal lines that intersect column margin. Formation boundaries that coincide with PAC boundaries are shown as heavier lines. Shaded curve to right of column indicates relative water depths. Abrupt deepenings at PAC boundaries are indicated by horizontal parts of curve; gradual shallowing by aggradation (within PACs) is indicated by diagonal parts of curve. Vertical part of curve represents proportion of each PAC attributed to gradual subsidence. Wp = Whiteport Member.**

of PAC boundaries through different major Helderberg facies suggest that the actual stratigraphic surfaces are isochronous surfaces separating time-stratigraphic units here referred to as PACs. We present here documentation of this conclusion from the Helderberg Group and suggest implications for the stratigraphic record in general.

## FORMATION BOUNDARIES AND PACs, HELDERBERG GROUP, KINGSTON, NEW YORK

At Kingston, New York, the Helderberg is entirely divisible into PACs. In the illustrated part of the sequence, seven of nine formation and member boundaries (defined by Rickard, 1962), from the basal angular unconformity to the base of the New Scotland Formation, occur at the boundaries of punctuated aggradational cycles (Fig. 1). For example, the Rondout-Manlius formation boundary is defined at a PAC boundary 10.5 m stratigraphically above the angular unconformity of the Rondout Formation with Ordovician rocks. At this surface separating PACs 2 and 3, subtidal fossiliferous "ribbon" limestones abruptly overlie supratidal massive dolomite.

The Manlius-Coeymans formation boundary occurs at a PAC boundary 25.5 m up in the section. Here the formation boundary separates the sea-level algal laminites of PAC 9 from the overlying bioturbated shelf calcarenites at the base of PAC 10.

The Coeymans-Kalkberg formation boundary at 30 m, the Hannacroix–Broncks Lake member boundary at 41 m, and the Kalkberg–New Scotland formation boundary at 53 m are similar surfaces. In each case the stratigraphic boundary is a PAC boundary in which markedly deeper facies overlie shallower facies. At the Coeymans-Kalkberg boundary, chert-bearing calcisiltites overlie well-washed, coarse, crinoidal calcarenites, and at the latter two contacts deeper calcisiltites are abruptly overlain by still finer fossiliferous shales and calcilutites.

In this stratigraphic section the only exceptions to the rule of coincidence of PAC and formal stratigraphic boundaries occur in the Rondout Formation, where two member boundaries (the Wilbur-Rosendale and the Glasco-Whiteport contacts) occur within PACs. At each of these contacts, the gradational change from limestone to dolomite in a shallowing-upward cycle is used to define the member boundary.

In every case where stratigraphic and PAC boundaries coincide, the facies immediately above and below the boundary are markedly disparate. *They cannot represent laterally adjacent paleoenvironments.* For example, at the Manlius-Coeymans formation boundary, the sea-level deposits of a lagoonal–tidal-flat mosaic (Laporte, 1967) are sharply overlain by near–wave-base shelf deposits (Anderson, 1972). Indeed the facies that most likely represent an environment slightly deeper and laterally contiguous with the algal laminite environment is the lagoonal stromatoporoid limestones that are normally found gradationally below the algal laminites. The facies slightly shallower and therefore contiguous with bioturbated shelf deposits is actually the bedded, well-washed calcarenites high in the Coeymans Formations, not the algal laminites of the Manlius Formation.

In summary, at Kingston, New York, in a stratigraphic section totally divisible into PACs, most stratigraphic boundaries are defined at points of abrupt lithologic change that now are observed to be PAC boundaries. Each of these surfaces represents a major paleoenvironmental discontinuity. Facies changes across these boundaries cannot be accounted for by deposition in, and migration of, paleoenvironments that were once laterally adjacent. Instead, these sharp facies changes are consistent with predictions of the PAC hypothesis, in which disjunct facies are superimposed by rapid base-level rises.

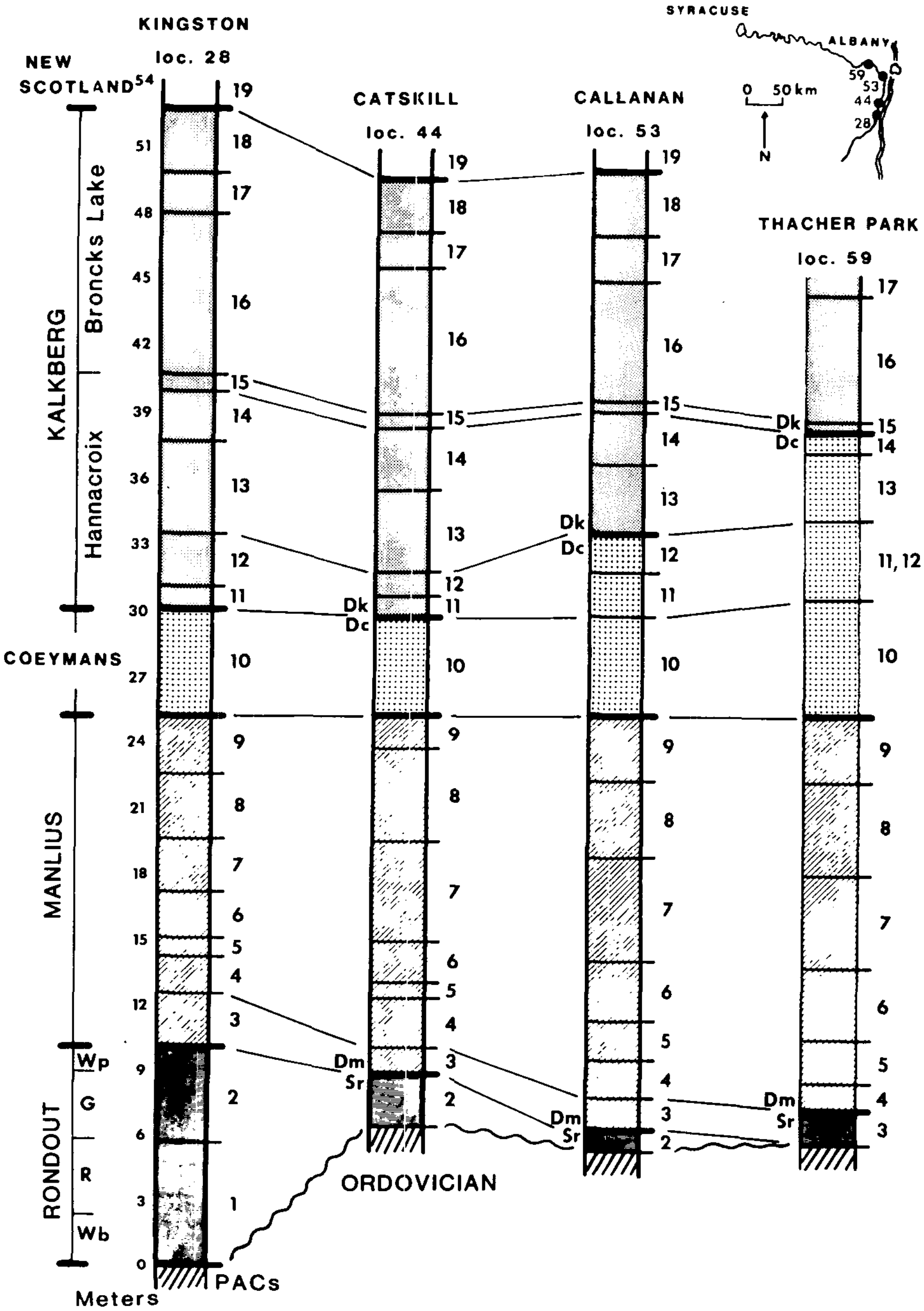


**Figure 2. Stratigraphic cross section and locality map, Helderberg Group, Hudson Valley, New York. PACs (numbered 1–19) are correlative in all sections. Formations are indicated by patterns and by symbols (Sr, Dm, Dc, Dk). Manlius-Coeymans, Hannacroix–Broncks Lake, and Kalkberg–New Scotland contacts occur at single isochronous PAC boundaries. Coeymans-Kalkberg boundary occurs at three different isochronous surfaces. Isochronous surfaces are drawn between sections where PAC boundaries at least locally coincide with member and formation boundaries.**

## LATERAL DIMENSION OF FORMATIONAL BOUNDARIES, HELDERBERG GROUP

At all correlative sections in the Hudson River valley, the Helderberg sequence consists entirely of PACs, and most formation and member contacts in the Helderberg Group coincide with PAC boundaries (Fig. 2). At every such contact, the sharp bounding surface separates distinct facies representing noncontiguous paleoenvironments. Fundamentally, these boundaries are either continuous between localities and isochronous (e.g., Kalkberg–New Scotland contact) if they coincide with a single PAC surface, or discontinuous and diachronous (e.g., Coeymans-Kalkberg contact) if they coincide with different PAC boundaries. For example, the Kalkberg–New Scotland boundary is a continuous isochronous surface separating PACs 18 and 19. At all localities, this surface was produced by the same punctuation event, a base-level rise of sufficient magnitude to produce a significant mappable facies change throughout the region.

In contrast, the Coeymans-Kalkberg boundary coincides with three different PAC boundaries at different localities. Specifically, this formation boundary is defined at the surface between PACs 10 and 11 at Kingston and at Catskill, the surface between PACs 12 and 13 at Callanan Quarry, and the surface between PACs 14 and 15 at Thacher Park. Each of these three PAC boundaries is a stratigraphically separate isochronous surface traceable throughout the Hudson Valley. Therefore, at these localities the formation boundary was produced by at least three different punctuation events. From this evidence, we conclude that this formation boundary is not a single continuous diachronous surface but is actually a stratigraphic series of isochronous surfaces. The only continuous diachronous mappable surface in these sections is the angular unconformity beneath the Rondout Formation.

## CONCLUSIONS

The Helderberg Group consists entirely of PACs, shallowing-upward cycles separated by sharp, isochronous nondepositional surfaces. Within each PAC, facies are gradational as a result of gradual shallowing of paleoenvironments. However, at PAC boundaries, facies change abruptly as a stratigraphic response to rapid, geologically instantaneous base-level rises. The resulting PACs are thin (1–5 m) time-stratigraphic units.

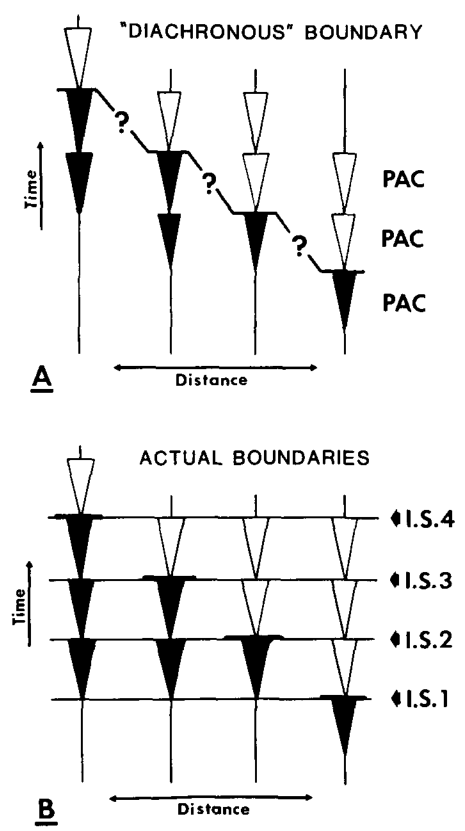


**Figure 3. A: Diagrammatic cross section of apparently diachronous formation boundary in sections divisible into PACs (triangles). B: Model of actual boundaries in sections divisible into PACs. Apparently diachronous formation boundary actually occurs at different isochronous surfaces (I.S.) at each locality.**

At any single locality, most formation and member boundaries in the Helderberg Group coincide with PAC boundaries. These contacts are sharp surfaces separating markedly different facies, facies that represent paleoenvironments that could not have been laterally contiguous. Therefore, most formation and member boundaries in the sequence did not form as a result of gradual migration of adjacent paleoenvironments. Indeed, such boundaries are discontinuities representing abrupt paleoenvironmental change in response to rapid base-level rises (punctuation events).

At different localities the same formation boundary may coincide with different PAC boundaries, in which case it must have been produced by separate punctuation events. Thus, an apparently diachronous formation boundary (e.g., Coeymans-Kalkberg boundary) is not a single diachronous surface; actually it is a stratigraphic series of isochronous surfaces, the boundaries between time-stratigraphic units (PACs). Therefore, the actual mappable surfaces in the Helderberg sequence are isochronous PAC boundaries, some of which locally are also formation and member boundaries. Other than major unconformities and some strictly local depositional surfaces within PACs, no actual diachronous surfaces exist in the Helderberg Group.

## IMPLICATIONS

The results of applying a model of episodic accumulation to the origin of formation boundaries in the Helderberg Group may have implications for the stratigraphic record as a whole, especially in light of growing evidence for pervasive episodic sedimentation (e.g., Dott, 1983). If the record is pervasively episodic, many of our traditional boundaries may very well represent significant isochronous discontinuities rather than continuous and diachronous facies change (Fig. 3A). Indeed, the only actual stratigraphic surfaces (except for unconformities) traceable for significant distances may well be isochronous surfaces separating time-stratigraphic units (Fig. 3B).

If our interpretation of the origin of formation boundaries is valid and generally applicable, the concept of the formation as a fundamental stratigraphic unit is in question. It is our contention that the concept of the formation as currently applied is linked descriptively and genetically to the paradigm (Kuhn, 1962) of stratigraphic gradualism. We may well be entering a Kuhnian period of crisis from which a new paradigm, episodic accumulation, may emerge. If so, one of the results of adopting an episodic paradigm is likely to be either a modified concept of the formation or designation of a different kind of fundamental stratigraphic unit.

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