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Interpretation of Cyclic Permo-Carboniferous Deposition in Alluvial Plain Sediments in West Virginia

Abstract: Extensive road cuts along Interstate Highway 77 north of Charlestown, West Virginia provide exposures of lateral variation in the upper Monongahela and lower Dunkard Groups (Permo-Carboniferous). The limited lateral extent of individual lithologies and of the cyclothems they define demonstrate that the cyclicity is of local (autocyclic) origin generated primarily by infrequent diversion of the main channel belt and secondarily by periodic crevassing and lateral migration of the channel belt. No evidence appears for external (allocyclic) generation of cyclicity by eustatic, tectonic or climatic mechanisms.

Introduction

In a general sedimentary model, cyclic deposits may be regarded as autocyclic or allocyclic (Beerbower, 1964, p. 32). The former are generated changes in sedimentary environment inherent in the sedimentation process, for example, delta switching. The latter are independent of particular depositional events, are generated outside the depositional unit and include tectonic, eustatic, and climatic cycles. Therefore, full interpretation of an alluvial cyclic deposit requires separation of autocyclic and allocyclic phenomena and isolation of the several particular causes of cyclicity (Beerbower, 1964, p. 36–39; Allen, 1965b, p. 163–167).

1. Autocyclicity
   (a) meander migration
   (b) chute cutoff
   (c) neck cutoff
   (d) crevassing
   (e) diversion
2. Allocyclicity
   (a) discharge changes
   (b) load changes
   (c) slope changes

The various cyclic mechanisms produce distinctive combinations of facies pattern and lithologic sequence, but sequence in itself is inadequate to define the mechanism (Beerbower, 1964, p. 36–39). Crevassing, diversion, meander migration and neck-type cutoffs, all result in superposition of a prograding sand-silt-shale unit on a flood plain claystone-limestone-coal unit. Crevasse deposits are distinguished by their limited lateral extent peripheral to a channel belt; diversion involves the formation of a new channel belt. Meander migration and neck-type cutoffs like crevassing are of limited lateral extent, but they also tend to differ in sequence since channel invasion tends to remove the prograding unit. Thus crevassing and diversion produce an alternate coarsening upward, fining upward sequence, and meander migration and neck-type cutoffs produce a simple series of fining upward units (*per* J. R. L. Allen, 1965a). Chute-type cutoffs, since they involve a sudden shift in channel position, deposit only fining upward units. Discharge and load changes may produce either coarsening upward, fining upward couples or a fining upward series according to the rate and amount of change in the system; slope changes (tectonic, eustatic, and so on) induce fining upward cycles. The cyclicity in all allocyclic cases *must* be reflected across the entire alluvial plain. Obviously in any narrow vertical section, all fining upward and all coarsening upward cycles will look alike. Only knowledge of lateral variation will serve to distinguish their origin. Equally, such distinction is necessary

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for interpretation of alluvial dynamics for autocyclic sequences and of tectonic, eustatic, and climatic pulses for allocyclic sequences.

The Dunkard and Monongahela rocks in the southwestern portion of the Dunkard basin, that is, in Wood, Jackson, Putnam and Kanawha counties, West Virginia, consist primarily of alluvial sediments (Cross and Schemel, 1956; Arkle, 1959; Beerbower, 1961). They clearly fulfill the criteria suggested by Allen (1965a) for alluvial cycles. Although road cut exposures are common, they rarely provide much information on either the over-all geometry of the sedimentary units or on their lateral variability. The construction of Interstate Highway 77 northward from Charlestown, West Virginia has provided, however, a series of exposures in which individual units can be followed for three to six miles. Preliminary study of these cuts provides the basis of this paper and for the application of the model proposed in my 1964 paper.

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Observations and Environmental Interpretation

Interstate Highway 77 trends almost due north from White Chapel, Kanawha County, across the Pocatalic River west of Sissonville and up the Left Hand and Dunden Forks of Sugar Creek to Kenna, Jackson County. I-77 and the parallel roads in this valley cut nearly every spur on the west side of the valley and many of those on the east side and provide long, well-exposed sections in the upper Monongahela and the lower Dunkard (*see* Cross and Schemel, 1956, Map II–Sheet 3). Some of the cuts are .25 mile or more in length; they are so closely spaced that individual sedimentary units can be traced easily and directly from one cut to the next for distances up to 6 miles.

Sixteen more or less distinct cyclothems are exposed; as described below some are of limited lateral extent and are variable in character. For convenience in discussion each is assigned a number beginning with the lowest unit almost due west of Sissonville and about .75 mile south of the Sissonville interchange. For reference, cyclothem 3 is exposed at road level at the Sissonville interchange, cyclothem 5 is at road level at the Goldtown interchange, and cyclothems 10, 11, and 12 are at the top of the cut at this interchange. Cyclothems that appeared as "splits" were designated by a letter suffixed to the number of the unit as first recognized.

In these exposures a typical cyclothem is a sedimentary couple consisting of (1) complexly interbedded shales, thin claystones, thin bedded siltstones, and silty sandstones (unit *b*); and (2) unbedded claystones (unit *c*). The cyclothems range in thickness from about 6 to more than 30 feet. The laminated unit (*b*) passes gradationally into the claystone (*c*) with progressive loss of bedding and decrease in grain size. The claystone, however, has a sharp contact with the next overlying laminated unit although the grain size change is progressive. The *b* unit represents the intermediate velocity, prograding environments, and *c* the low velocity, flood plain environments that I described earlier (1964, p. 35). In the notation of that paper, with "/" indicating discontinuity and "–" continuity, they form a cycle pattern [*b–c/b–c*]. The upper part of each cyclothem also corresponds to the upward fining cycle of J. R. L. Allen (1965a); the lower part, however, coarsens upward as described in many deltaic cyclothems (Duff and others, 1967, p. 81ff.) and as suggested in my model for alluvial cyclicity (1964, p. 35, 39).

Imposed on this pattern are a number of lithologic variants, channel-fill sandstones (unit *a*), coals, and nodular limestone beds. Where channels—the high velocity environment—appear, the cyclothems assume the patterns [*a–b–c/b/a–b–c*], [*a–b–c/a–b–c*] and [*a–b/a–b*]. In the latter two cases the cyclothems correspond to the fining upward type of Allen.

Significant lateral variation in the I-77 exposures are shown in 9 of the 16 cyclothems—variation critical to the interpretation of cyclicity. The best channel fill exposures are in the cyclothem 4 (Fig. 1A). A mile south of the Sissonville interchange, this unit begins with a silty shale (b_4) succeeded upward by thin, lensing beds of shaley and sandy siltstone. These grade up into poorly bedded silts and then to a claystone (c_4). Shaley coal 4 inches deep tops the claystone. The coal and claystone extend northward nearly to the Sissonville interchange, but the siltstone-shale unit is reduced to about 6 feet of poorly bedded, silty shale with a few thin siltstone beds. At the interchange, however, this cycle is represented by a thick sandstone channel-fill (a_4) and a thin claystone. The channel cuts through the upper part of the cyclothem 3 (c_3) and into a smaller channel-fill (a_3) in that cyclothem, yielding locally a $[b_2-c_2/a_3/a_4-b_4-c_4]$ sequence. As cut by the highway (not necessarily perpendicular to channel strike) the channel-fill is about 2 miles wide with the steeper bank to the south. The northern two-thirds of this fill consists of thin bedded shales and silts; north of the channel shoulder the cyclothem resumes the more typical b_3-c_3/b_4-c_4 pattern, but within .5 mile the laminated silt beds grade into red shale and thence disappear in a thick claystone unit which includes the coal and nodular limestone described below. At this point the cyclothem 4 disappears as the pattern (Fig. 1B) becomes $[b_3-c_3-c_4/b_5]$.

Apparently similar though less well exposed channels are represented in cyclothems 3 and 12. The latter is of interest because it removes, locally, all of the cyclothem 11 and most of 10 to yield the sequence $[b_9-c_9/b_{10}/a_{12}]$.

As is illustrated in Figure 1B, cyclothem 3 in its northernmost outcrops includes a channel filled with claystone and delimited by a basal coal and underclay. A similar relationship was described by Williams (1964, p. 17–18) in the Pennsylvanian of western Pennsylvania. The absence of silt indicates abrupt abandonment of the channel followed by peat accumulation and then by vertical accretion of clay in a backswamp environment. With compaction of the peat the channel remained as a shallow depression on the floodplain; the last stages of filling are represented by a lens of nodular (?algal) limestone above the channel.

The disappearance of cyclothem 4 is paralleled by variation in cyclothem 7. At its southernmost exposure it comprises the typical $[b_6-c_6/b_7-c_7]$ pattern, and b_7 includes a considerable number of silty sand beds. In .5 mile northward the sandier layers disappear, and 2 miles beyond, at the Goldtown Interchange, b_7 is reduced to a silty, unbedded unit between the c_6-c_7 claystones. Unlike b_4, however, b_7 retains some identity with local thin, lensatic, siltstones filling small, very shallow channels between c_6 and c_7.

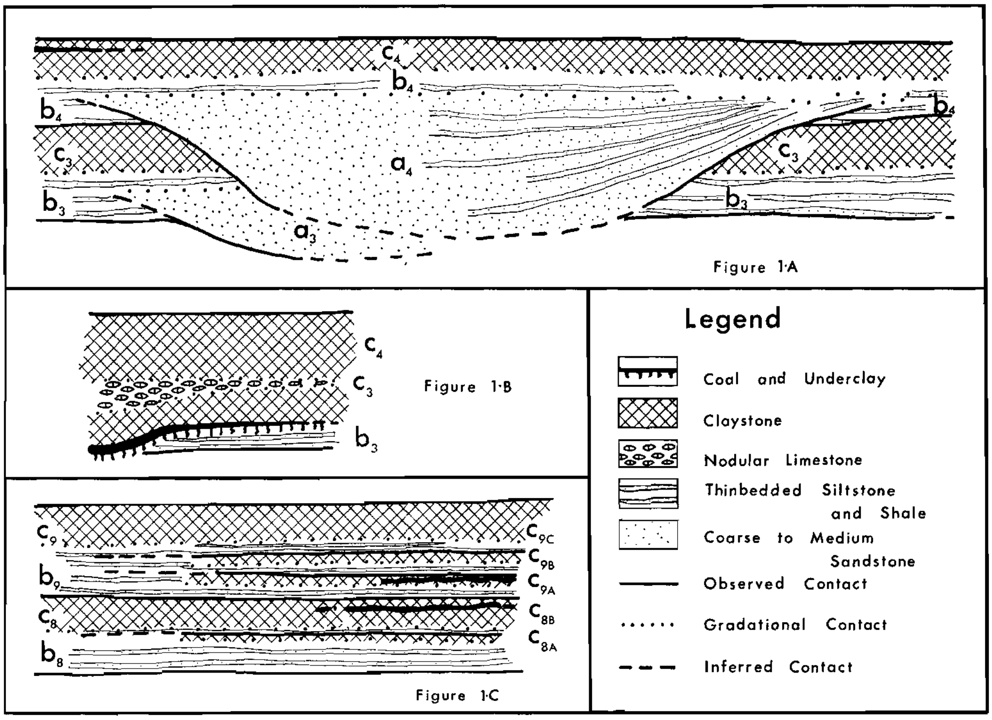

Figure 1. Diagrammatic north-south sections of Dunkard cyclothems reconstructed from road cut exposures along Interstate Highway 77. *A*. Cyclothems 3 and 4. Length of section about 4 miles; thickness about 50 feet. North to right. *B*. Cyclothems 3 and 4 just north of section shown in *A*. Length about 1 mile; thickness about 35 feet. *C*. Cyclothems 8 and 9. Length about 2 miles; thickness about 40 feet. North to right.

From an alternate viewpoint, these variations can be considered "splits" within a single cyclothem inserted in the *c* phase. The inverse phenomenon, that is, a split in the *b* (or lateral loss of the *c* phase) is also recorded. South of Goldtown, the sequence consists of $[b_8-c_8/b_9-c_9/b_{10}-c_{10}]$. Unit b_9 is 8 to 10 feet thick and includes several distinct silty sandstone lenses. To the north from this point two red claystones are apparently intercalated into b_9 (Fig. 1C) so that the sequence takes the form $[b_8-c_8/b_{9A}-c_{9A}/b_{9B}-c_{9B}/b_{9C}-c_{9C}/b_{10}-c_{10}]$. In addition, 3 miles north of Goldtown, carbonaceous shale appears as a local lens at the base of b_{9B}. Cyclothems 5 and 8 also show splits.

In these five cyclothems at least, the lateral extent of the defining lithotopes, that is, shale-siltstone versus claystone, is approximately 2 to 3 miles. Since the section is not necessarily at right angles to the channel belt these may not be minimum dimensions. They do, however, yield an order of magnitude commensurate with that observed for the width of depositional environments in modern alluvial plains (Allen, 1965b). Cyclothems 6, 8, and 10 show no significant lateral variation through 4 or 5 miles of exposure—but this uniformity is easily explained if the channel belts for these cycles trended approximately north and south. Since these cyclothems are similar in thickness and other characteristics to the others, there is no reason to assume they differ in origin.

Interpretation

In alluvial plain sedimentation, cycles induced by allocyclic (extrinsic) mechanisms should be basin wide in scale; autocyclic mechanisms will produce cycles of limited extent—similar in scale to the individual depositional environments within an alluvial plain system. On this ground, cyclothems 4, 5B, 7, 8B, 9B and 9C must be interpreted as autocyclic. Of the remainder, exposure is insufficient for interpretation of cyclothems 1, 2, 3, 11 and 12; the properties of cyclothems 5A, 6, 8A, 9A and 10 are consistent with either kind of mechanism.

Cyclothem 4 apparently resulted from the avulsion (diversion) of a channel from a subjacent meander belt into what was previously a flood plain, backswamp environment, and from the subsequent abandonment of the channel following another diversion. The basal shales and siltstones of 4 represent a prograding alluvial cone. Extension of the trunk channel across the cone produced a new meander belt—marked by levee and crevasse splay deposits as well as by channels. The former environments are presumably preserved in the upper shales, siltstones, and silty sandstones adjacent to the channel. The claystone-coal filling in the northernmost of the two channels is most simply interpreted as a clay plug in a channel abandoned abruptly in a chute type cutoff. The sand filling in the southern channel might represent either a neck-type cutoff or channel avulsion. The latter hypothesis is favored because the bar top stratum silts and sands are blanketed by flood plain claystones indicating the removal of the meander belt from the immediate area.

Cyclothem 7 appears to represent a similar sequence—except that no channels are exposed in the I-77 road cuts. In the southern outcrops the siltstones and shales in this cyclothem may be taken as a complex of levee and crevasse splay deposits on the margin of the meander belt. These feather laterally into silty claystones with thin, narrow sandstone lenses. The latter may mark individual crevasse splays of unusual lateral extent.

Variation in cyclothem 9 is more complex, and further observation may radically alter its interpretation. The claystones that divide the cyclothem in its northern exposures appear to be wedges of flood plain material that dovetail southward between wedges of levee-crevasse splay silts and shales. If this apparent geometry is correct, minor lateral fluctuation of the meander belt–floodplain boundary—by meander migration or extensive crevassing—could have induced the intertonguing. The splits in cyclothems 5 and 8 may have had a similar origin since the insertion of the claystone within the siltstone hemicycle clearly occurs by wedging in of the alluvial plain element with concomitant thinning of the underlying units.

If the remaining eight cycles had an autocylic cause, the siltstone/claystone couple is most easily interpreted as alternation of alluvial cone and levee with backswamp environments. The relative rarity of channels implies that the alternation arose by abrupt channel avulsion rather than by progressive channel migration. None of the channels observed appear to climb section. If, as appears most unlikely, they are allocyclic, the alternation corresponds to one I predicted for discharge fluctuations (Beerbower, 1964, p. 39). In the absence of positive evidence for allocyclicity, further discussion of this alternative seems undesirable.

Conclusions

Several alluvial cyclothems in the upper Monongahela and the lower Dunkard are demonstrably of local, autocyclic, origin. This conclusion probably applies to most of the other cyclothems recognized in the I-77 exposures. Contrary to my earlier opinion (Beerbower, 1961, p. 1047) there seems no need to invoke climatic changes or other allocyclic explanations for the cyclothem pattern observed in the southern, alluvial, facies of the Dunkard Series.

This conclusion, however, cannot be extended beyond the particular region studied—for reasons cited in my 1964 (p. 41) paper. In fact, geochemical studies of the Dunkard deltaic facies cyclothems (Vemuri, 1967) support a contrary view and appear to argue for climatic causes. The work of Williams and others (1964) in the deltaic Carboniferous of western Pennsylvania, for example, supports superposition of autocyclic cyclothems (delta switching) on allocyclic patterns of eustatic origin.

The major cause of cyclicity in the section studied appears to be channel avulsion. The rate of diversion seems comparatively low since channels are relatively infrequent—totalling perhaps 1/10 of the exposed section, and overbank deposits—alluvial cone, levee, crevasse splay, and backswamp dominate the exposures. And this in spite of low subsidence rates which expose the overbank deposits to channel reworking for long periods of time, for example, a 50 foot channel removes two or three episodes of deposition representing on the order of up to 400,000 years. This is in marked contrast to Catskill and Old Red alluvial cyclothems which consist principally of channel fills with a small admixture of overbank sediments although subsidence was much more rapid. We are, clearly, some distance from a complete understanding of cyclic phenomena in alluvial sequences.

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