"Nunda Sandstone" Depositional Event in the Pipe Creek Black Shale, South Wales – Varysburg Area, New York

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ABSTRACT

The Upper Devonian (Frasnian) Nunda Member of the West Falls Formation is characterized by siltstones and sandstones of gravity flow origin, and is marked by distinctive, thick sandstone units at its top in southern Wyoming County, New York. Recent study of these thick, culminating beds shows that the shales and thin sandstones interbedded with most of the thick sandstones can be correlated westward with the Angola Shale Member, whereas the uppermost massive layers of the Nunda are interbedded with black shales of the Pipe Creek Member-succession. Hence, the Angola-Pipe Creek boundary extends eastward into the uppermost part of the Nunda succession; for this reason we herein refer to Angola-equivalent sandstones as Nunda and Pipe Creek-equivalent sandstones as "Nunda."

Both the Nunda and "Nunda" intervals thicken eastward and southeastward impressively near South Wales in eastern Erie County, and massive 3-6 m thick sandstone beds develop in the uppermost Nunda and "Nunda" in Wyoming County. "Nunda" facies is expressed as grey to brown, micaceous sandstone that can be laminated, massive or chaotic. The "Nunda" succession typically displays a sharp basal contact with silty grey, Angola-type mudstone beds as well as with the basal part of the Pipe Creek shale but has a complex interfingering relationship with overlying Pipe Creek shale deposits. Locally the "Nunda"-Pipe Creek lithologic boundary is characterized by disturbed bedding. Sharply defined olistoliths observed within the lower part of the "Nunda" in two localities are composed of Pipe Creek-type black shale clasts including one observed clast displaying what is probably the Angola-Pipe Creek contact. This evidence suggests that the "Nunda" records one or more large gravity flow events that occurred during the time of Pipe Creek black mud deposition and which, at least locally, scoured up the Angola Shale-Pipe Creek Shale contact.

INTRODUCTION

The Late Devonian (Upper Frasnian) Pipe Creek Member of the West Falls Group is an important correlational marker in sections mainly west of the Genesee Valley (Pepper and DeWitt, 1950; Pepper et al., 1956; Richard, 1975; Van Tyne, 1982). In Erie and northernmost Chautauqua County it overlies the Angola Shale Member, a heterolithic succession of nodular grey silty mudstone, grey mudstone with nodular pyrite horizons, and thin black shale units (Tesmer, 1963; Buehler and Tesmer, 1963). Thicker siltstone and sandstone beds appear in the upper Angola in the vicinity of West Falls in Erie County; this coarse facies (Nunda Member) rapidly thickens eastward from there, particularly in the vicinity of South Wales (Jacobi et al., 1990; Jacobi et al., 1994). Farther east, in the Java Village-Johnsonburg area in Wyoming County, a succession of turbiditic sandstone layers capped by massive (4-7m thick) sandstone beds occurs below the Pipe Creek black shale (Pepper et al., 1956; Jacobi et al., 1994). Jacobi et al., (1990, 1994) noted that the Nunda sandstone beds displayed abrupt terminations instead of grading distally into thinner turbiditic layers. Moreover, these same researchers showed that 1) higher sandstone beds distinctly thin over differentially thickened underlying beds, suggesting that the sand accumulations had positive relief on the seafloor, and 2) flow directions in the sandstone suggested a lobate geometry to these sand bodies. This information indicated to Jacobi et al., (1990, 1994) that the thick Nunda sandstones represent sand lobes on a submarine fan. These lobes were generated by sand-rich gravity flows characterized by inefficient, viscous internal hydraulics. These characteristics contrast with evidence for sand-poor, efficient flow in thin, turbiditic sandstones observed lower in the section (Jacobi, et al., 1990,1994).

One of us (Baird), while examining the regional basal contact of the Pipe Creek Shale, noticed the abrupt eastward appearance of "Nunda"-type sandstone within the basal part of the Pipe Creek beginning in gullies immediately west of the Village of South Wales. East of the village in a ravine north of Warner Hill Road (**Fig. 1**), thicker sandstone beds appears in the basal Pipe Creek, and contorted sandstone

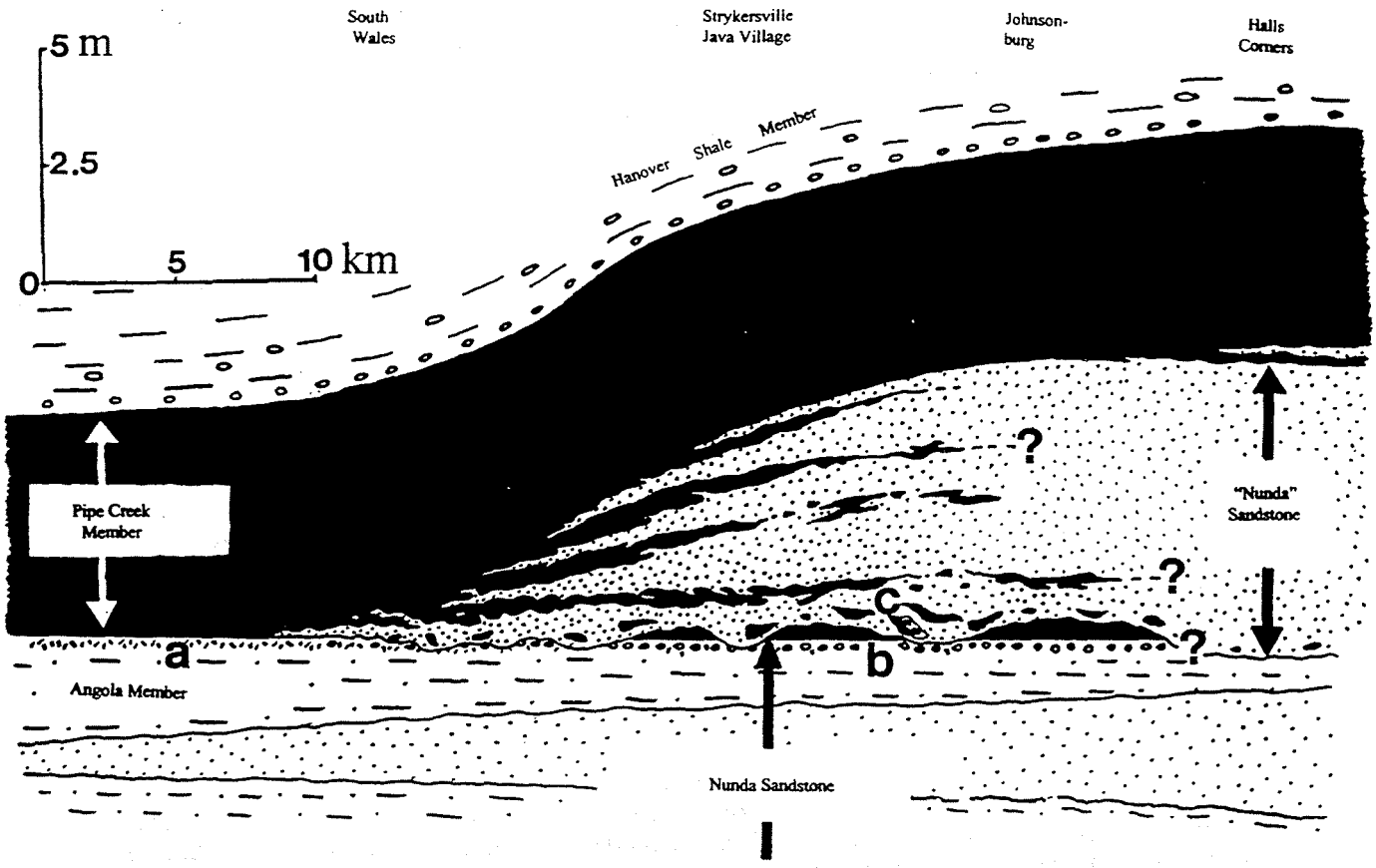


Figure 1. Generalized east-west cross-section of the Pipe Creek Member and associated stratigraphic units in the region between West Falls and Warsaw, New York. Note relationship between the Pipe Creek black shale and the complex "Nunda" sandstone which is interpreted to be the product of several major gravity flow events (see text). Lettered features include: a, pyrite-rich zone of Angola Shale below Pipe Creek member in eastern Erie County; b, carbonate nodule-rich zone below lower contact of probable Pipe Creek shale in non-eroded inlier below "Nunda" sandstone; c, olistolith showing exhumed Angola-Pipe Creek contact. Question marks denote uncertainty as to the position and character of the Nunda-"Nunda" contact where the sandstones appear to be juxtaposed southwest of Warsaw, and as to whether discrete "Nunda" beds within Pipe Creek in the Strykersville area amalgamate eastward to give the impression of a single massive flow event or whether the massive bed in the Johnsonburg-Halls Corners area is truly a single event.

intermixed with black shale appear above the basal sandstone. Similarly, Jacobi et al. (1990, 1994) noted disturbed beds in the "Nunda" at this locality as well as the rapid increase in underlying Nunda thickness in this area. To the east and southeast of the South Wales-Holland area, very thick, massive sandstones appear near the top of the Nunda interval with maximum observed bed thicknesses of several meters (**Fig. 1**). In the Strykersville-Johnsonburg area of Wyoming County, the thick, massive culminating beds usually number two to three in sections and they locally overly thin erosional remnant inliers of Pipe Creek black shale (**Fig. 1**).

It is significant that the base of the Pipe Creek shale can be traced eastward into the interval of thick sandstone development (Fig. 1). This means that there is an Angola-equivalent Nunda sandstone succession and a Pipe Creek-equivalent "Nunda" sandstone; for purposes of discussion herein we refer to all massive, laminated and contorted sandstone within the Pipe Creek sedimentary package as "Nunda" with quotation marks since this unit is, as yet, unnamed. This paper provides a brief description of the "Nunda" facies and a discussion regarding its regional significance with respect to surrounding facies.

"NUNDA SANDSTONE"

The base of the Pipe Creek Shale in the West Falls and Emery Park areas of Erie County is sharp, but apparently non-erosional; approximately 5m of hard Pipe Creek black shale rests abruptly on bioturbated silty green-grey mudrock of the Angola Shale in this area. One persistent Nunda sandstone layer extends westward to the west branch of Cazenovia Creek at West Falls, but much of the West Falls succession is mudstone in this region (Buehler and Tesmer, 1963; Jacobi, et al., 1990, 1994).

At Emery Park, however, the base of the Pipe Creek Shale contains a dilute fraction of micaceous sand above the upper Angola contact. In the gully paralleling Darling Road 1.5 km (0.9 mi) west of South Wales, the basal 8-10 cm of the Pipe Creek is marked by a mud-rich micaceous sandstone containing a breccia of black shale clasts (Fig 2c). This unit displays a sharp basal contact on the Angola, and appears to represent the northwestern limit of the "Nunda" as a recognizable unit. To the south and east of South Wales the "Nunda" sandstone thickens to a meter or more in tributary localities bordering the East Branch of Cazenovia Creek; typically it displays a sharp base on the Angola, displays horizontal internal lamination, and grades upward into the Pipe Creek through a transitional zone of micaceous, sandy black shale. However, in an unnamed ravine 0.25 km (0.15 mi) north of Warner Hill Road and 0.7 km (0.4 mi) east of South Wales, 0.5 m of "Nunda" sandstone is overlain by a 0.6 m zone of complexly interlayered and contorted black shale and sandstone blocks that pass upward into uniform black shale. At this locality the sand appears to have been injected into soft, but coherent black mud that peeled and rolled as the sand surged through it. The resulting "ice cream roll" fabric is a freeze-frame image of this deformation.

East of the East Branch of Cazenovia Creek, the "Nunda" thickens dramatically into a massive brown sandstone body that caps waterfalls on area creeks. In the Java Village, Strykersville, and Johnsonburg areas of Wyoming County, this sandstone interval can reach thicknesses of 6 and 7 m! (Fig. 1). The base of the "Nunda" is sharp both on Angola-type grey, nodular, silty mudrock facies and on thin intervals of basal Pipe Creek shale that are locally present, whereas the upper boundary grades complexly into the Pipe Creek. For example, at Angel Falls in Java Village (**STOP 2**) the massive "Nunda" facies at the falls rests abruptly on a 8-9 cm-thick black shale unit that appears to be a basal erosional remnant of the Pipe Creek Member. However, the "Nunda" grades upward into the Pipe Creek succession. Examination of the highest sand-rich interval at this locality reveals sheets and pods of brown sandstone complexly intermingled with black shale clasts and masses through an interval of approximately 75 cm-thickness. Much of the black shale occurs in brecciated pieces ("broken formation"), but some of the texture suggests a soft-sediment condition for both the black mud and sand (Fig. 2a, b).

On a small, west-flowing tributary of Cayuga Creek that borders the east edge of the Bryncliff resort (0.4 km [0.25 mi] south of U.S. Route 20 east of Parsons Corners), the "Nunda" reaches the greatest overall complexity of any section so far observed. It is expressed as two or more brown sandstone units complexly interlayered with darker sandy Pipe Creek shale. The basal "Nunda" sandstone unit displays a sharp base on the grey (Angola-type) mudstone lithology. Although the Pipe Creek shale is not observed to underlie this basal sandstone at this locality, clasts of Pipe Creek shale and carbonate nodules typical of

the uppermost Angola Member occur reworked at the base of the "Nunda". In adjacent sections where the basal Pipe Creek contact is intact, these same nodules characterize the intensely bioturbated 15 cm interval of underlying Angola-type facies. Within the thick basal sandstone are coherent olistoliths of Pipe Creek-type black shale. Below the "Nunda" interval on this creek are two lower Nunda sandstone beds that overlie Angola Shale at the base of the section. Above the 6-7m "Nunda" interval is a 6-7m succession of black Pipe Creek shale.

In creeks near Johnsonburg, still farther east, the "Nunda" sandstone becomes even thicker (Fig. 1). In a ravine below the Hickory Hill Camp (1.6 km [1.0 mi] northwest of Johnsonburg), the "Nunda" sandstone is approximately 6 m-thick. In this section at the base of the "Nunda" interval is 0.5 m of Pipe Creek shale that rests abruptly on nodular grey mudstone. Downstream from the nodular mudstone level is a thick Nunda sandstone bed and still lower, less thick sandstones and associated silty grey mudstone layers.

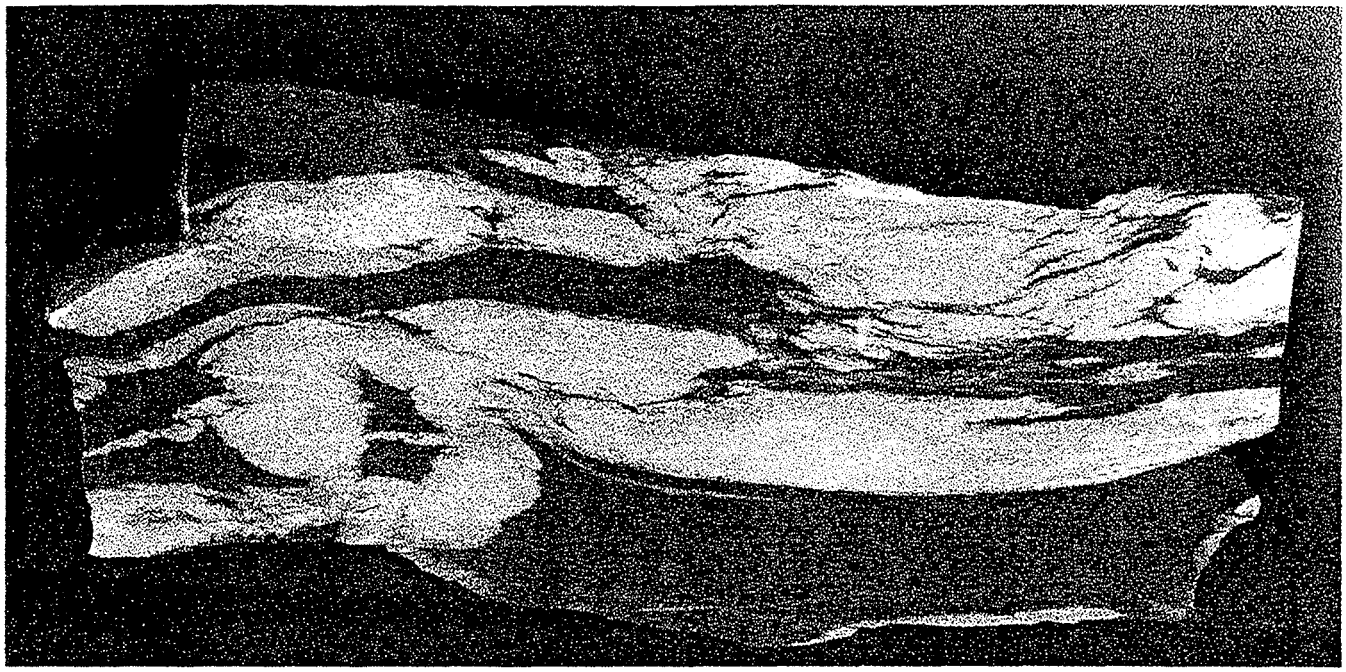
"NUNDA" DEPOSITIONAL EVENT

Most siltstone and sandstone beds in the Nunda succession have been attributed to gravity flow processes associated with westward-northwest progradation of the Late Devonian Catskill Delta (Sevon and Woodrow, 1985; Broadhead, et al., 1982; Jacobi, et al., 1990, 1994). Most observed layers are relatively thin C- and D- starting turbidites that are tabular in outcrop, many displaying sole mark features consistent with a turbidite origin. The thin beds are numerous and appear to be the products of efficient, highly fluidized gravity flows associated within a probable radial turbiditic fan system (Jacobi, et al., 1990, 1994).

In contrast to the thin turbiditic beds are the aforementioned massive sandstone units that are far less common in outcrop. These typically display non-graded, laminated to structureless interiors and often spall into conchoidal pieces in outcrop. As noted above, the "Nunda" sandstone displays local disturbed bedding features and is quite complex. Jacobi, et al. (1990, 1994) believed that the massive beds were the products of inefficient, sand-rich density flows and that such flow events were probably distinct in origin from those responsible of the thin, graded siltstone and fine sandstone beds elsewhere in the section.

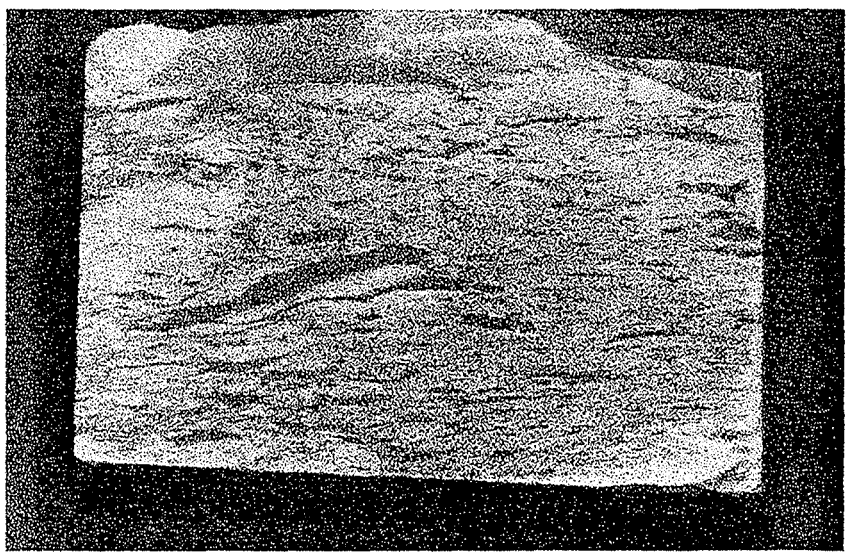
A key question concerns the timing of the "Nunda" gravity flow events relative to the onset of Pipe Creek black mud deposition. Were the "Nunda" events synchronous with the earliest black mud accumulation or did they occur well after that time? We believe that initial deposition of the "Nunda" sand flow events occurred well after onset of black mud deposition because "Nunda" sandstone apparently overlies the basal part of the Pipe Creek in several sections. In particular, we observe olistoliths of, at least, partly lithified Pipe Creek black mudstone within the "Nunda". These indicate that the already deposited black mud had been sheared off of the seafloor during one or more "Nunda" flow events. Most significantly we observe in a ravine 1.0 km (0.6 mi) north of Java Village a detached olistolith of Pipe Creek lithology displaying a bedding contact with Angola-type mudstone adhering to it. This suggests that the Angola-Pipe Creek contact, once present in the region, was sheared off and incorporated into the flow system at least locally (Fig. 1). Although soft-sediment interaction of the higher "Nunda" sands with minimally consolidated Pipe Creek deposits may be the result of later, minor flow events emplaced onto water-rich Pipe Creek muds, large sand fluid-escape structures (sand blows) suggest that some of the deformation may be related to liquefaction resulting from ground shaking. The events that triggered emplacement of the Nunda and "Nunda" massive beds can only be conjectured. However, it is likely that such events were of a seismic nature.

Figure 2 (facing page). Disturbed bedding associated with Pipe Creek shale – "Nunda" Sandstone contact. 2A, B show injections of "Nunda" Sandstone within Pipe Creek lithology, top of "Nunda" interval at Angel Falls in Java Village, N.Y.; 2C shows breccia of Pipe Creek black shale clasts in thin marginal "Nunda" sandstone deposits, creek immediately south of Darling Road west of South Wales, N.Y. All figures X1 and oriented top-up.



A) ANGEL FALLS, JAVA VILLAGE

B) ANGEL FALLS, JAVA VILLAGE



C) DARLING ROAD

To summarize, questions that remain after our preliminary work include the following.
1) Is the deformation we observe in the "Nunda" sands primarily the result of sand flow transport or from essentially in-place liquefaction?
2) The usual model for transgressive and highstand systems tracts is that little coarse clastic sediment reaches the basin. Yet here, where the black shales are assumed to mark a relative sea level rise, the clastic input did not switch off immediately, as if the sand transport and deposition are not tightly yoked to the sea level change. Does this lag in the cut-off time of sand deposition (relative to sea level rise) imply that some factor other than relative sea level rise locally controlled sand deposition (e.g., reworking of older Nunda sands exposed through fault block activity)? Or does it merely indicate that the end of sand deposition in the basin does not occur instantaneously when a sea level rise occurs?
3) What happens to the "Nunda" to the east and southeast of the Warsaw area?

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