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# Sequence stratigraphy and onlap history of the Donets Basin, Ukraine: Insight into Carboniferous icehouse dynamics

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ABSTRACT

The degree to which Permo-Carboniferous cyclothemic successions archive evidence for long-term variations in ice volume during the Late Paleozoic Ice Age is insufficiently resolved. Here we develop the sequence stratigraphy and onlap–offlap history for a 33-my interval of the Carboniferous using the U–Pb calibrated succession of the Donets Basin, Ukraine, in order to assess the relationship between sea-level, high-latitude changes in glacial extent, and climate. Integrated subsurface and outcrop data permit meter-scale correlation of 242 biostratigraphically constrained limestones and coals, and in turn individual cyclothems, across ~250 km of the Donets Basin. Rapid uniform subsidence and basinwide continuity of marker beds indicate Pennsylvanian deposition under relatively stable tectonic conditions. Three scales of sequences (avg. durations of ~140 ky, ~480 ky and 1.6 my) are recognized on the basis of stratigraphic stacking patterns and basinwide architecture of marine to terrestrial facies assemblages.

The hierarchy of sequences and the geographic and stratigraphic positions of shifts in base-level sensitive facies across the Donets ramp permit the construction of an onlap–offlap history at a sub-400 ky scale. Major sea-level lowstands occur across the mid-Carboniferous boundary and during the early Moscovian. These lowstands coincide with glacial maxima inferred from high-latitude glacigenic deposits. The middle to late Pennsylvanian is characterized by a stepwise onlap, culminating in an earliest Gzhelian highstand, suggesting contraction of Carboniferous ice sheets prior to the initiation of Early Permian glaciation.

The stratigraphic position of climate sensitive facies within individual Donets cyclothems indicates a turnover from seasonal sub-humid or semi-arid climate to everwet conditions during the late lowstand and maximum ice sheet accumulation. Comparison of the stratigraphic and aerial distribution of coals and evaporites in the Donets Basin with the onlap–offlap history further indicates everwet conditions during lowstands and inferred glacial maxima and drier climate during onlap and inferred ice sheet contraction at the intermediate (~0.8 to 1.6 my) and long ($10^6$ yr) time-scales. Taken together, the relationship between inferred climate and glacioeustasy suggests a likely teleconnection between high-latitude ice sheet behavior and low-latitude atmospheric dynamics.



## 1. Introduction

Cyclothemic successions, which characterize low- to mid-latitude Permo-Carboniferous successions globally, have long been considered archives of glacioeustasy driven by the waxing and waning of continental ice sheets in high-latitude Gondwana (e.g., Wanless and Shepard, 1936; Heckel, 1977; Algeo and Wilkinson, 1988). The magnitude of these high-frequency ($10^5$ years) glacioeustatic fluctuations was inferred to be between 50 and >120 m based on stratigraphic (e.g., Heckel, 1986) and stratal relationships (e.g., Soreghan and Giles, 1999) as well as geochemical proxy records (e.g., Joachimski et al., 2006), suggesting the existence of geographically extensive and long-lived ice sheets throughout the Late Paleozoic Ice Age (LPIA). Recently, studies of chronostratigraphically well-constrained glacigenic deposits in high-latitude successions and interbedded non-glacigenic facies have revealed evidence for a climatically more dynamic ice age, one that consisted of a series of discrete (1 to 8 my) glaciations separated by glacial minima or possibly non-

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glaciated intervals of comparable duration (Isbell et al., 2003, 2008; Fielding et al., 2008, 2010; Gulbranson et al., 2010).

The presence of multiple ice sheets that waxed and waned variably, and perhaps asynchronously, should be archived in Permo-Carboniferous cyclothemic successions given their stratigraphic sensitivity to sea-level changes that would have recorded, in part, the sum of changes in ice volume globally at any given time. Indeed, a few studies of paleotropical cyclothemic successions (Feldman et al., 2005; Fischbein et al., 2009; Bishop et al., 2010; studies summarized in Rygel et al., 2008) provide independent stratigraphic evidence for periods of diminished magnitudes (≤30 m) of short-term glacioeustatic fluctuations and by inference, changes in the extent and rates of growth and decay of continental ice sheets. Moreover, recent climate simulations of the LPIA reveal the high sensitivity of ice sheet size to orbital forcing and $pCO_2$, suggesting that magnitudes of Permo-Carboniferous glacioeustasy might be expected to have been quite variable (Horton et al., 2007; Horton and Poulsen, 2009). At present, however, the degree to which the tempo and magnitude of glacioeustatic fluctuations evolved throughout the LPIA remains insufficiently resolved.

The cyclothemic succession in the Donets Basin, Ukraine, records near continuous paralic sedimentation in the eastern Pangaean paleotropics throughout the Carboniferous and earliest Permian. Biostratigraphically dated limestones and coals provide laterally extensive marker beds that tightly constrain correlations at the meter-scale across up to 250 km of the basin. In turn, base-level sensitive facies within correlated cyclothems permit the construction of an onlap–offlap curve for a 33-my interval of the Carboniferous of the Donets Basin. In this paper we argue for a eustatic origin for the onlap–offlap history based on a cyclothem-scale correlation of the Donets and Midcontinent successions and reconstruction of a relatively uniform accommodation history for the Donets Basin. Comparison of the onlap–offlap curve to high-latitude glacigenic records suggests changes in ice volume as a driver of inferred Pennsylvanian lowstands and highstands. The temporal relationship of the distribution of climate-sensitive facies in the Donets succession to onlap–offlap events and inferred ice volume changes suggests a mechanistic linkage between Pangaean tropical continental climate, ice sheet extent and relative sea level.

## 2. Geological setting and chronostratigraphy

The Donets Basin is part of the northwest–southeast trending Dnieper–Donets intracratonic rift basin (~200 km wide by 700 km long) that formed in the southwestern part of the Eastern European Craton during the Devonian through Carboniferous due to underlying plume activity or to back-arc extension-related subduction along the southern margin of the basin (Fig. 1; Stephenson et al., 2001, 2006; McCann et al., 2003). Thermal post-rift subsidence during the late Mississippian through Pennsylvanian permitted the accumulation of an up to 14 km sedimentary wedge (Stephenson et al., 2006; Sachsenhofer et al., in press). Subsidence slowed significantly in the Early Permian (Fig. 2) and the southeastern part of the basin was tectonically inverted in the late Paleozoic and Mesozoic (Saintot et al., 2003; Stephenson et al., 2006). Notably, the sub-parallel trends in both up-dip and down-dip locations on the Donets long-term accumulation curves (Fig. 2) indicate that depositional rates for the late Mississippian through Pennsylvanian were relatively rapid and regionally uniform throughout the study area.

Fluvio-deltaic and nearshore-marine mixed carbonate-siliciclastic sediments were deposited on the Donets ramp, which steepened distally over several hundred km into the Uralian seaway and Peri-Caspian Basin of the northern Tethys Ocean (Alekseev et al., 1996). A low depositional slope (≪1°) is indicated by the basinwide extent of many marine limestones and the widespread and uniform stratigraphic distribution of deltaic deposits, including coal, across much of the basin. The Donets study area remained in the eastern Pangaean tropics through the Permo-Carboniferous (Fig. 1C; Dercourt et al., 2000; Blakey, 2008).

### 2.1. Chronostratigraphic framework

The Carboniferous through lowermost Permian Donets succession was formally divided into formations (designated by capital letters A through S) on the basis of biostratigraphically constrained marine limestones (Tschernyshev and Lutugin, 1897; Lutugin and Stepanov, 1913; Lebedev, 1924). The Carboniferous limestone marker beds (n = 242), as well as numerous coal beds, were correlated over hundreds of km of the Dnieper–Donets aulacogen (Zhemchuzhnikov

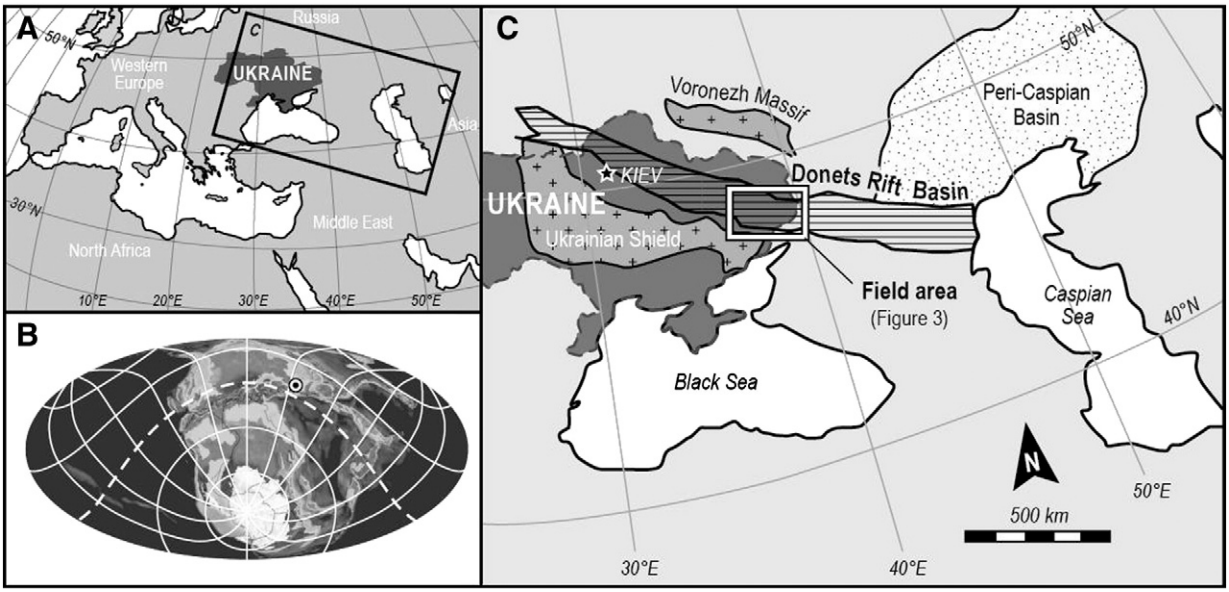


**Fig. 1.** Geographic (A), paleogeographic (B), and geologic (C) setting of the Donets Basin. (A) Rectangle outline delineates region shown in C. (B) Mollweide projection for ~300 Ma from Blakey (2008); circle is Donets Basin position and white dashed line is the paleoequator. (C) Study area (white rectangular outline) in Dnieper–Donets aulacogen (horizontal lined pattern).