LATE DEVONIAN EVENTS AND MASS EXTINCTIONS. C. A. Sandberg[1], W. Ziegler[2], and J. R. Morrow[3], [1]U.S. Geological Survey, Box 25046, MS 939, Federal Center, Denver, CO 80225, U.S.A., sandberg@usgs.gov; [2]Forschungsinstitut Senckenberg, D-60325 Frankfurt am Main, Germany; [3]Department of Earth Sciences, University of Northern Colorado, Greeley, CO 80639, U.S.A.

Introduction: The Late Devonian Epoch, one of the most intensively studied of all the Paleozoic Epochs, was a time of major sea-level changes, catastrophic events, some of which were impact related, and two mass extinctions, one of which was impact related. These many events are plotted herein against the generally accepted sea-level curve [1, 2]. Detailed knowledge and dating of Late Devonian events resulted from a high-resolution biochronology, based primarily on conodont zonations, but supported in part by ammonoid, ostracod, and spore zonations. This detailed knowledge was gained by intensive biostratigraphic studies during the past two decades, inspired by the IUGS Subcommission of Devonian Stratigraphy and by IGCP Projects on Bio-Events and Mass Extinctions. Many Late Devonian events produced changes in the environmentally sensitive mudmound levels in Belgium [3].

The initial Late Devonian Stage, the Frasnian, was a time of general transgression during the Taghanic onlap that began in the late Middle Devonian. The final Famennian Stage was a time of general regression, probably due to Southern Hemisphere glaciation, interrupted by four major transgressions, probably related to interglacial episodes. Both the late Frasnian and late Famennian mass extinctions occurred during, not at the start of, rapid regressions that closely followed rapid transgressions. The stepwise late Frasnian mass extinction, one of the five greatest in Earth's history [4], is believed to have occurred as a result of environmental stresses that were related to not just one but to a series of multiple, non-critical impacts. The late Famennian mass extinction, on the other hand, is believed to have occurred at the culmination of stresses produced by alternating glacial and interglacial episodes.

Frasnian: Some Frasnian events are closely related to or even may have produced significant transgressions. The enigmatic Amönau Event, which locally produced a megabreccia, can now be tied to the onset of volcanism across a 75-km transect of the Rheinisches Schiefergebirge in Germany and to a eustatic rise in sea level. It is dated as occurring within the Early *falsiovalis* conodont Zone at the first occurrence of *Ancyrodella rotundiloba*, the conodont used to define the start of the Frasnian. We are now trying to determine whether this volcanism resulted from an oceanic impact. The oceanic, sub-critical Alamo Impact in southern Nevada is at present the best evidenced Late Devonian impact, even though its crater is now buried or obliterated. Evidence of its ~1.5-km-deep crater derives from Middle Ordovician to possibly Late Cambrian conodonts that were blasted from the crater depths and redeposited in the resulting chaotic megabreccia and tsunami-related turbidites [5], along with carbonate impact spherules, shocked-quartz grains, and a locally high iridium concentration [6, 7]. This impact occurred in the middle of the *punctata* Zone and coincides with a major transgression and the demise of the first mudmound level in Belgium. Because of the current controversy in methodology for radiometric dating, we are now uncertain whether the Siljan Impact in southern Sweden coincides with the Alamo Impact, with the late Frasnian mass extinction, or was part of an intervening comet shower.

The late Frasnian mass extinction, commonly known as the Kellwasser Event, occurred not at the highstand of transgression [8] but within the regressive part of a thin transgressive-regressive black shale bed. Where well developed, this shale contains a detailed record of several stepped extinctions and introductions of shallow-water biota, culminating in an abiotic layer at its top. Researchers are still trying to locate an impact exactly coincident with this position. Possibly the Siljan Impact was the source of microtektites found within the extinction shale in Belgium. However, it seems more likely that the extinction occurred as a result of a series of sub-critical impacts or comet showers during the Frasnian. This scenario is supported by the stepwise extinction of several animal groups [9] and by the decreasing size and biotic diversity of the first three Belgian mudmound levels.

Famennian: To date, no direct evidence of any impacts has been found in Euramerica during the less turbulent Famennian Stage. A possible, closely post-extinction time of impact, however, is within the late part of the earliest Famennian Early *triangularis* Zone, when normal sedimentation was interrupted globally by deposition of coarse tsunami-related breccias. This event has been attributed, alternatively, to collapse of platform margins during continuing regression [2]. Only one local Famennian mudmound level, the Baelen [10] is known in Belgium, and this lacks the stromatoporoids and corals that were important to Frasnian mudmound construction. The Baelen mudmound was constructed during the later part of the second major Famennian interglacial? transgression. The late Famennian mass extinction, commonly known as the Hangenberg Event, occurred during a severe sea-level drop within the Middle *praesulcata* Zone, near the end of the Devonian.

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