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AGE OF THE TRIASSIC/JURASSIC BOUNDARY: A VIEW FROM THE HARTFORD BASIN

DAVID E. SEIDEMANN

Department of Geology and Geophysics, Yale University, New Haven, Connecticut 06511 and Department of Geology, Brooklyn College, Brooklyn, New York 11210

ABSTRACT. The sedimentary rocks of the Hartford basin, Connecticut accumulated during the Late Triassic and Early Jurassic and are potentially useful in establishing the age of that time boundary. Recently published K-Ar and $^{40}Ar/^{39}Ar$ dating studies suggest that the age of lava flows in the basin is 187 ± 3 Ma, an age younger than previous estimates, which were partly based on excess ^{40}Ar-bearing rocks. On the basis of this date and the biostratigraphy of the Hartford basin, the Triassic/Jurassic boundary is estimated to be between 184 and 195 Ma. This is younger than estimates ranging from 200 to 213 Ma suggested in three published and commonly used time scales. However, the estimates for the age of the boundary in these time scales are likely to be too old, because they are based partly on anomalously old K-Ar dates from the Hartford basin. The estimates are further skewed to older values by selective exclusion of younger dates. As new information from the Hartford basin and other regions is used to revise the time scale, it is evident from this review of previously published time scales that care must be taken to avoid the unwarranted exclusion of data.

INTRODUCTION

During the initial stages of the creation of the Atlantic Ocean a series of rift basins formed along the east coast of North America. The basins contain sedimentary rocks that, on the basis of paleontologic information, accumulated over a period of time from the Late Triassic to the Early Jurassic (Cornet and Traverse, 1975; Cornet, ms; Olsen, McCune, and Thomson, 1982). Mafic dikes, sills, and flows are associated with these rocks. Given the association of igneous rocks, which may be dated isotopically, with sedimentary rocks deposited during the Late Triassic and Early Jurassic, it has long been recognized that these basins may be useful in determining the absolute age of the Triassic/Jurassic boundary.

Attempts have been made to establish the absolute age of the rocks of these basins through the use of conventional K-Ar and $^{40}Ar/^{39}Ar$ dating (Armstrong and Besançon, 1970; Reesman, Filbert, and Krueger, 1973; Dallmeyer, 1975; Houlik and Laird, 1977; Sutter and Smith, 1979; Dooley and Wampler, 1983; Lanphere, 1983; Seidemann and others, 1984). The dates obtained scatter over a large range, probably due to the presence of excess radiogenic ^{40}Ar or varying degrees of ^{40}Ar loss (Armstrong and Besançon, 1970; Sutter and Smith, 1979; Dooley and Wampler, 1983; Seidemann and others, 1984).

I believe a reliable estimate for the age of one lava flow from the Hartford basin has now been obtained through the use of $^{40}Ar/^{39}Ar$ age spectrum techniques and by conventional K-Ar dating of a suite of lava-flow samples (Seidemann and others, 1984; Seidemann, 1988). In this paper the age of the Triassic/Jurassic boundary will be estimated on the basis of this new geochronologic information and the stratigraphy of the Hartford basin. This estimate will be evaluated in light of published time scales. Given that a significant mass extinction occurred at the end of the Triassic, a reliable estimate of the age of this boundary would help in evaluating the theory that such extinctions are periodic (Raup and Sepkoski, 1984).

AREA OF STUDY

The Hartford basin of Connecticut and Massachusetts is a half-graben containing strata dipping up to 20 degrees to the east, where normal faults separate the basin from Paleozoic rocks, which were the source of the sediments in the basin. Three tholeiitic flows (Talcott, Holyoke, and Hampden, proceeding up section) separate the four sedimentary formations (New Haven, Shuttle Meadow, East Berlin, and Portland; see fig. 1). Numerous tholeiitic dikes and sills occur throughout the basin.

K-Ar DATING STUDIES

Potassium-argon dates obtained from the flows of the Hartford basin exhibit the scatter typical for igneous rocks of these basins related to the presence of small, variable amounts of excess radiogenic ^{40}Ar and to ^{40}Ar loss (Armstrong and Besançon, 1970; Reesman, Filbert, and Krueger, 1973; de Boer, 1968). However, one flow, the basal Talcott, shows no evidence of the presence of excess radiogenic ^{40}Ar and evidence for only small amounts of ^{40}Ar loss (Seidemann and others, 1984; Seidemann, 1988). The average of conventional K-Ar dates for this flow, 187 ± 3 Ma, is concordant with an $^{40}Ar/^{39}Ar$ plateau age (187 ± 10 Ma) and is believed to be a reliable estimate of the cooling age of the flow. This belief is strengthened by noting that the date for the flow is consisent with the dates of high-temperature plateaus in age spectra for four Hartford basin mafic intrusions (188 ± 5 Ma, Sutter and Smith, 1979) that are believed to be contemporaneous with the flows (Philpotts and Martello, 1986; Toro, ms). These dates and all the others reported in this article are calculated using the following constants for the decay of ^{40}K by beta emission and electron capture and for the natural abundance of ^{40}K; $\lambda\beta = 4.96 \times 10^{-10}/yr$, $\lambda E.C. = 5.81 \times 10^{-11}/yr$ and $^{40}K/K = 0.01167$ atom percent. Two sigma uncertainties are reported for all dates.

BIOSTRATIGRAPHY OF THE HARTFORD BASIN

Correlation of sedimentary units of the nonmarine Mesozoic basins of North America with each other and with Mesozoic deposits of the world has always posed problems because these basins lack marine fossils traditionally used in most Mesozoic biostratigraphy. These problems

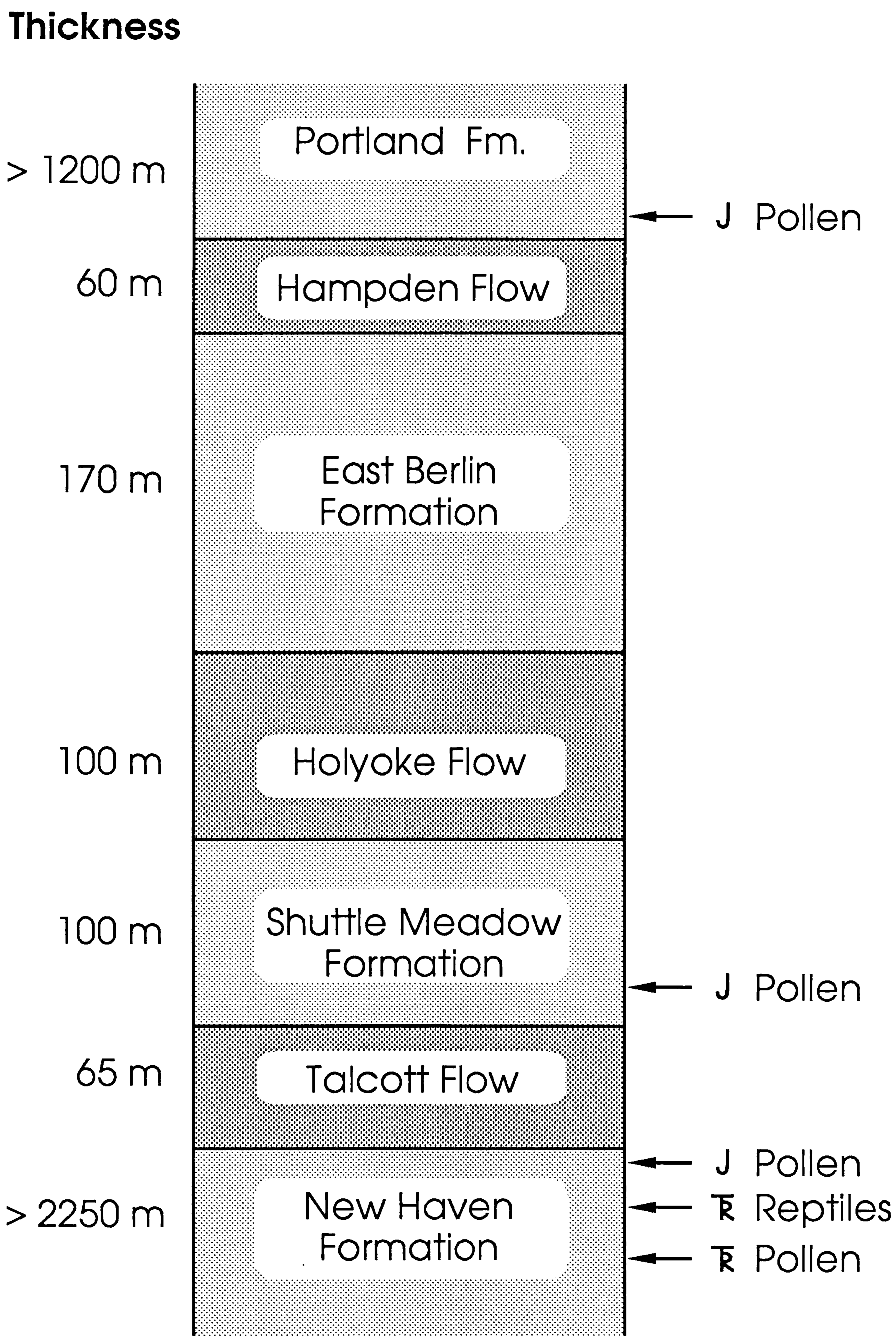

Fig. 1. Schematic representation of formations of the Hartford basin, Connecticut. Fossils and ages shown for sedimentary formations are from Cornet and Traverse (1975), Cornet (ms), Olsen, McCune, and Thomson (1982), and Robbins, Wilkes, and Textoris (1989).

have been partially circumvented through the use of palynology (Cornet and Traverse, 1975; Cornet, ms), because pollen is preserved in both marine and nonmarine sediments and terrestrial vertebrate fossil assemblages (Olsen, McCune, and Thomson, 1982; Olsen and Galton, 1977).

In the Hartford basin, an early Norian (Late Triassic) palynoflorule was found near the base of the New Haven Formation, the lowermost sedimentary unti present (Cornet, ms; fig. 1). A Hettangian (Early Jurassic) palynoflorule was found in the upper New Haven Formation at its conformable contact with the overlaying Talcott flow, the oldest flow in the basin (Robbins, Wilkes, and Textoris, 1989). The palynoflorule locations are separated by a stratigraphic distance of 1.8 km. Sedimentary units above the Talcott flow (Shuttle Meadow and Portland Formations) contain Early Jurassic palynoflorules (Cornet, ms). Fossils of Triassic reptiles are found in the middle of the New Haven Formation, 1 km below the Talcott flow (Olsen, 1980; P. E. Olsen and J. H. Ostrom, personal commun. cited *in* Cornet and Traverse, 1975). Fossil fish evidence, which was reported earlier to be useful in stratigraphic correlation (Olsen, McCune, and Thomson, 1982), is no longer believed to be so (P. E. Olsen, 1985, personal commun.). The fossil data are consistent with the suggestion that the New Haven Formation was deposited during a large part of the Norian, all of the Rhaetian (Late Triassic), and the earliest part of the Jurassic (Cornet, ms). The Triassic/Jurassic boundary would thus be found within the upper New Haven Formation.

ABSOLUTE AGE OF THE TRIASSIC/JURASSIC BOUNDARY: A VIEW FROM THE HARTFORD BASIN

An estimate of the absolute age of the Triassic/Jurassic boundary may be made in light of the more reliable date obtained for the Talcott flow and the biostratigraphy of the Hartford basin.

The Triassic/Jurassic boundary can be no younger than the age of the Talcott flow, given the Jurassic palynoflorules found at its base. Thus, the younger limit for the age of the Triassic/Jurassic boundary is established by the 187 ± 3 Ma date for the Talcott flow, assuming it is a reliable estimate of the age of the flow.

The Triassic/Jurassic boundary must be no older than the age of the Triassic reptile remains 1 km below the flow in the New Haven Formation. The age of these remains, and hence the older limit for the age of the boundary, may be estimated by assuming that: (1) the 187 ± 3 Ma date for the Talcott flow is a reliable estimate of its age; (2) sedimentation was continuous between the deposition of the Triassic fossils of the New Haven Formation and the extrusion of the overlying Talcott flow, and (3) a value for the sedimentation rate of the sediment deposited between the Triassic fossils and the overlying Talcott flow can be reliably estimated.

Indirect evidence suggests that the New Haven Formation underlying the Talcott flow was continuously deposited. Long, unbroken sequences of sedimentary cycles believed to be produced by orbitally forced climate changes are recorded in the lacustrine sedimentary rocks overlying the Talcott flow (Olsen, 1986). In the nearby Newark basin, similar long unbroken sequences occur in lacustrine sedimentary rocks believed to correlate with the fluvial New Haven Formation of the Hartford basin (Olsen, 1986). The existence of an unbroken, climatically controlled sedimentary sequence overlying the New Haven Formation in the Hartford basin and a similar sequence deposited contemporaneously with it in the nearby Newark basin suggest that the New Haven Formation was likewise continuously deposited. Direct evidence of the continuity of deposition is not present in the New Haven Formation, because fluvial deposits do not readily record high-frequency climatic cycles.

The sedimentation rate of the lacustrine deposits found in the Hartford and Newark basins will be used to approximate that of the fluvial New Haven Formation. Varves present in the lacustrine rocks of the Hartford basin (Hubert, Reed, and Carey, 1976) and the Newark basin (Van Houten, 1969) yield similar estimates for the sedimentation rates (350–450 mm/1 Ka and 215–305 mm/1 Ka, respectively).

If sedimentation was continuous, *and the values* for the *sedimentation rate of the* New Haven Formation and the age of the Talcott flow *are* correct, the older limit of the age of the Triassic/Jurassic boundary can be calculated. At the lowest sedimentation rate (that is, 215 mm/1 Ka), it would have taken 5 Ma to accumulate the 1 km of sediment between the Triassic fossils of the New Haven Formation and the overlying Talcott flow. Given the 187 ± 3 Ma date for the Talcott flow, the older limit of the age of the Triassic/Jurassic boundary is calculated to be 192 ± 3 Ma.

Thus, on the basis of the geochronology and biostratigraphy of the Hartford basin, the age of the Triassic/Jurassic boundary would be between 184 and 195 Ma. This range is younger than ages suggested in published and commonly used time scales (204 ± 4 Ma, Odin and Létolle, 1982; 213 ± 14 Ma, Harland and others, 1982; and 200 ± 5 Ma, Webb, 1981; see fig. 2). This discrepancy may reflect inaccuracy in the estimate of the boundary for the rocks of the Hartford basin. Several possible sources for such an inaccuracy exist.

1. My age estimate of the Talcott flow (Seidemann, 1988), which was primarily based on conventional K-Ar data, may be too young due to loss of ^{40}Ar. This possibility seems less likely when one considers ^{40}Ar/^{39}Ar data. The ^{40}Ar/^{39}Ar age spectrum for the Talcott flow exhibits a plateau at 187 ± 10 Ma (Seidemann and others, 1984). The plateau ages for the Fairhaven dikes and the Mount Carmel sill, which are believed to be cogenetic with the Talcott flow (Philpotts and Martello, 1986; Toro, ms), are 185 ± 7 and 195 ± 8 Ma, respectively

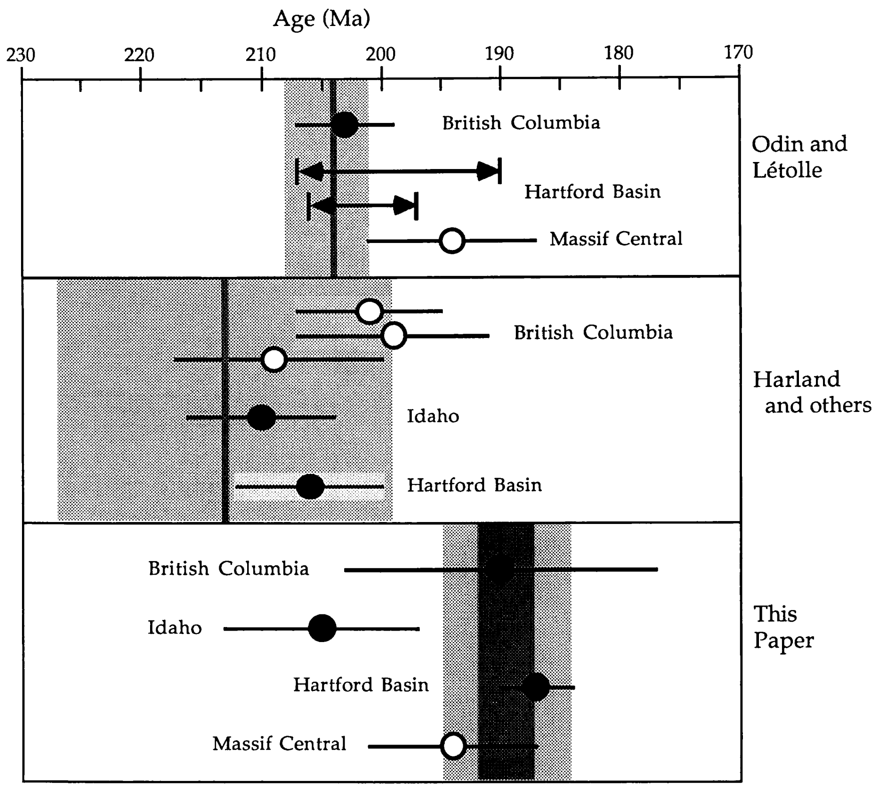

Fig. 2. Comparison of age of Triassic/Jurassic boundary as selected in two commonly used time scales and in this paper. Age of boundary is shown as dark vertical line (2σ uncertainty is lightly shaded). Basis for selecting boundary in each case is discussed in text. Pertinent dates from Lower Jurassic rocks in various locales are shown as solid circles (average of several dates) or unfilled circles (single dates); lines are 2σ uncertainties. Lines terminated with arrows give range for group of dates. Note that dates for Hartford basin, Idaho, and British Columbia rocks suggested in this paper are younger than those suggested by Odin and Létolle (1982) and by Harland and others (1982). Difference is due to inclusion by these authors of anomalously old dates for Hartford basin and selective exclusion of young dates for Idaho and British Columbia.

(Sutter and Smith, 1979). The mean of the plateau ages for the flow and the equivalent intrusives is 189 ± 6 Ma (unweighted standard error on the mean). The agreement between the mean of the plateau ages and the 187 ± 3 Ma estimate made on the basis of conventional K-Ar data suggests that the K-Ar dates have not been significantly lowered by ^{40}Ar loss.

2. The estimate of the time elapsed in depositing the 1 km section of sediment between the Triassic fossils of the New Haven Formation and the Talcott flow may be inaccurate due to incorrect assumptions about the sedimentation rate or the continuity of sedimentation.

3. Inaccuracy may arise due to the difficulty in biostratigraphic correlation between the nonmarine fossils of the basin and the marine fossils traditionally used in biostratigraphy of the Mesozoic.

Alternatively, the estimate of the age of the Triassic/Jurassic boundary made on the basis of data from the Hartford basin may be more accurate than those in published time scales (Odin and Létolle, 1982; Harland and others, 1982; Webb, 1981). Indeed, it has been demonstrated that these estimates are partly based on K-Ar dates for the mafic rocks of the Hartford basin, which probably contain excess radiogenic ^{40}Ar; therefore, the estimate may merit reevaluation (Seidemann, 1988).

AGE OF THE TRIASSIC/JURASSIC BOUNDARY: REEVALUATING PUBLISHED TIME SCALES

Odin and Létolle (1982) based their estimate of 204 ± 4 Ma for the Triassic/Jurassic boundary primarily on dates from the Hartford basin, from British Columbia (Armstrong, 1982), and on one date from the Massif Central, France (see fig. 2). Among these, they regarded the dates from the Hartford basin, which range between 190 and 207 Ma, as the best documented. However, I have demonstrated that the 187 ± 3 Ma date obtained for the lowermost flow of the basin probably best reflects the age of these rocks and that dates at the older end of the range reported by Odin and Létolle are likely to be anomalously old due to the presence of excess ^{40}Ar (Seidemann, 1988). Furthermore, in citing ^{40}Ar/^{39}Ar data (Sutter and Smith, 1979) Odin and Létolle reported only the oldest of the four plateau ages obtained for mafic intrusives of the Hartford basin (196 ± 8 Ma). The average of all four plateau ages is 188 ± 5 Ma (standard error on the mean, unweighted), a value compatible with the 187 ± 3 Ma date that I believe is a reliable estimate for the age of the lowermost flow (Seidemann, 1988). Thus some of the dates from the Hartford basin that Odin and Létolle used in estimating the age of the Triassic/Jurassic boundary are probably too old, in part due to the presence of excess ^{40}Ar and in part to the selective use of data.

In estimating the age of the boundary, Odin and Létolle did not rely heavily on the dates from British Columbia, because most of these rocks are only known to be post-Norian to pre-Sinemurian in age and therefore may characterize Rhaetian as well as Hettangian levels. The only clearly Jurassic rocks among those used in the estimate are for igneous intrusions that yielded a date of 203 ± 4 Ma (Wanless and others, 1974); if this age is correct, the Triassic/Jurassic boundary must be older than this value (Odin, 1982). This date must be viewed as problematic, however, because a younger date of 177 ± 8 Ma was obtained from a tuff within the Jurassic rocks cut by these intrusions (Wanless and others, 1974). There is no a priori reason to regard the 203 ± 4 Ma date used by Odin and Létolle in their estimate as more reliable than the 177 ± 8 Ma date for these Jurassic rocks.

Thus, the 204 ± 4 Ma estimate for the age of the Triassic/Jurassic boundary suggested by Odin and Létolle is likely to be too old, given that it is based largely on dates for Jurassic rocks in the Hartford basin and British Columbia that are skewed to older values than are appropriate. A 194 ± 7 Ma date for Hettangian rocks of the Massif Central (France), also cited by Odin and Létolle, is compatible with a younger estimate for the age of the boundary.

Harland and others (1982) estimated the age of the Triassic/Jurassic boundary to be 213 ± 14 Ma using a mathematical function that is a measure of how well a boundary is bracketed by dates from rock units stratigraphically above and below the boundary. The calculated age of the boundary is strongly dependent on five dates for Early Jurassic rocks, one from the Hartford basin (Armstrong and Besançon, 1970), three from British Columbia (Wanless and others, 1974), and one from Idaho (Armstrong and Besançon, 1970; see fig. 2). Harland and others chose a date for the rocks of the Hartford basin (206 ± 6 Ma) that is probably too old due to the presence of excess ^{40}Ar (Seidemann, 1988). The three dates used for the intrusions of British Columbia (201 ± 6, 199 ± 8, and 209 ± 9 Ma) are problematic because a younger date of 177 ± 8 Ma was obtained from a Jurassic tuff cut by the intrusions (Wanless and others, 1974). The date of 210 ± 6 my for the Idaho rocks represents an average of the three oldest values from a set of four discordant dates (185 ± 8, 205 ± 8, 206 ± 16, and 222 ± 16 Ma; Armstrong and Besançon, 1970). Given that a large degree of discordance suggests a disturbed system, it is probably not appropriate to use these dates in a calculation of the time boundary. If these dates are to be used, data should not be selectively deleted in the absence of independent criteria establishing whether the scatter in dates reflects the loss of ^{40}Ar or the addition of excess ^{40}Ar.

The estimate of the age of the Triassic/Jurassic boundary made by Harland and others, like that of Odin and Létolle, was based on dates that are too old, in part due to the presence of excess ^{40}Ar and in part due to the selective use of data. Revised estimates of the age of the boundary vary, depending on the assumptions made in incorporating the new information. In general, however, a younger age with a greatly increased uncertainty is calculated. For example, a 208 ± 24 Ma age is obtained by using an average date for each of the three locations cited.

Webb (1981) placed the Triassic/Jurassic boundary at 200 ± 5 Ma. This estimate is based in part on dates from the Hartford basin that range from 188 ± 8 to 206 ± 6 Ma and average 198 ± 4 Ma. This average, although younger than the 206 ± 6 Ma date used by Harland and others (1982) for the rocks of the Hartford basin, is still probably too old because there is excess ^{40}Ar in some of the dated samples (Seidemann, 1988). As was the case for the time scales discussed previously, Webb included the dates for two Jurassic intrusives from British Columbia (203 ± 9 Ma, standard error on the mean) that are problematic, in that the intrusives crosscut a rock yielding a younger date (177 ± 8 Ma). The 200 ± 5 Ma estimate of the age of the

Triassic/Jurassic boundary may be too old, because it depends in part on anomalously old dates from the Hartford basin and on dates from British Columbia of uncertain reliability.

CONCLUSION

The estimates of the age of the Triassic/Jurassic boundary made in each of the time scales examined (Odin and Létolle, 1982; Harland and others, 1982; Webb, 1981) depend on dates from the Hartford basin that are likely to be too old due to the presence of excess ^{40}Ar. The estimates are further skewed to older values by selective exclusion of younger dates. This apparently reflects a bias in favor of ^{40}Ar loss as a cause of scattered or conflicting data. Even though this conclusion is sometimes justified, it cannot be assumed automatically given the possibility that the younger dates may be more accurate (that is, if the anomalies are the result of the presence of excess ^{40}Ar). The selective exclusion of any data (younger or older) can not be justified in the absence of supporting evidence. As new information from the Hartford basin and other regions is used to revise the time scale, it is evident from this review of previously published time scales that care must be taken to avoid the unwarranted exclusion of data.

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