論文の内容の要旨

論文題目：Astronomical cycle recorded in the rhythms of the Mesozoic bedded chert and its relation with the global silica cycle

（中生代層状チャートの堆積リズムに刻まれた
天文学的周期とグローバルシリカ循環）

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Abstract

Orbital forcing is one of the main drivers of climate change. The orbital cyclicity recorded in sediments provides the high resolution and robust astronomical time scale for geologic records and hence a clue to understanding the dynamics of Earth surface system. Numerous studies have examined cyclic bedding and its relation to astronomical cycles, primarily on carbonate sequences. In contrast, few reports have searched for orbital cycles on siliceous sequence such as bedded chert.

Bedded chert consists of centimeter-scale rhythmic alternations of chert and shale beds, which are mainly composed of biogenic silica and terrigenous material, respectively. Numerous hypotheses have been proposed for the origin of bedded chert and its sedimentary rhythms. Although previous studies have hypothesized that the origin of bedded chert is related to astronomical cycles, conclusive proof remains elusive. In addition, the meaning of paleoceanographic and paleoclimatologic changes recorded in sedimentary rhythms of bedded chert was still debated.

This thesis explores the nature and ultimate origin of the sedimentary rhythm of bedded chert. For this purpose, I first reconstructed a continuous sequence of the Lower Triassic to Lower Jurassic bedded chert in the Inuyama area, central Japan. To test the possibility that the sedimentary rhythm of bedded chert has distinct cyclicities, I measured individual chert and shale bed thickness with bed by bed throughout the sequence. The

average duration of a chert–shale couplet based on biostratigraphy is 19 kyr similar to that of the precession cycle during the Triassic to Jurassic. Spectral analysis of a bed number series of chert bed thickness reveals the cyclicities of ca. 1,500, 400, 200, 100, 20, 5, and 2 beds. Then I converted the bed number series to a time series, assuming that the 20 bed cycle represents a 405 kyr eccentricity cycle, because this cycle is originated from gravitational interaction between Jupiter and Venus, and is highly stable and constant frequency due to the great mass of Jupiter. Spectral analysis of the time series revealed distinct periodicities of ca. 30,000, 8,000, 4,000, 2000, 100 and 40 kyr, in addition to 405 kyr. Besides 30,000, 8,000, 4,000, 2,000 kyr, these periodicities agree well with the 120, 95, and 37 kyr periodicities for eccentricity and obliquity cycles during the Triassic. The ca. 4,000 kyr and 2,000 kyr periodicities are correlated to present-day long-term eccentricity cycles of 4,800 and 2,400 kyr evolved by the chaotic behavior of solar planets. Collectively, these similarities in the periodicities of dominant cycles and their hierarchy in chert bed thickness with those of astronomical cycles strongly support the hypothesis that the sedimentary rhythm of bedded chert is paced by astronomical cycles.

Using one chert-shale couplet and ca. 20 bed bundle as approximately 19 kyr and constant and stable 405 kyr cycle of periodicity, I constructed the cyclostratigraphic age model for the Lower Triassic to Lower Jurassic bedded chert sequence. This age model is anchored by the end-Triassic mass extinction (ETE) zone based on the biostratigraphic correlation between the Inuyama area and shallow marine sequences in Peru, where the 201.36 ± 0.13 Ma of U-Pb age had measured within the ETE zone.

For the reconstructed sequence, I examined the meaning of paleoceanographic and paleoclimatologic changes recorded in sedimentary rhythms of bedded chert on timescales of obliquity and eccentricity cycles based on the estimation of the biogenic silica and terrigenous burial rates observed in the bedded chert. To accomplish this objective, I conducted the major element chemical analysis of individual chert and shale beds on the continuous sequence with bed-by-bed resolution. The biogenic silica and terrigenous contents were estimated, assuming the terrigenous material in the bedded chert as constant composition with the lowest SiO_2 content of shale samples analyzed, which is consistent with composition of the modern terrigenous material accumulated in the pelagic ocean. I calculated weights of biogenic silica and terrigenous material accumulated as a chert-shale couplet per unit area, which are well correlated with the chert bed thickness ($r = 0.96$) and shale bed thickness ($r = 0.90$), respectively. Based on these clear correlations, I regarded the chert bed thickness as an approximate measure of biogenic silica burial rate during one precession cycle, and reconstructed the variation in the biogenic silica and terrigenous burial rates during the Early Triassic to Early Jurassic for the bedded chert sequence in the Inuyama area. The spectral analyses of time series of shale bed thickness also show periodicities similar to the obliquity and eccentricity cycles, suggesting that terrigenous burial rate changed in pace with the astronomical cycles. The range of terrigenous burial rate changes is consistent with that of the modern eolian dust burial rate in equatorial pelagic ocean. Thus, orbitally controlled eolian dust burial rate in the pelagic ocean would be the possible cause of the changes in the terrigenous burial rate for the Lower Triassic to Lower Jurassic bedded chert in obliquity and eccentricity cycles.

Together with paleogeographic distribution of bedded chert compiled from previous studies, the biogenic silica burial rate in the global ocean in the form of bedded chert was a half to several times higher than the biogenic silica burial rate in the modern ocean (DeMaster et al., 2004). This result suggests that bedded chert was the major sink of dissolved silica in the ocean at least during the Early Triassic to Early Jurassic.

If I can assume that the biogenic silica burial rate in the bedded chert in the Inuyama area varied in a manner similar to that in the global ocean on timescales longer than 19 kyr, it is possible to use chert bed thickness of Inuyama bedded chert as a potential measure for global silicate weathering intensity. Based on this idea, the biogenic silica burial rate in the form of bedded chert can be regarded as a measure of the global silicate weathering intensity during Early Triassic to Early Jurassic.

In order to validate this hypothesis, variation in the biogenic silica burial rate of bedded chert in the Inuyama area was compared with the variation in $^{87}Sr/^{86}Sr$ isotopic ratio of sea water during the Early Triassic to Early Jurassic. Assuming the constant hydrothermal flux, and the constant isotopic values of present hydrothermal source and continental source, the phase and relative amplitude of variation in $^{87}Sr/^{86}Sr$ isotopic ratio agree well with those of the variation in the biogenic silica burial rate of bedded chert in the Inuyama area filtered with 30 myr window. An exception is during the Early Jurassic, which can be explained by the increased hydrothermal flux in association with the concomitant rapid opening of the Tethys ocean. These results support the idea that the biogenic silica burial rate in the form of bedded chert as a measure of the global silicate weathering flux.

To further explore the meaning of paleoclimatologic changes recorded in the sedimentary rhythms of bedded chert, I examine the major controlling factor of the global silicate weathering intensity during the Late Triassic to Early Jurassic. Because more than 70 % of the global silicate weathering occurred in low latitude region of Pangea during the Late Triassic to Early Jurassic, according to the results of the global biogeochemical cycle model, and because the regional silicate weathering rates would be depend on the runoff and temperature based on the modern observations, precipitation variation driven by orbitally-forced summer monsoon was the potential controlling factor of the global silicate weathering intensity. To test this possibility, I examined the phase relationship between the chert bed thickness variation of Inuyama bedded chert and the lake level changes in the Newark basin in the northern low latitude region of Pangea, which is considered to reflect the summer monsoon intensity in the low latitude region. Using the end-Triassic mass extinction zone as the high resolution tie point for their sequences, the ca. 100 kyr, 405 kyr, 1,800 kyr, and 3,600 kyr cycles of the lake level changes in the Newark basin are nearly in-phase with those cycles of chert bed thickness variation in the Inuyama area. Although the provincialism of terrestrial palynoflora has been pointed out, the synchronism of the ETE zone within 150 kyr has been confirmed based on the U-Pb ages of the ETE zones of the lacustrine sequence in the Newark basin and the shallow marine sequence in Peru, where could be correlated with the ETE zone of the bedded chert sequence in the Inuyama area by radiolarian and conodont biostratigraphy. According to this U-Pb age correlation, in-phase prelationships of 1,800 kyr, and 3,600 kyr cycles between the lake level changes in the Newark basin and chert bed thickness variation of bedded chert sequence in the Inuyama area, although 100 kyr and 405 kyr cycles are within the error of 150 kyr. If the biogenic silica burial rate in the form of bedded chert was a measure of the global silicate weathering flux, the nearly in-phase relationships between the lake level changes in the Newark basin and chert bed thickness variation of Inuyama bedded chert support the possibility that the major controlling factor of the variation in the global silicate weathering was the precipitation in low latitude region of Pangea driven by the orbitally controlled summer monsoon on timescales of at least 1,800 kyr and 3,600 kyr eccentricity cycles.

The biogenic silica burial rate in the form of bedded chert will provide new insights on the nature of the global silicate weathering intensity over the orbital timescale before Mesozoic. These findings will contribute to the decoding the dynamics of the global silica cycle in the geologic time.