



Preliminary Report on a *Chikyu* Drilling Program Offshore of Shikoku: Success in Collecting Continuous Strata to Understand Fluctuations in the Super–interglacial Kuroshio Current and the Generative Mechanisms of Turbidites

A research team led by Professor Minoru Ikehara of the Center for Advanced Marine Core Research, Kochi University, has conducted a study to elucidate the actual conditions of fluctuations in the Kuroshio Current from the past to present and their relationships to climate change in East Asia based on seafloor sediments in the southern waters of the Japanese Archipelago and the East China Sea. This preliminary report shows the results of a drilling expedition conducted from August 22–31, 2021 onboard the deep–sea scientific drilling vessel, *Chikyu* (*1) under the Shallow Core Program (*2). The program is jointly overseen by the Japan Agency for Marine–Earth Science and Technology (JAMSTEC) and the Japan Drilling Earth Science Consortium (*3).

✂Key Points

- Continuous strata were successfully recovered, allowing fluctuations in the Kuroshio Current to be restored and analyzed over an approximately 250,000–year period
- The continuous strata were also used to elucidate the mechanism(s) by which turbidites (*4) are generated on the shelf and slope offshore of Shikoku, as well as the frequency of their occurrences
- An educational vessel–boarding framework (*5) was implemented for the first time, wherein graduate students wishing to conduct shipboard research were recruited nationwide, allowing the next generation of researchers to train on a drilling vessel

1. Details of Implementation

The Kuroshio is the western boundary current that comprises subtropical circulation in the North Pacific Ocean and is one of the largest warm currents in the world, along with the Gulf Stream in the North Atlantic Ocean. It is responsible for carrying massive amounts of heat stored as a result of strong tropical solar irradiance, from pools of warm water in the Western Pacific Ocean northward into the mid–latitudes. In this way, the Kuroshio is associated with the distribution of heat, salt, and water vapor in the North Pacific Ocean, and it has a substantial impact on climate change and precipitation patterns (including intensity and fluctuations) in the Japanese Archipelago and East Asia.

Of the glacial and interglacial periods that have alternated with a frequency of approximately 100,000 years, the interglacial period estimated to have been warmer than pre-industrial climatic conditions is called a “super-interglacial” (*6) and has attracted considerable research attention as an analog for estimating a future warming global environment. Clarifying the state of the Kuroshio Current during this period using geological records is important because it can provide evidence of what happened on Earth in the past with regards to the potential effects of global warming, which is anticipated to further accelerate in the future, affecting both the Kuroshio and the global climate, including Japan. In the study summarized here, piston core drilling was conducted onboard the *Chikyu* offshore of Shikoku, where traces of fluctuations in the Kuroshio Current from the past to the present were expected to have been recorded in the seafloor sediments. A continuous stratigraphic interval was successfully collected, from which such fluctuations could be restored over an approximately 250,000-year period.

2. Summary of Results and Future Developments

A total of three holes were drilled at the Site C9037 (Fig. 1) by *Chikyu*, and a total of 300 m of cores approximately 100 m each were recovered. The hydraulic piston coring system (*7) used involved the cutting shoe shooting the seafloor and repeatedly collecting columnar geological samples at intervals up to 9.5 m. In this case, sediment gaps occurred between each sample, so splicing the three cores collected at a single location enabled a virtually successive stratigraphic record with almost no gaps. The age of the lowest sections of the recovered strata was estimated to be between 250,000-290,000 years old based on shipboard microfossil (*8) analysis.

The drilling core was subjected to transmission imaging with an X-ray CT scanner and magnetic measurements were made with a multi-sensor core logger on board the *Chikyu*. After the end of the expedition, the core was transferred to the Kochi Core Center (*9), where it was stored in a refrigerated state. Since September 7, 2021, core splitting, photography, color measurements, and visual core description of the drilling core have been conducted at the Kochi Core Center; these measurements have gradually clarified the state of the recovered sediments. The results of non-destructive measurements and visual core descriptions have shown that the strata extracted in this expedition formed a thick deposit of fine mud containing microfossils (Fig. 2), with the partial presence of a volcanic ash layer and turbidites. It is known that the strata below the seafloor are home to many living microorganisms, and lifting them out to the surface via drilling changes their surrounding environment; thus, their compositions are assumed to change constantly with repeated drilling. Sampling was also conducted in for the systematic and sequential verification of these subseafloor microorganisms in order to determine if and how the biological information in the strata has changed over time following drilling. Future goals in the summarized research program include plans for conducting international joint research to reconstruct and analyze fluctuations in the Kuroshio

Current, especially super-interglacial fluctuations, over an approximately 250,000-year period by advancing specialized microfossil, sedimentological, geochemical, and microbiological analyses. Additionally, a detailed analysis of the patterns of deposition and composition of the volcanic ash layers and turbidites is expected to provide new insights into the frequency of large-scale flood events, which are thought to be the mechanism of turbidite generation, as well as into the effects of megathrust earthquakes that occur along the Nankai Trough.

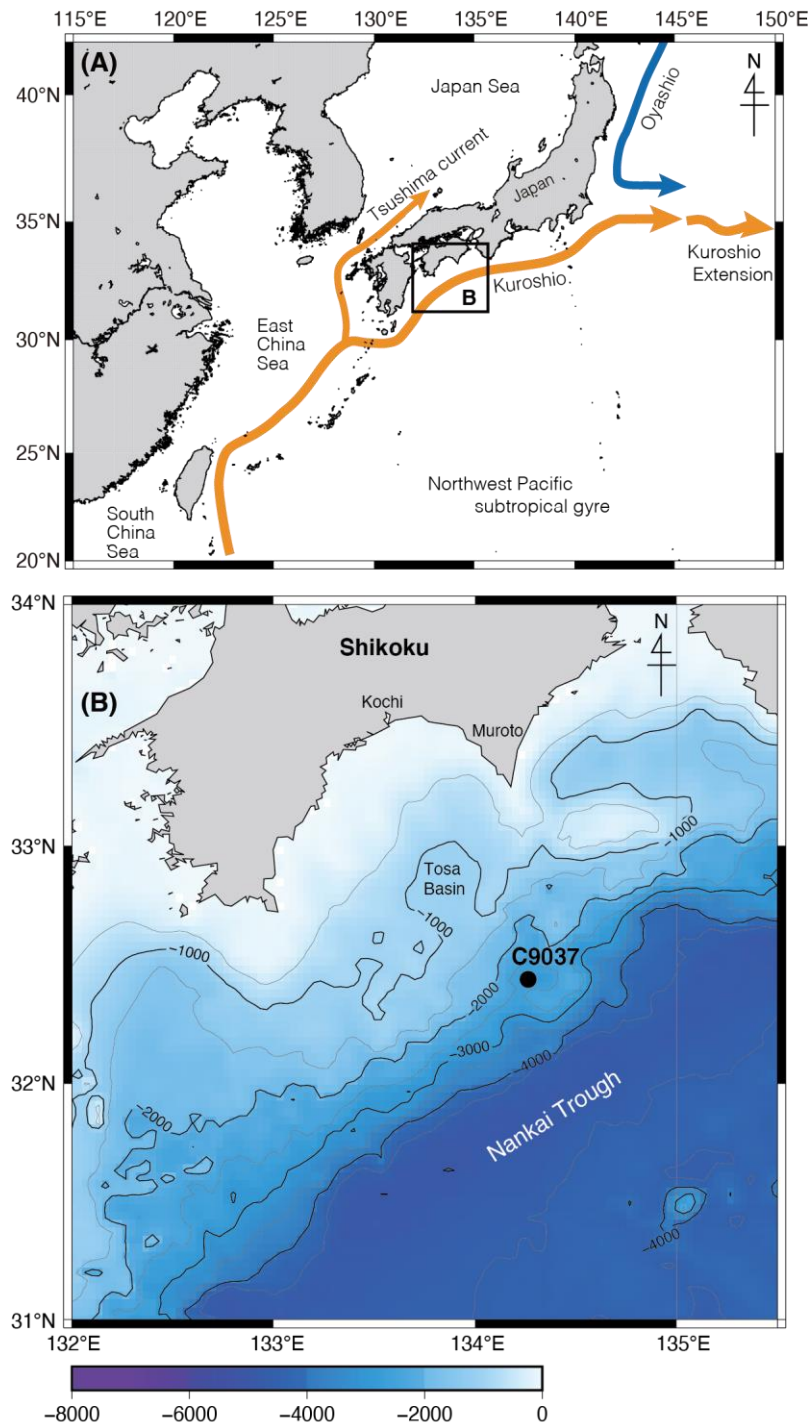


Figure 1 Site location maps. (A) Index map with major surface currents in the northwest Pacific and marginal seas. (B) Map showing the drilling location (C9037).

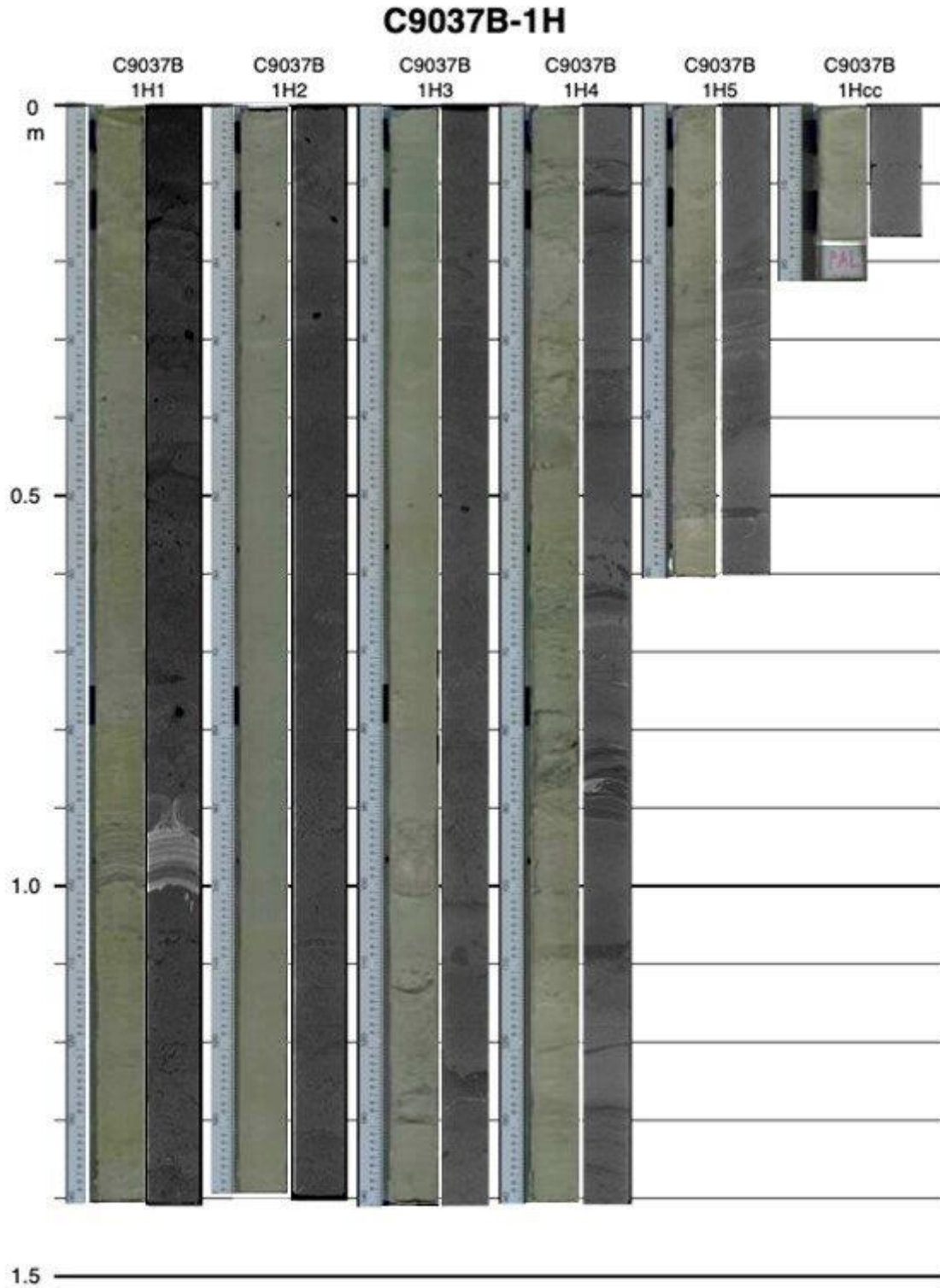


Figure 2 Example of core drilled at the Site C9037 location off the coast of Shikoku. Cores from the seafloor to a depth of approximately 6.4 m were cut to approximately 1.4 m and ordered from left to right. Cross-sectional photographs are shown on the left and X-ray CT transmission images are shown on the right

【Supplemental information】

※1 Deep-sea Scientific Drilling Vessel *Chikyu*

A scientific drilling vessel owned by JAMSTEC, it is the world's first riser drilling-equipped science vessel, capable of drilling deeper below the seafloor than any other science drilling vessel to date. The vessel has been used in attempts to understand the mechanism(s) of mega-earthquake/tsunami occurrence, the subseafloor biosphere, and global climate changes. (http://www.jamstec.go.jp/mare3/e/ships/research_vessel/chikyu.html)



Image of the *Chikyu* at sea.

※2 *Chikyu* Shallow Core Program (SCORE)

A scientific drilling program jointly implemented by JAMSTEC and the Japan Drilling Earth Science Consortium (J-DESC, *3). The mechanism used to conduct scientific drilling is a piston core that is applied to the seafloor surface and can be employed within a short period of time by effectively utilizing the round-trip routes when *Chikyu* goes to sea in preplanned expeditions. Drilling proposals are solicited and reviewed among members of J-DESC; of the proposals recommended after review, those that JAMSTEC can implement are conducted. (https://j-desc.org/about_us/about-iodp/score/)

※3 Japan Drilling Earth Science Consortium: J-DESC

A consortium established in 2003 mainly by universities and research institutions in Japan with the aim of promoting earth drilling science and strengthening collaboration among organizations and researchers. This group is primarily involved in developing scientific plans and research concepts related to earth drilling science, soliciting and reviewing proposals of related institutions, facilitating useful collaborations, developing research-related human resources, supporting and cooperating in international projects, and in providing information to raise public awareness. (<http://j-desc.org/eng/>)

※4 Turbidites

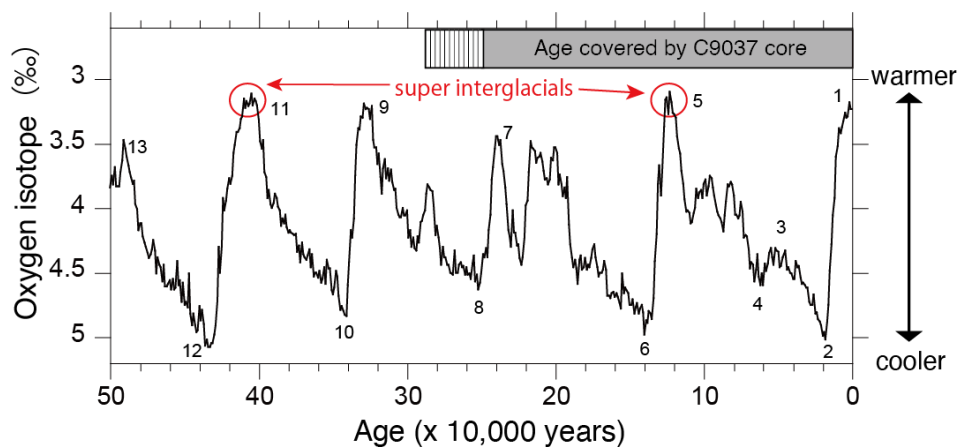
Characteristic strata deposited from a stream in which a mass of water containing sediments is formed by large-scale floods, seafloor slope collapse, raising of the seafloor sediments, and other processes. These water masses flow down along a seafloor slope by gravity. Larger particles sink earlier than smaller ones, so turbidites exhibit clear size-sorting, with coarser grains at the bottom and finer grains at the top.

※5 Educational Vessel-Boarding Framework

A program for graduate students who can participate in drilling expeditions as researchers under the supervision of a chief scientist on a SCORE expedition. A total of six students participated after solicitation of applicants from universities across Japan. The program provides an opportunity for graduate students with an interest in earth drilling science to experience a cruise onboard the *Chikyu*, and it is anticipated to serve as a steppingstone to future participation in international research cruises, such as the International Ocean Discovery Program (IODP).

※6 Super-interglacial

A previous interglacial period that is likely to have been warmer than today is called a “super-interglacial.” Such periods play important roles as analogs to a future warming Earth, and there are many examples of research into the various attributes of super-interglacials, such as changes in atmospheric and seawater temperature, extent of ice sheet melting, and sea level dynamics. During the super-interglacial that occurred approximately 125,000 years ago (oxygen isotope stage 5), the mean global temperature was approximately 1°C higher than that prior to the Industrial Revolution. It is estimated that, during this super-interglacial, the West Antarctic Ice Sheet and part of the Greenland Ice Sheet melted and sea levels were 6-9 m higher than at present.



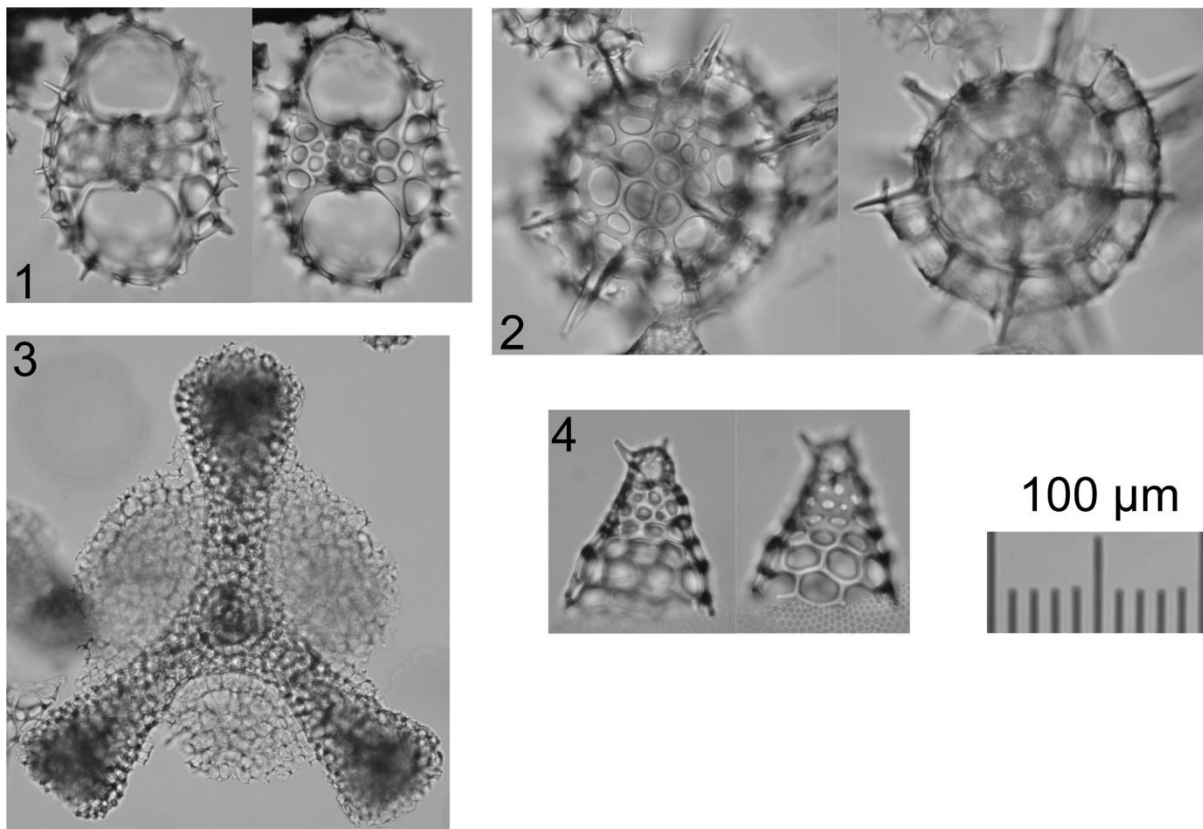
Fluctuations in oxygen isotope ratios over the last 50,000 years showing global climate change (revised from Lisiecki and Raymo, 2005)

※7 Hydraulic Piston Coring System

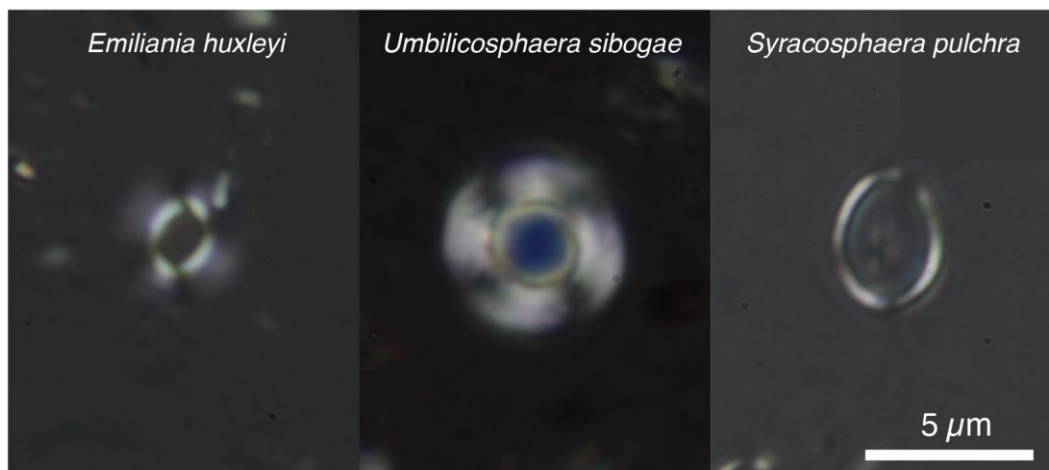
A method in which strokes the inner core barrel into the sediment using a hydraulic piston action, and cores up to a maximum 9.5 m in length is continuously collected. This approach is capable of collecting a stratigraphic sample without rotating the drill bit.

※8 Microfossil

A general term for small fossils whose sizes range from a few millimeters or less and whose morphology can typically only be observed using a microscope. This term includes various biological groups (i.e., is polyphyletic). Many microfossils are found in large quantities on the seafloor, at the bottom of lakes, and in terrestrial sediments, and are of use when estimating past environments and dating geological formations. Unicellular eukaryotes, such as foraminifers, radiolarians, diatoms, and calcareous nannofossils are found in seafloor sediments off the coast of Shikoku.



Micrograph of radiolaria (sample 913_C9037A_5HCC_45.5_50.5cm). (1) *Tetrapyle circularis* and (3) *Dictyocoryne muelleri* often found in waters affected by the Kuroshio Current; (2) *Actinomma boreale* and (4) *Cycladophora davisiana* found in the intermediate water from the subsurface in subarctic seas



Example of calcareous nanofossils found in sediments at the C9037 location off the coast of Shikoku

※9 Kochi Core Center

A research center jointly operated by the Center for Advanced Marine Core Research of Kochi University and the Kochi Institute for Core Sample Research of JAMSTEC. It is located on the Kochi University Monobe Campus and is a research facility with a large core refrigeration storage. Many geological samples collected from the seafloor in domestic and international projects are stored and international research is being conducted at the Center. (<http://www.kochi-core.jp/>)

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