Correction

ENVIRONMENTAL SCIENCES, EARTH, ATMOSPHERIC, AND PLANETARY SCIENCES

Correction for "Global variability in seawater Mg:Ca and Sr:Ca ratios in the modern ocean," by Mario Lebrato, Dieter Garbe-Schönberg, Marius N. Müller, Sonia Blanco-Ameijeiras, Richard A. Feely, Laura Lorenzoni, Juan-Carlos Molinero, Karen Bremer, Daniel O. B. Jones, Debora Iglesias-Rodriguez, Dana Greeley, Miles D. Lamare, Aurelien Paulmier, Michelle Graco, Joan Cartes, Joana Barcelos e Ramos, Ana de Lara, Ricardo Sanchez-Leal, Paz Jimenez, Flavio E. Paparazzo, Susan E. Hartman, Ulrike Westernströer, Marie Küter, Roberto Benavides, Armindo F. da Silva, Steven Bell, Chris Payne, Solveig Olafsdottir, Kelly Robinson, Liisa M. Jantunen, Alexander Korablev, Richard J. Webster, Elizabeth M. Jones, Olivier Gilg, Pascal Bailly du Bois, Jacek Beldowski, Carin Ashjian, Nejib D. Yahia, Benjamin Twining, Xue-Gang Chen, Li-Chun Tseng, Jiang-Shiou Hwang, Hans-Uwe Dahms, and Andreas Oschlies, which was first published August 25, 2020; 10.1073/pnas.1918943117 (*Proc. Natl. Acad. Sci. U.S.A.* **117**, 22281–22292).

The authors wish to note the following: "This study's seawater Sr:Ca values were systematically low as a consequence of normalization to another published low value for the International Association for the Physical Sciences of the Oceans (IAPSO) (1). IAPSO has been used at the Ocean Drilling Program, Texas A&M University (ODP-TAMU) (http://www-odp.tamu.edu/), and is still being used as the primary standard for elemental composition of seawater/interstitial water. Consequently, our seawater value of Sr:Ca = 8.28 mmol:mol was systematically low by approx. 3.70%, if we accept seawater Sr:Ca 8.60 mmol:mol as the recommended value for IAPSO North Atlantic surface water salinity standard.

The uncertainty budget should be expanded including the uncertainty of IAPSO composition. The largest contribution to expanded uncertainty of our data comes from the uncertainty of the IAPSO reference composition, which is 3.29% using all published values. This will result in 3.30% (1 SD) expanded uncertainty for seawater Sr:Ca (and 0.5%, for seawater Mg:Ca) of the entire data set with respect to accuracy.

We have corrected all seawater Sr:Ca values with a factor of 1.0243 in all our tables (e.g., *SI Appendix*, Table S1 averages) and in the figures (Fig. 4, Fig. 5), where a ratio was used. Note that the seawater Sr:Ca % changes are small, thus changes are hardly noticeable on large displays (e.g., Figures), but they can be seen in the tables and averages/SD calculations. Seawater Sr:Ca ratios are also corrected in the main text where relevant.

We include the updated AQC data, where the correction factor of seawater Sr:Ca = 1.0243 has been applied (Dataset S4)."

A number of corrections have been made to the publication. The range "7.70 to 8.80 mmol:mol" has been corrected to "7.70 to 9.10 mmol:mol" in three locations throughout the article text: in the Abstract, line 13; on page 22283, left column, second full paragraph, line 16; and in the same paragraph, line 23.

Also on page 22283, right column, second full paragraph, line 19, "'coastal seas' and 'open ocean'" has been corrected to "'inshore' and 'offshore'".

On page 22291, starting on the left column, second full paragraph, in line 28, the following section of text is being corrected:

"Every batch of six samples was bracketed by an IAPSO measurement for normalization to seawater Mg:Ca = 5.140 mol:mol and seawater Sr:Ca = 8.280 mmol:mol. A stepwise linear drift correction was applied over a batch of six samples during all of the analyses. Then, every second batch of six samples, a one-sample replicate measurement was done from the previous batch. The final data are used as drift-corrected after applying the normalization factors for seawater Mg:Ca and Sr:Ca ratios following the stepwise drift correction (Dataset S4). Results were normalized to an external standard (IAPSO, using Mg:Ca = 5.140 mol:mol, Sr:Ca = 8.280 mmol:mol). This approach minimizes variability, which with reference to IAPSO was 0.6 to 0.7% overall. Mean uncertainty from duplicate measurements per sample on 33 randomly chosen samples was 0.1 to 0.2 and 0.1 to 0.4% relative SD (1 SD) for seawater Mg:Ca and Sr:Ca, respectively (Dataset S4). This is well below 1% uncertainty for the dataset, which provides confidence in the accuracy of the data (in particular to open ocean samples, which rely on minimum uncertainty)."

The corrected section of this text reads:

"Results were normalized to an external standard (IAPSO, ORIL, U.K. using Mg:Ca = 5.140 mol:mol, Sr:Ca = 8.481 mmol:mol) in a way commonly used in isotope studies. This approach minimizes variability and uncertainties, respectively, resulting from both instrument drift during the day and instrument set-up between different days. Mean uncertainty estimated from duplicate measurements per sample on 33 randomly chosen samples was 0.35 and 0.85% relative SD (1 SD) for seawater Mg:Ca and Sr:Ca while measurement uncertainty (5 runs) was 0.16 and 0.37% RSD, respectively (Dataset S4). The expanded uncertainties including uncertainty of the true values for IAPSO are 3.30% for seawater Sr:Ca and 0.5% for seawater Mg:Ca. Uncertainty as estimated from measurement reproducibility that is important for detecting small differences even in our open ocean sample suite is well below 0.40% for seawater Mg:Ca and 0.90% for seawater Sr:Ca."

Figs. 4 and 5 have been corrected online. The corrected figures and their legends appear below.

In the *SI Appendix*, page 4, first full paragraph, line 30, "8.280 mmol:mol" has been corrected to "8.481 mmol:mol."

In the same paragraph, starting on line 36, the following section of text is being corrected:

"Typical average uncertainty as estimated from 5 replicate measurements of every sample was 0.1-0.2 and 0.1-0.4%RSD (1SD) for seawater Mg:Ca and Sr:Ca, respectively. Repetition of every 11th sample (Replicate Samples) yielded average uncertainties of 0.2-0.4 and 0.4-0.8%RSD, respectively. A compilation of all analytical quality control data and examples can be found in SI Appendix 4."

The corrected section of this text reads:

"Mean uncertainty estimated from duplicate measurements per sample on 33 randomly chosen samples was 0.35 and 0.85% relative SD (1 SD) for seawater Mg:Ca and Sr:Ca while measurement uncertainty (5 runs) was 0.16 and 0.37% RSD, respectively (SI Appendix 4). The expanded uncertainties including uncertainty of the true values for IAPSO are 3.30% for seawater Sr:Ca and 0.5% for seawater Mg:Ca. Uncertainty as estimated from measurement reproducibility that is important for detecting small

CORRECTION

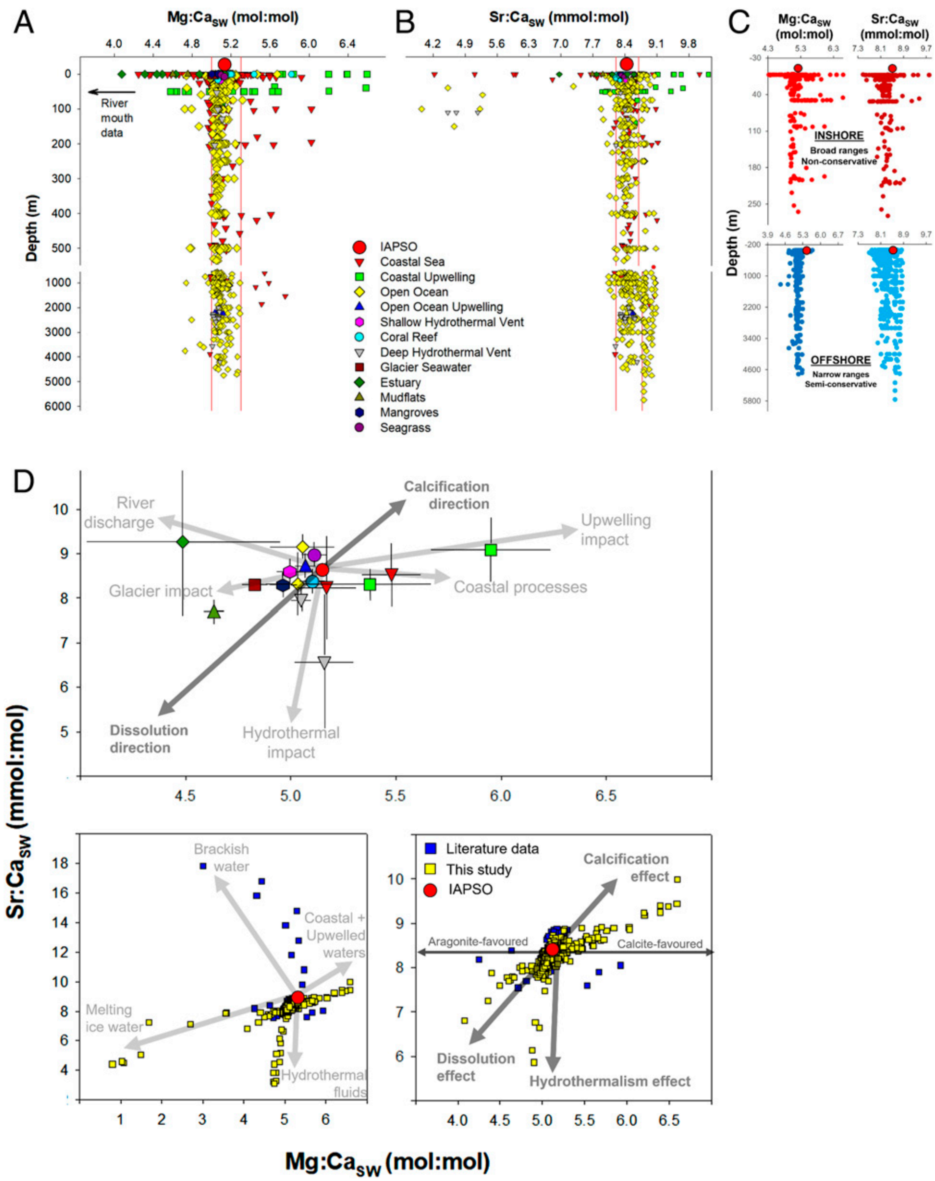

Fig. 4. Modern ocean seawater Mg:Ca and Sr:Ca ratios vs. depth, and conceptual diagrams of Sr:Ca vs. Mg:Ca to identify processes. Data classified horizontally for seawater Mg:Ca (*A*) and Sr:Ca (*B*) ratios per ecosystem, and vertically with depth. Seawater Mg:Ca ratios data from river mouths can be found in *SI Appendix*, Fig. S1. Data within the red lines represent literature assumed knowledge of modern seawater ratios. (*C*) A selection of curated seawater Mg:Ca and Sr:Ca ratios vs. depth, classified as "coastal seas" and "open ocean" to distinguish variability at large, separating the two major environments where marine science disciples obtain samples/data. (*D*) Cross plots of averages and SDs of modern seawater Mg:Ca vs. Sr:Ca ratios with arrows indicating the direction of change for ocean processes. Also included are individual data points cross plots comparing literature vs. this study data. In all figure panels, IAPSO (this study) seawater Mg:Ca and Sr:Ca ratios are used for comparison.

differences even in our open ocean sample suite, was well below 0.40% for seawater Mg:Ca and 0.90% for seawater Sr:Ca. When averaging only the first three measurements for our IAPSO reference sample right after initial calibration of all three analytical sessions where the samples were run, then the measured IAPSO average was Sr:Ca = 8.481 ±0.068 mmol:mol. Comparing data routinely obtained for multi-element analyses of seawater, then we find measured IAPSO averages ranging from Sr:Ca = 8.273 to 8.555 mmol:mol. It is always the Ca that is making the difference: we measure around 409 mg L^{-1} Ca (10.20 mM Ca) while ODP-TAMU reported 422 mg L^{-1}, 10.55 mM Ca. Our Sr results are identical with ODP_TAMU: 7.62 mg L^{-1} Sr (86.97 μM Sr)."

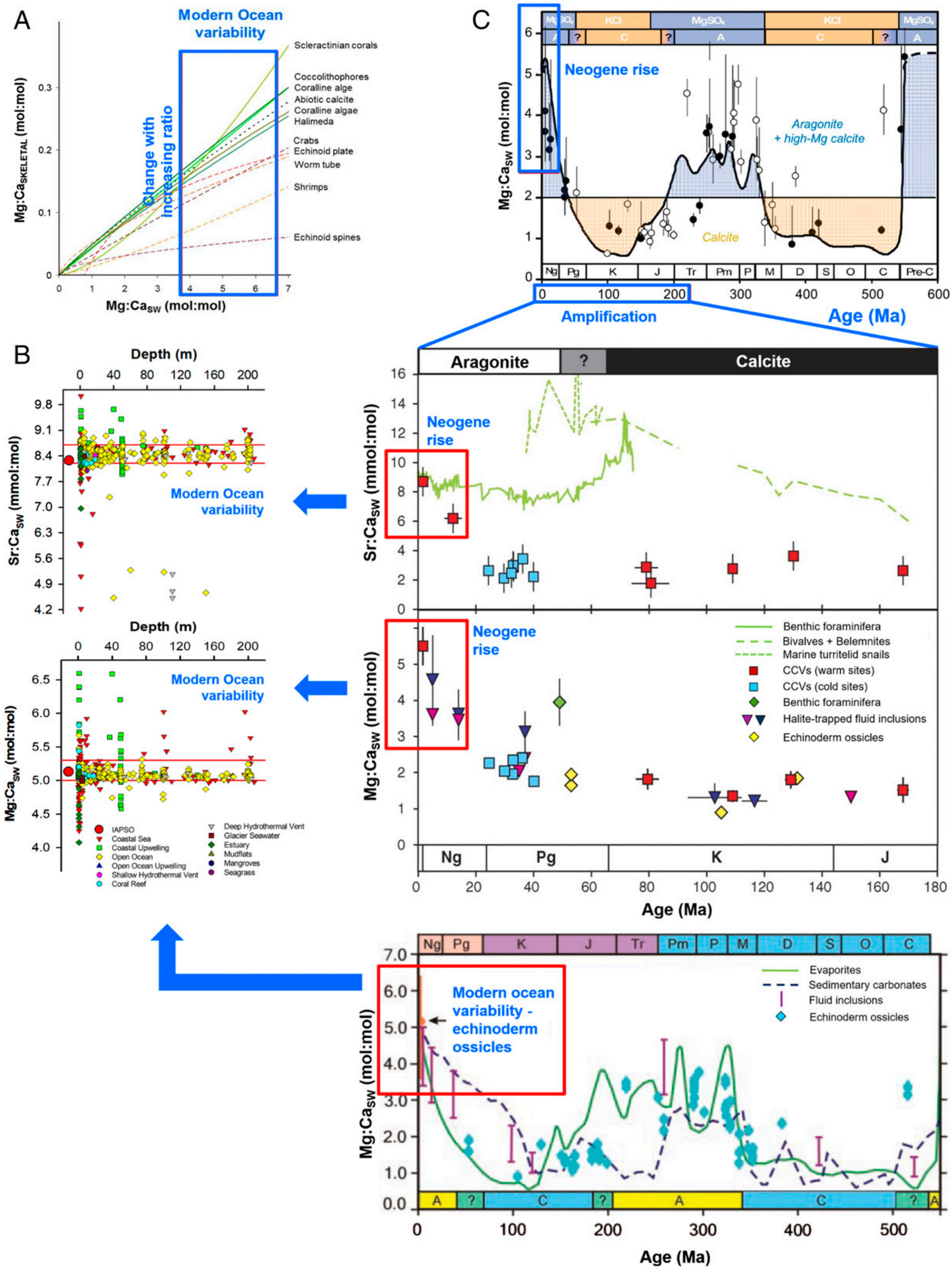

Fig. 5. Modern ocean seawater Mg:Ca and Sr:Ca ratios compared to reconstructions over geological time intervals. (*A*) Relation between seawater Mg:Ca and organism skeletal Mg:Ca, indicating the effect of modern seawater Mg:Ca natural variability on marine calcification. Reprinted from ref. 3, which is licensed under CC BY 3.0. (*B*) Upper ocean integrated 250-m modern ocean values for seawater Mg:Ca and Sr:Ca in various ecosystems showing that variability is similar to the reconstructed Neogene Period (23.03 Ma). From refs. 7 and 23. Reprinted with permission from AAAS. (*C*) Phanerozoic Period (541 Ma) values for seawater Mg:Ca and the last 200 My of seawater Mg:Ca and Sr:Ca ratios are presented for comparison with modern ocean variability. Aragonite and calcite seas periods are included, and the geological periods: J, Jurassic; K, Cretaceous; Pg, Paleogene; and Ng, Neogene. Data, boxed and within the red lines, represent literature assumed knowledge of modern seawater ratios. Reprinted from ref. 3, which is licensed under CC BY 3.0. In all figure panels, "IAPSO (this study)" seawater Mg:Ca and Sr:Ca ratios are used for comparison. The raw data used in the geological time reconstructions can be checked in the figure legends in the corresponding papers (8, 12, 23).

https://doi.org/10.1073/pnas.2119099118

Table S1 in the *SI Appendix* has been corrected to display the seawater Sr:Ca values.

Lastly, Supporting Dataset S4 has been replaced with a corrected version.

1. J. M. Gieskes, T. Gamo, H. Brumsack, Chemical Methods for Interstitial Water Analysis aboard JOIDES Resolution. Technical Note 15 (1991)

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