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Review Article

Nature of the sedimentary rock record and its implications for Earth system evolution

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The sedimentary rock reservoir both records and influences changes in Earth's surface environment. Geoscientists extract data from the rock record to constrain long-term environmental, climatic and biological evolution, with the understanding that geological processes of erosion and rock destruction may have overprinted some aspects of their results. It has also long been recognized that changes in the mass and chemical composition of buried sediments, operating in conjunction with biologically catalyzed reactions, exert a first-order control on Earth surface conditions on geologic timescales. Thus, the construction and destruction of the rock record has the potential to influence both how Earth and life history are sampled, and drive long-term trends in surface conditions that otherwise are difficult to affect. However, directly testing what the dominant process signal in the sedimentary record is — rock construction or destruction — has rarely been undertaken, primarily due to the difficulty of assembling data on the mass and age of rocks in Earth's crust. Here, we present results on the chronological age and general properties of rocks and sediments in the Macrostrat geospatial database (https://macrostrat.org). Empirical patterns in surviving rock quantity as a function of age are indicative of both continual cycling (gross sedimentation) and long-term sediment accumulation (net sedimentation). Temporal variation in the net sedimentary reservoir was driven by major changes in the ability of continental crust to accommodate sediments. The implied history of episodic growth of sediment mass on continental crust has many attendant implications for the drivers of long-term biogeochemical evolution of Earth and life.

Introduction

Charles Darwin articulated one of the most widely perceived discrepancies between the sedimentary rock record and a prediction from a scientific hypothesis. Specifically, he was disturbed by the sudden appearance of complex animal fossils (trilobites, in particular) in the 'lowest-known' fossil-bearing strata. This observation seemed to pose a serious challenge to his ideas about gradual, continuous evolution of life from a single common ancestor. To account for this apparent discrepancy, Darwin predicted that there had to be a long history of Earth and life, as yet unseen by geologists of his time. 'To the question why we do not find records of these vast primordial periods', he wrote, 'I can give no satisfactory answer' [1]. Darwin proposed that one obvious solution to this problem was rooted in the essential character of the rock record itself:

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"*I look at the natural geological record, as a history of the world imperfectly kept, and written in a changing dialect; of this history we possess the last volume alone, relating only to two or three countries. Of this volume, only here and there a short chapter has been preserved; and of each page, only here and there a few lines.*"

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The 'tattered manuscript' analogy comported well with contemporary views of the sedimentary record, traceable to James Hutton and his 1788 work, 'Theory of the Earth'. Hutton is credited widely with first describing the rock cycle, an unceasing loop of sediment deposition, rock uplift (by a clearly expressed, but then unknown, mechanism) followed by erosion that both continuously destroys and creates sedimentary rocks. If rock once existed that recorded life's slow march from simplicity to complexity, the relentless attrition of rock by erosion and geologic destruction has removed it, thereby solving Darwin's dilemma. Beginning in the 1950s, however, work by geologists and paleontologists pushed the record of biological evolution much deeper into Precambrian strata, revealing the long sought after history of animal life prior to the explosion of skeletal fossils during the Cambrian Period. This history is evident predominantly in microfossils found in shale and chert nodules (e.g., [2,3]), thus partially alleviating one concern about the fossil record with which Darwin grappled.

The Huttonian model of the rock cycle, in contrast, remains firmly entrenched among Earth scientists. The most basic prediction of this model is that the dominant signal present in the surviving sedimentary rock record should be one of effectively constant (and equal) rates of production and destruction [4]. That is, once a mass of sediment is deposited, it is subject to some continuous random probability of destruction. If this probability is non-zero (it need not be constant with time), then rock quantity will inexorably decline with increasing age, analogous to the decay of radioisotopes or the survivorship of a dissolved element in the ocean before sequestration and deposition in marine sediments.

Any such signal of degradation as a predominate process should manifest as an approximately exponential decline in surviving quantity with increasing age. Russian geologist Alexander Ronov led the first effort to compile data that could test this hypothesis. Using a combination of geological maps and borehole observations to arrive at a surface–subsurface model, Ronov and his team generated global volume estimates in Earth's sedimentary shell (excluding Antarctica) for general lithology types in the Phanerozoic and latest Precambrian [5–12]. In 1970, the hypothesis of a decaying rock record was first tested against a working version of Ronov's database, then available only for the Devonian through Jurassic Periods. It was therefore supplemented with sedimentary volume estimates from the deep sea and extrapolations based on maximum known sediment thicknesses for assigning masses to older geological time intervals [13]. This pre-plate tectonics compilation of deep sea sediment and extrapolated pre-Devonian, post-Jurassic sedimentary rock volume was well described by the expected exponential survivorship model. Analyses of geologic map area of exposed rock vs. age further entrenched this interpretation [14]. Empirical deviations from a single exponential fit were interpreted as transient departures from approximately equal rates of sedimentary rock formation and destruction (either from increasing sediment accumulation rates or decreasing the 'erodability' of sedimentary rock). These 'cycles' were attributed tentatively as a process signal driven by the then-burgeoning concept of global plate tectonics [4,15].

In 1980, Ronov et al. [16] finished their global compilation of sediment volumes . In his English-language published synopsis and description, they compared the empirical data on global sedimentary rock quantity with predictions from the standard model of the sedimentary cycle, noting:

> "*Contrary to our expectation, this diagram does not show any regular decrease of the relative mass of the rocks with increasing age and demonstrates only its periodic fluctuations.… This permits us to assume that the destruction of sedimentary rocks by erosion did not play the main role in the changes in their volumes during the Phanerozoic, and that these changes are due mainly to periodic fluctuations of sedimentation rates with time*"

There are several reasons why this conclusion differed from previous work [4,13–15], but an important one is the tectonic context of the sedimentary deposits analyzed. Ronov et al. [16] restricted their analysis to sedimentary deposits located on continental crust, as opposed to combined sediment volumes from both continental and oceanic crust [13]. This difference is notable, because ocean floor must be destroyed to balance the crustal production rate of $\sim$3.0 km^2 year^{-1} [17] at mid-ocean ridges. Thus, in the deep sea, it is impossible for crust, and any sediments deposited on it, to survive intact for long periods of time. Deep sea sediment quantity indeed declines approximately exponentially, with an empirical half-life of $\sim$30 millions years [18]. Continental crust and the sediments deposited on it, on the other hand, may persist for most of Earth history [19].

Constraining sedimentary mass fluxes

Ronov's conclusion about the nature of the continental sedimentary rock reservoir was not broadly embraced, but his team's data on rock type have been used very widely, including in the first models of the Phanerozoic

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history of atmospheric pO_2 [20]. In most models that used these data, the total mass of sedimentary rock did not change (consistent with established views of the rock cycle), but it did cycle. In this steady-state view, organic carbon and pyrite burial and weathering rates varied with shifts in the composition of the sedimentary reservoir (i.e., changing proportion of carbonates vs. shales, constrained by Ronov's data), which in turn drove a time-varying geologic flux of oxygen into the surface environment.

Because building rock volume compilations is time-intensive (and would, according to the standard model of rock cycling, only yield a record overprinted strongly by erosion), geochemical proxy studies of well-constrained stratigraphic sections have emerged as the most common mode to study climate and biogeochemical cycling in deep time. As a result, geochemical proxy records and models underpin most of our modern hypotheses for how Earth's surface has evolved across geologic time, including the trajectory of atmospheric pO_2 [21–23], CO_2 levels in the aftermath of global glaciation [24] and paleotemperatures of seawater [25].

Interpreting most deep-time geochemical time series is, however, an underconstrained problem. Nonunique solutions are especially common for isotope measurements designed to constrain important burial fluxes into the lithosphere, such as carbon (e.g., [26,27]) and sulfur isotopes (e.g., [28]). For example, in strata older than ~180 million years, carbon isotope measurements ($\delta^{13}C$) of carbonate rock are made exclusively on shallow-water platformal successions, owing to the recycling of oceanic crust. Such environments are prone to diagenesis [29–31] and local basin restriction [32] that can disconnect its $\delta^{13}C$ signal from the global carbon cycle. Even if global signals of $\delta^{13}C$ are retrieved, the basic models employed to invert these measurements to burial fluxes of organic carbon (and hence O_2 fluxes to the surface environment) have been challenged [33]. Similar debates have also proceeded around sulfur isotopes [34], with recent work, for example, showing strong control of pyrite $\delta^{34}S$ by local depositional environment, rather than global-scale processes (e.g., [35]).

A new approach to an old problem

Fully understanding Earth history requires that all available data are brought to bear. Some of the challenges involved in interpreting geochemical records require additional tools for understanding burial (and weathering) fluxes of biogeochemically important elements in deep time. Both of these factors motivate a modern reexamination of syntheses of the rock record itself, *sensu* Ronov et al. [16]. Here, we summarize some key results from Macrostrat, a relational geospatial database that provides general, but also comprehensive, chronostratigraphic summaries of the age and properties of rocks for portions of the upper crust (https://macrostrat.org; [36]). The Macrostrat database is organized around the geologic unit, a body of rock or sediment that is recognized as being distinct (in some fashion) from other such adjacent units in a single geographic location or region. Macrostrat units are recognized within specific, defined geographic regions called columns that include both surface and subsurface information.

In total, there are 33 903 lithologically and temporally resolved surface and subsurface geological rock units distributed across 1474 geologic columns in North and South America, the Caribbean, New Zealand, and the deep sea [36]. Macrostrat columns characterize the chronostratigraphic distribution of rock bodies (i.e., what types of rocks were forming at what time and in what places), and not their physical contact relationships, as in a geologic map. Each rock unit in each column is described by a variety of physical attributes, including thickness estimates, general lithology descriptions, inferred environments of deposition/emplacement and stratigraphic nomenclature. Most Macrostrat data, including all results discussed here, are accessible via an Application Programming Interface (API: https://macrostrat.org/api, described further in Supplementary Material; also see [36] for more information about the database and its construction).

The most basic Macrostrat measurement of sedimentary rock abundance is a binary description of rock presence or absence for a given age and location. Figure 1 shows the aggregate signal from the 949 North American regions (polygons in inset map), expressed as a proportion of columns that contain sedimentary or metasedimentary rock, tabulated in 1 million year (Myr) increments for the past 3500 Myr. Total sediment quantity does not decline smoothly with increasing age, and an exponential fit (red dashed line in Figure 1) provides a poor description of the data (Shapiro–Wilk test for normality of residuals, $P = 3 \times 10^{-44}$).

A good exponential fit is consistent with stochastically constant rates of sedimentation and erosion, but such constancy is not required to produce a rock record that decays exponentially with age. Figure 2 shows model simulations of sediment burial and erosion histories, and the surviving rock records that are produced. In one scenario, burial fluxes of sediment vary stochastically around a periodic forcing meant to emulate, for example,

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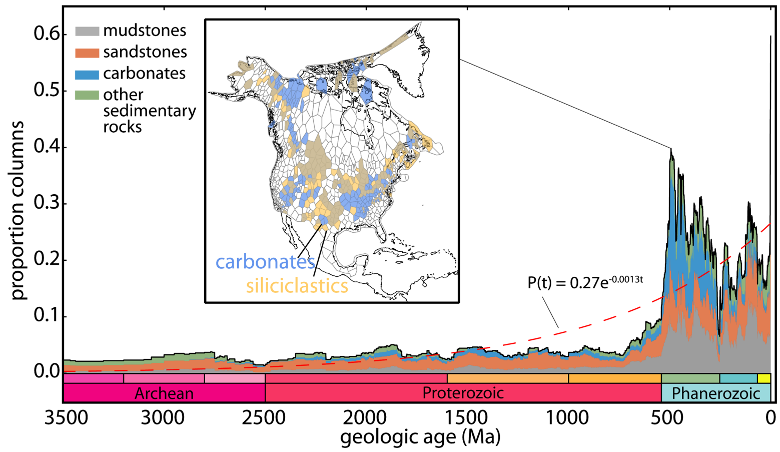

Figure 1. Time series of North American sediment abundance for the past 3500 Myr.

This quantity is measured as the changing proportion of columns (n = 949) that contain sedimentary or metasedimentary rock. The total signal is parsed into major rock types (shaded polygons beneath the black line). For example, at 493 Ma, 378 columns contain sedimentary or metasedimentary rock, 307 of which contain carbonate and 234 contain silicilastics (predominantly sandstones and mudstones); 164 contain both (inset map).

tectonically driven cyclicity related to supercontinent formation and breakup (Figure 2A). In each time step, sedimentary rock already deposited is assigned randomly a probability of destruction, ranging from 0 to 0.0035 Myr^{-1}, corresponding to residence times of infinity to 286 Myr. This treatment results in the time-varying erosion rates shown in Figure 2B. These combined histories result in a surviving rock record that shows periodic oscillations, but that declines inexorably downward with increasing age (Figure 2C). In another scenario, sediment burial varies randomly (Figure 2D), but sedimentary rock is only episodically eroded (Figure 2E). Such a scenario results in a 'stepped' rock record, but decreasing rock quantity with increasing age remains the predominant process signal (Figure 2F). In each case, for every rock age cohort, its time-integrated probability of erosion is non-zero (even if it is an integration of a highly variable erosion history; Figure 2B,E) and thus must decline with increasing age (Figure 2C,F). Other model variants, involving burial and erosion histories that are both periodic, yield this same conclusion (Supplementary Figure S1).

In the empirical data (Figure 1), this expected exponential decay is not observed. Instead, two separate states are evident, one during the Precambrian and another during the Phanerozoic. Each differs dramatically in mean value, but has little or no long-term trend up or down. The boundary between these two states is widely recognized as the 'Great Unconformity' [37–39], a surface of non-deposition, and highly spatially variable amounts of crustal exhumation, that separates Phanerozoic sediment from Precambrian crystalline basement (and a much lesser amount of Precambrian sediments and metasediments). Within the Precambrian and Phanerozoic, fluctuations are observed that, at least during the Phanerozoic, closely correspond to 'tectono-stratigraphic' units of Sloss [40] and the supercontinent coalescence-breakup cycle [41,42]. It is notable that these are the exact same 'cycles' that Garrels and Mckenzie [4] suggested might be a signature of plate tectonics, and that Sloss [40] identified qualitatively based on field relationships. Several shorter-term fluctuations in sediment storage on the continents are also evidenced, such as a drop in quantity attributable to sea level fall during the late Ordovician glaciation [43]. The breakup of the supercontinent Rodinia [44] during the Cryogenian–Ediacaran (720–541 Ma) undoubtedly played a role in the increase in sediment abundance across the Cambrian transition, with the onset of thermal subsidence of Laurentia's margins beginning in the terminal Ediacaran [45,46]. These familiar drivers, however, cannot be invoked to explain fully the data, notably why the mean value of preserved Phanerozoic rock quantity differs so markedly from that of the Precambrian (Figure 1).

Significance and implications

The results in Figure 1 provide prima facie evidence for the hypothesis that erosion and rock cycling are not the primary process signals in the surviving sedimentary rock record [16]. Instead, the weight of evidence

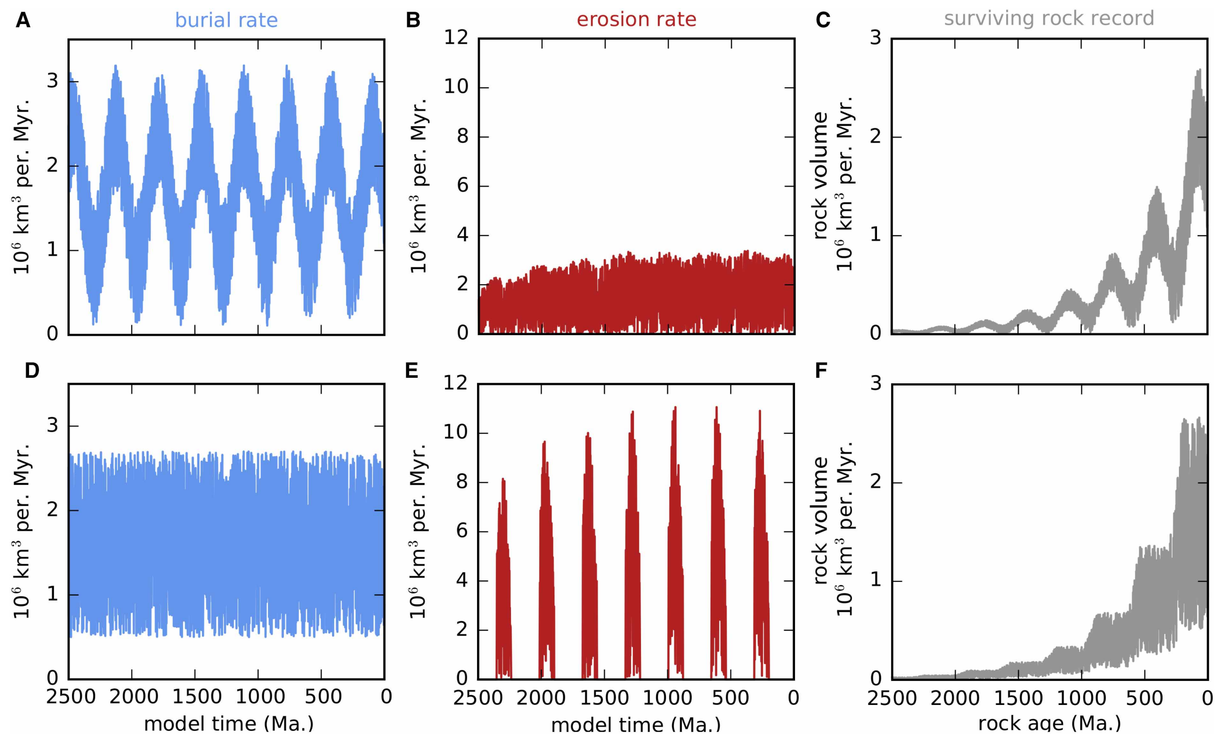

Figure 2. Forward models of the surviving rock record.
Synthetic histories of sediment burial (panels **A** and **D**) and sediment erosion (panels **B** and **E**) make predictions of rock volume vs. rock age (panels **C** and **F**). Panels **A** and **B** yield **C**. Panels **D** and **E** yield **F**.

indicates that, in aggregate, the sedimentary record at the temporal and spatial scale of the current database (Figure 1) is driven by changes in total rates of net sediment accumulation, as first argued by Ronov et al. [16]. Note that gross sediment flux (e.g., represented by sediment delivery by rivers) need not be directly reflected in the net sedimentary record [18]. Rates of gross sedimentation may have always been high and nearly constant, with time-varying mechanisms (e.g., basin formation, continental flooding and sea level) translating some of that flux into a long-term net sediment reservoir, thereby driving the temporal signals in Figure 1.

Before exploring the implications of these results, it is obvious to ask whether North America is a sufficiently large and tectonically diverse enough sample of continental crust to reflect global signals, or whether it is an idiosyncratic record driven principally by regional tectonic boundary conditions. The best way to address this question is to expand Macrostrat column coverage to other continents [47]. Expansion is a significant effort, albeit one that is ongoing. In the absence of a truly global data set, our results can be compared to related geologic syntheses, including Ronov's global sedimentary volume time series (Figure 3A), analyses of a geologic map of Australia (Figure 3B) and stratigraphic nomenclature data from Germany (Figure 3C). Each available dataset shows evidence of a large step-like increase across the Proterozoic–Phanerozoic boundary. These comparisons do not obviate the need for a global dataset, but they do support the interpretation that Figure 3 captures global processes — similar to the conclusion of Ronov et al. [16], who also tested the assertion that global signals are common to distributed continents in geologic syntheses.

Is there a viable model wherein erosion could yield the observed step change difference between Phanerozoic and Proterozoic sediment abundance? If parameterized as in Figure 2, a focused, singular period (i.e., between 800 and 500 Ma) of erosion could both lower the mean amount of sediment relative to the Phanerozoic and produce the lack of secular trend in rock mass vs. rock age evident in the observed Proterozoic record (Figures 1 and 3A,B). However, the amount of erosion required to remove the Proterozoic sediment volume now missing from the preserved record is enormous — an average of ~14 vertical kilometers of sedimentary rock would have to be removed from all continents within ~200–300 Myr, if no difference between average rates of Proterozoic and Phanerozoic sediment accumulation rates is assumed [48]. Required denudation rates would be lessened if this material was removed episodically throughout the Proterozoic, as in Figure 2E, but

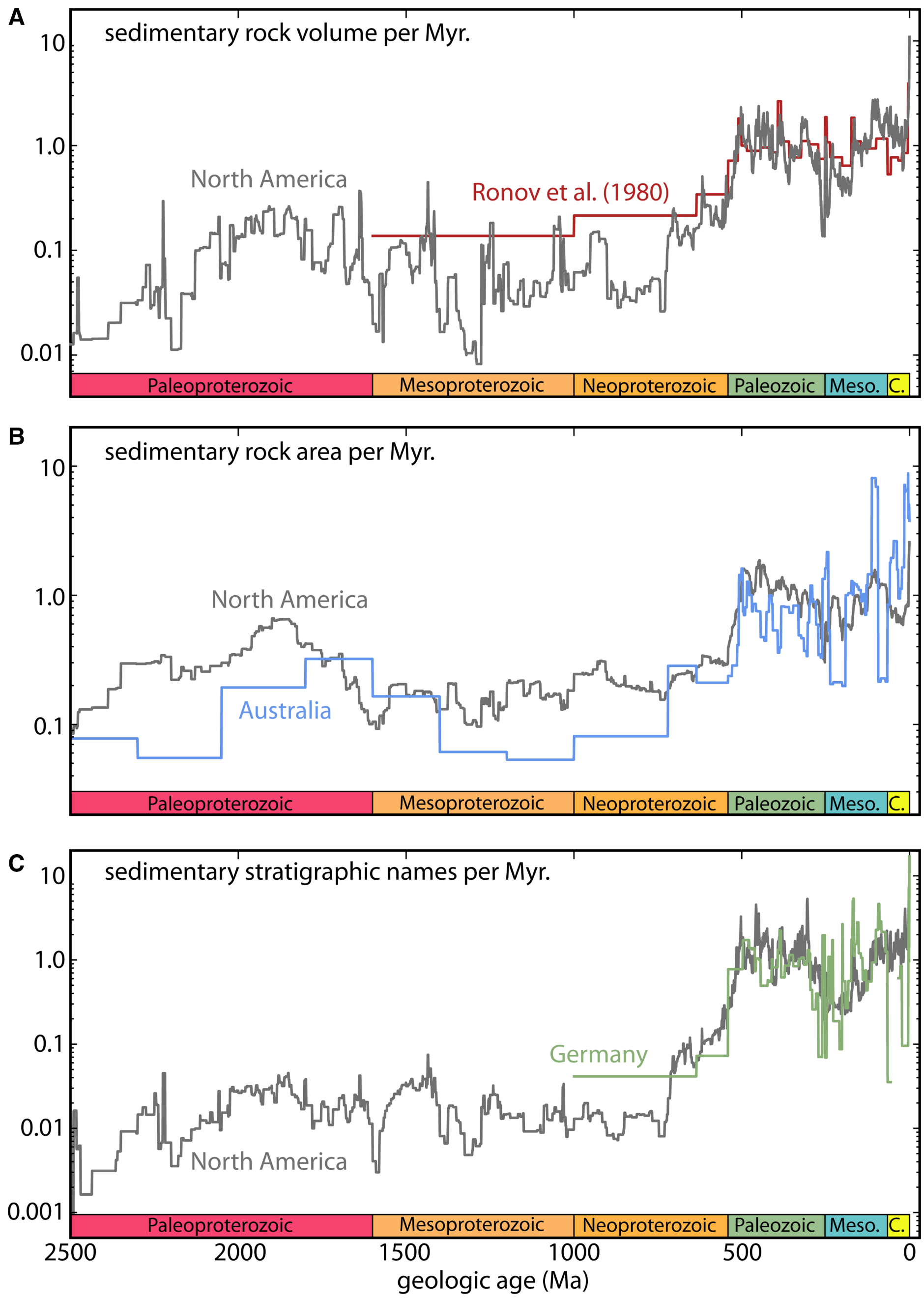

Figure 3. Comparing time series derived from North American Macrostrat with other geologic syntheses.
These comparisons include Ronov's estimates [16] for global sediment volumes for the latest Precambrian and Phanerozoic (**A**), sedimentary rock area calculated from an Australian geologic map (**B**; [65]) and German sedimentary rock names (**C**; [66]). Each time series is normalized by its own Paleozoic–Mesozoic mean value.

sediment older than some given age would have to be shielded from further erosive episodes, in order to avoid the staircase decline pattern shown in Figure 2F. Even if the physicality of such 'protection' could be justified, this erosion-driven model still points to fundamental differences between the Proterozoic and Phanerozoic sedimentary systems, with Proterozoic sediments more prone to erosion that leads to lower net sediment accumulation rates on the continents when compared with the Phanerozoic, with a step increase initiated suddenly in the Cambrian.

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The interpretation that Figure 1 reflects a dominantly global signal that records fluctuating rates of sediment accumulation and storage on the continents has many implications for the long-term evolution of the Earth surface system. Many major features in the history of life and the environment over the past 2.5 billion years are mirrored in this simple description of the timing and magnitude of changes in the total amount of surviving sediment vs. age (Figure 4A). We have elsewhere made the case that these obvious similarities are not consistent with notions of sampling bias in the fossil record [49,50] and are more than coincidental in the case of atmospheric oxygen concentration [48]. Organic carbon burial flux on continental crust, calibrated by Macrostrat volume estimates for specific rock types and total organic carbon (TOC) measurements, were combined with independently derived oxidative weathering terms in order to forward-model atmospheric oxygen levels. Model results are not driven by time-dependent sediment properties (e.g., different mean values of weight percent TOC and $CaCO_3$ in Proterozoic vs. Phanerozoic sediments), but rather by secular shifts in the fraction of this total sediment burial that is captured in long-lived, tectonically stable continental settings. The results reproduce many fundamental features in the canonical view of atmospheric oxygen over Earth history, constructed through proxy records [51], implying a causal connection [48]. Thus, at least in the case of atmospheric oxygen and its Neoproterozoic–Paleozoic rise, the sedimentary record is not likely to be a passive and incomplete recorder of its history. Instead, the unsteady growth of the sedimentary reservoir on the continental crust may have been the proximate driver of atmospheric oxygenation.

Erosion and rock destruction, as classically conceived [4,13–15], are not the dominant process signals in geologic syntheses of sedimentary rock quantity (Figures 1, 3 and 4A), so long as those syntheses include both surface and subsurface data [18]. However, it must be the case that erosion has, to some much lesser extent, affected even the long-term net record of sedimentation. Erosion does occur, and it is clearly detectable in Macrostrat on regional scales [52], even though it cannot be the predominate process signal in the aggregate data.

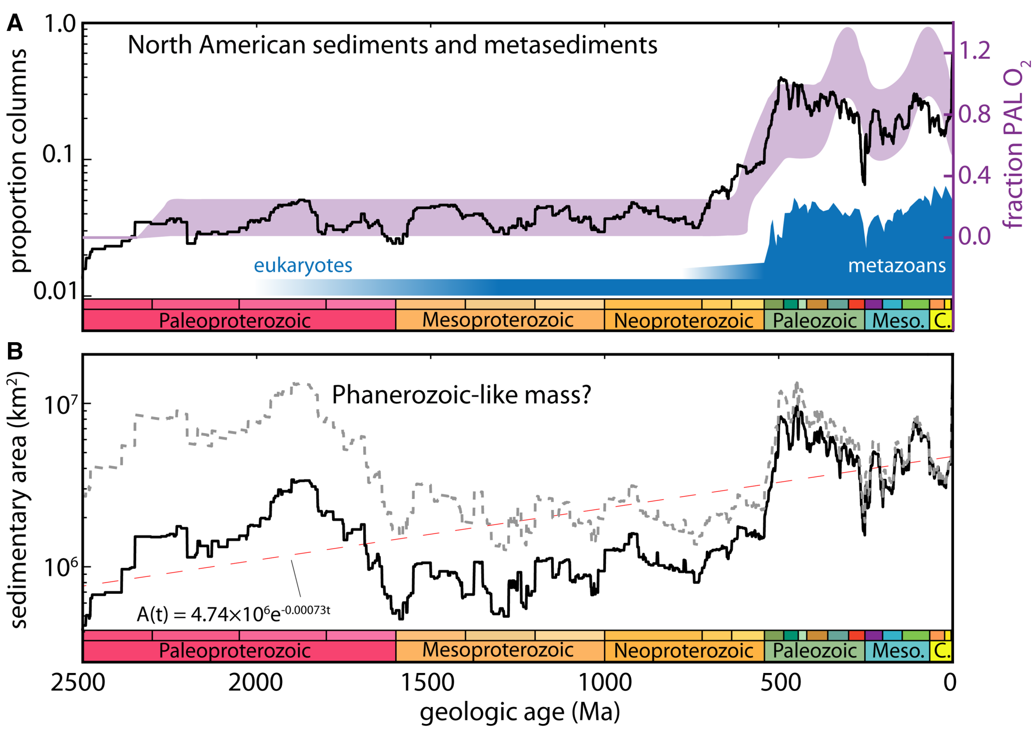

Figure 4. The surviving rock record and Earth system evolution.

(**A**) Sedimentary and metasedimentary quantity in North America (left logarithmic y-axis, measured as the proportion of geologic columns containing any sediment of a given age) is displayed along with the canonical history of atmospheric oxygen (right linear *y*-axis, [51]). A schematic depiction of major biological events in the Earth system is depicted also, including the origins of eukaryotes [51] and metazoans [67], and a scaled diversity of Phanerozoic marine animal genera [68]. (**B**) Speculative restoration of North American sedimentary rock area (gray dashed line), reconstructed from an exponential fit (red dashed line) to the extant rock record (solid black line). Panel **A** adapted from Figure 1 of [48].

To model this signature of erosion, an exponential fit is the best place to start because of the expected persistence of this signal, regardless of the specific time-varying history of erosion and burial (Figure 2). An exponential fit (red dashed line in Figure 4B) explains very little of the total variance, implying that the process of erosion (episodic or constant) is not prominent, and yields an expected half-life for sedimentary rock of nearly 1 billion years. However slow though this erosion might be, and small in comparison to the effects of changes in net rates of sedimentation, this model would mean that surviving Mesoproterozoic rocks are expected to be ~0.30–0.50 × their original volume, with the Phanerozoic being comparatively untouched (but still reduced relative to their original masses). For example, the preserved area of Devonian rock is predicted to have been reduced by $\sim 2 \times 10^6\ km^2$, a decrease large enough to accommodate easily regional observations of rock erosion (e.g., loss of $0.21 \times 10^6\ km^2$ of Devonian strata from the Slave craton [53]). In fact, the entire Canadian shield ($\sim 3.4 \times 10^6\ km^2$) could have hosted and lost Paleozoic sedimentary strata, and the differences between the Proterozoic and Phanerozoic systems would still persist (Figure 4B).

Using the exponential fit, one can attempt to 'restore' (albeit speculatively) the expected sedimentary mass that has been destroyed via this slow cycling of sedimentary rocks. Such an analysis provocatively suggests that there may have been a Phanerozoic-like mass of sedimentary rock at the end of the Paleoproterozoic (dashed gray line in Figure 4B) and that this mass has been lost to erosion over the following 1.5 billion years. This idea arises from the broad local maximum, centered at ~1900 Ma, seen in surviving rock area (black solid line in Figure 4B). A similar-aged local maximum is also seen in Australian sedimentary rock area (Figure 3B), suggesting, once again, that this pattern may be present on multiple continents.

Although using a poor-fit exponential model to reconstruct sedimentary rock volumes is wrought with uncertainty, these results are intriguing. If it were the case that there was an initial Paleoproterozoic pulse in the growth of sedimentary mass on the continents, followed by a cessation of that growth and a transition to a long-lived Mesoproterozoic low in net sediment accumulation, then it should be the case that atmospheric oxygen would first increase during the Paleoproterozoic and then decrease. This idea might help to explain the emerging model that seawater SO_4^{2-} [54], and maybe pO_2 [55], reached 40–50% of modern values following the Great Oxidation Event (GOE), when O_2 first permanently rose to measurable levels at ~2200 Ma [56]. Following this GOE 'overshoot', pO_2 is thought to have fallen to well below 10% PAL for the remainder of the Proterozoic [51]. This hypothesis also raises the possibility that Phanerozoic-like rates of continental organic carbon burial and the attendant long-term sequestration of reduced sedimentary phases are necessary to maintain an oxygen-rich atmosphere, and that this state may not be maintained indefinitely.

The current episode of Phanerozoic continental sediment storage could come to end, and the empirical data suggest that the sedimentary system may enter a state akin to the early Mesozoic, as the re-assembly of continental blocks that separated during Pangea breakup proceeds [42]. If net sedimentation on the continents slows, then the future may see a decline in atmospheric oxygen — similar to the end-Permian, with its crash in both net sediment quantity (Figure 1) and pO_2 [57]. If continental sediment accumulation does not rebound, as it did during the later Mesozoic (Figure 1), then pO_2 may continue to drop, eventually reaching levels not seen since the mid-Proterozoic.

Positing pO_2 fluctuations of this type presupposes that the most important determinant of atmospheric oxygen concentration on geologic timescales is net sediment accumulation on continental crust. While this notion is certainly not new [58], the long-standing assumption has been that the continents, once amassed, have not varied substantially in their ability to sequester sediments across geologic time, consistent with classic views of the rock cycle [13]. In the absence of directional and sustained changes in net organic carbon burial on continental crust, major changes in the surface environment require some other perturbation, such as variations in geological O_2 sinks [59–61] or nutrient availability that controls primary productivity [62–64]. These are all certainly important factors in governing Earth's surface conditions. However, the rock record suggests that long-term net accumulation of continental sedimentary rock has varied substantially across Earth history (Figures 1 and 3), with inflection points corresponding to major state changes in the histories of atmospheric oxygen and life (Figure 4). These observations raise the interesting possibility that the presence of water, oxygenic photosynthesis and even active tectonics is not sufficient to maintain an oxygen-rich atmosphere. Large and possibly sustained changes in surface redox conditions may therefore be inevitable on a timescale that is determined by the fundamental processes controlling long-term rates of net sediment accumulation on continental crust. Ultimately, these processes must be coupled to fundamental processes occuring in the solid Earth, dictated by plate tectonics and the geodynamics of Earth's interior.

Conclusions

Alexander Ronov's team was the first to test whether the dominant signal in the surviving sedimentary record is erosion and rock destruction — an idea traceable to James Hutton and the foundation of modern geology. Ronov concluded that this model could not explain a global synthesis of sedimentary deposits on continental crust [16]. We revisit this seminal work with a new, higher-resolution approach to measuring rock quantity, aided by advances in computer technology and data informatics. Fundamentally, these new results corroborate Ronov's conclusion about the nature of the rock record. There is a profound and abruptly defined difference between the Precambrian (pre-541 Ma) and Phanerozoic (post-541 Ma; Figures 1, 3 and 4). Although we do not yet know the ultimate physical and/or geodynamic model to explain these observations, the simple empirical similarities between the surviving continental sedimentary rock record and independent proxy records of both atmospheric oxygen concentration and biological evolution (Figure 4A) are notable and suggest a casual connection. The well-established effects that growth in sedimentary mass, and its associated organic carbon component, have on surface redox evolution [20,58] adds further evidence that there is a strong process connection. Earth's ability to perform this vital long-term organic carbon sequestration has changed substantially over billions of years, as well as on shorter timescales. This history highlights the importance of biochemistry coupled to sediment sequestration as a planetary process that is necessary for the appearance of complex, oxygen-utilizing life and, ultimately, its persistence.

Summary

- An analysis of the empirical record of sedimentary rock mass vs. age reveals that erosion and rock destruction are not the dominant process signals in the surviving geologic record.
- This work corroborates and expands upon the seminal work of Alexander Ronov and colleagues, who found that (1) there is little or no long-term decline in sedimentary rock quantity with increasing age during the Phanerozoic, and (2) global patterns in sedimentary rock quantity on the continents predominate over regional patterns.
- These results indicate a profound difference in average rates of net sediment accumulation on continental crust between the Proterozoic and Phanerozoic Eons, although rates of gross sedimentation may have remained approximately constant throughout Earth history.
- The empirical record of surviving sedimentary rock mass vs. age mirrors major features in biological and geochemical proxy records of oxygen concentration in Earth's atmosphere. This similarity suggests a process connection between the long-term evolution of the continental sedimentary reservoir and Earth's surface environment.

Abbreviations

GOE, great oxidation event; Myr, million year; TOC, total organic carbon.

Author Contribution

Both authors contributed to the development of hypothesis, analysis and writing.

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Competing Interests

The Authors declare that there are no competing interests associated with the manuscript.

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