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26 September 1968; revised 12 December 1968 ■

Sedimentary Rock Types: Relative Proportions as a Function of Geological Time

Abstract. *Proportions of sedimentary rock types remaining today differ from period to period. These differences may be chiefly the result of differential rates of deposition and erosion of the various components of the rocks. Lower percentages of limestones and evaporites in Precambrian rocks than in post-Precambrian rocks probably represent selective loss of these more easily removable components from the original deposits.*

The proportions of sedimentary rock types in the geologic column vary as a function of age; for example, evaporites amount to several percent of post-Precambrian sedimentary rocks whereas they are far less than 1 percent of Precambrian rocks of sedimentary origin. It is often assumed that the ratios of sedimentary rock types of a particular age represent the relative proportions of sediment types deposited at that time. We propose that age differences in ratios of rock types may be largely due to differential rates of overturn of sedimentary materials in which the various components of the sedimentary rock mass circulate at markedly different rates controlled by their erodibility.

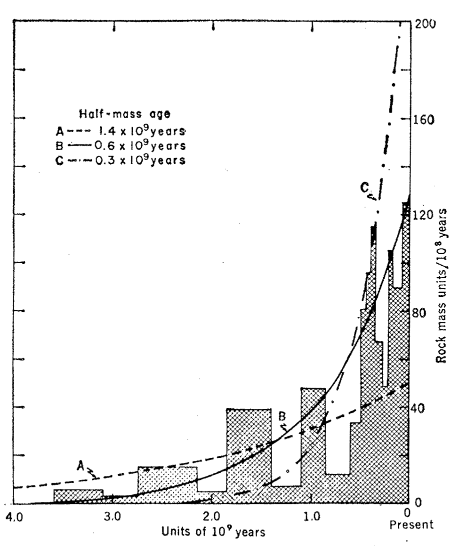

Fig. 1. Distribution of mass of sedimentary rocks as a function of age. Curves based on models that assume the total mass of sediments existing today has remained constant throughout geologic time. Curves A, B, and C represent total deposition of a mass of sediments equal to two, five, and ten times the existing mass, respectively. The corresponding half-mass ages are 1.4, 0.6, and 0.3 billion years. Hachured histogram is an estimate of the actual mass distribution based on observed occurrence (*1*) and our interpretation of the Precambrian distribution.

Sediments have been continuously deposited and destroyed throughout geologic time. The rates of deposition and destruction certainly have not been constant, as evidenced today by the irregular distribution of sediment mass as a function of age; however, one can construct highly simplified models in an attempt to simulate the gross aspects of today's mass distribution.

Based on the assumptions of a total mass that is constant with time, constant and equal rates of deposition and destruction, and an equal probability of destruction of equal masses (independent of age) distributions of sedimentary mass as a function of age are predicted (Fig. 1). The 5x model is of the right order of magnitude to fit actuality; the 10x model predicts too small a mass of older sediments, and the 2x model far too much (Fig. 1). The choice of the 5x model, as opposed to either of the others, is compelling. This conclusion would not change even if there were large errors in estimates of the actual age distribution of existing sediments. The mass distribution required to fit the 10x and 2x models is contrary to the experience of many geologists.

Approximately half the total mass of existing sediments is younger than 600 million years, whereas the rest is distributed irregularly over an interval of about 2500 to 3000 million years; that is, the half-mass age of all sedimentary rocks is about 600 million years. However, the half-mass ages of the various components of the sedimentary lithosphere appear to be different; that of carbonate rocks is about 300 to 400 million years and that of evaporites perhaps 200 to 300 million years (Fig. 1) (*2*).

The near absence of evaporite deposits in Precambrian rocks may then be largely attributable to a rapid turnover of these relatively soluble materials. The present mass–age relations indicate that a cycling rate two to three times that of the shales would be sufficient to account for present day distributions. Also, there has long been an apparent discrepancy between the 20 to 30 percent of carbonate rocks in the post-Precambrian record and the 5 to 10 percent predicted for all sedimentary rocks by geochemical balance calculations (*3*). If carbonate rocks cycle approximately 1.5 to 2 times faster than shale, they would be predicted to make up decreasing percentages of existing sedimentary rocks as a function of increasing age, even though their percentage of the total mass may always have been very nearly the same. The predicted present distribution of shale, carbonate, and evaporite as a function of age (Fig. 2) based on half-mass ages of 600, 300, and 200 million years, respectively, agrees favorably with the actual distribution (*2*). Finally, the possibility emerges that the very large percentages of cherty rocks, particularly of middle Precambrian age, may reflect the slow cycling of chert because of its high resistance to erosion and its characteristic protected position at the bottom of sedimentary basins.

From these qualitative relations we suggest that geochemical "uniformitarianism" should be strongly consid-

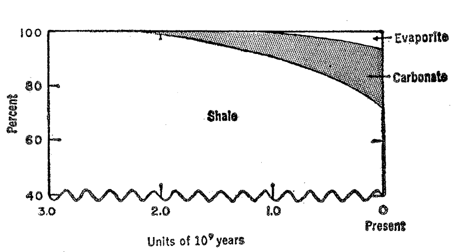

Fig. 2. Calculated present distribution of shale, carbonate, and evaporite as a function of time. The calculation is based on half-mass ages of shale, carbonate, and evaporite of 600, 300, and 200 million years, respectively.

ered when interpreting the ratios of various rock types of any given age. In other words, the total mass of sediments of all ages existing at any given time in the geologic past may have had about the same ratios of rock types that we observe today. Differences in the ratios of rock types as a function of age in the rock mass existing today may depend on differential cycling rates of the components. We do not contend that all age differences in ratios of rock types existing in sedimentary rocks are caused by differential removal and deposition of various components of the sedimentary mass, but that geological conclusions based on use of today's ratios as indications of the ratios at the time of sedimentation should be tempered by consideration of the effect of differential cycling.

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References and Notes

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24 October 1968

Xenon: Effect on Radiation Sensitivity of HeLa Cells

Abstract. *HeLa cells, plated onto plastic petri dishes, were exposed to various atmospheres composed of air and carbon dioxide; helium, oxygen, and carbon dioxide; and xenon, oxygen, and carbon dioxide in a pressure vessel. Survival curves with x-rays, 280 kilovolts (peak), show that air and helium have the same effect, but that xenon potentiates x-irradiation to the extent that the dose to produce a given level of survival with xenon is 0.58 of the dose required with air.*

Ebert and Howard (*1*), reporting on the growth rate of *Vicia faba* irradiated under atmospheres of xenon and air, showed that the presence of xenon produced a hypoxic type of protection, as measured by growth rate. Later experiments by Evans, Roberts, and Orkin (*2*) on the 30-day survival of mice irradiated under Xe-O_2 atmospheres produced similar results. In conjunction with a study of the distribution of xenon gas within mammalian cells exposed to Xe-O_2-CO_2 atmospheres at various pressures and periods of exposure, we investigated the influence of xenon and helium gases on the radiation sensitivity of the HeLa cell.

HeLa S-3 cells (*3*) were maintained in sterile, glass prescription bottles in Eagle's minimum essential medium supplemented with 10 percent fetal bovine serum, after the methods of Puck and Marcus (*4*). Cells were treated with a mixture of trypsin and EDTA to remove them from the glass surface and were plated onto Falcon plastic petri dishes (tissue culture grade). The number of cells plated was varied so that the fraction of cells expected to survive irradiation would produce between 100 and 200 clones. Control plating efficiencies were between 45 and 75 percent. Plates were incubated at 37°C under a charcoal-filtered, water-saturated atmosphere of 95 percent air and 5 percent CO_2 for 4 to 24 hours prior to experimentation. Initially all irradiations were performed 4 hours after plating, but, based on the findings of Barendsen and Walter (5), we shifted to 24 hours after plating to allow cells to recover from the traumatic effects of trypsinization. In terms of clone formation, cells irradiated at 24 hours will appear less sensitive than those irradiated at 4 hours, because of cell multiplicity. Methods for correcting for cell multiplicity have been described by Sinclair and Morton (*6*); however, these corrections affect mainly the shoulder of the survival curve without changing the value of D_0, the dose that, on the straight line portion of the survival curve, will reduce survival to 37 percent.

Cells were irradiated in a pressure vessel that holds four 60-mm petri dishes. A gassing system was designed that allows for precise delivery of each gas to the pressure vessel. Control plates were gassed with premixed air (95 percent) and CO_2 (5 percent). Plates treated with experimental gases were first flushed with a mixture of O_2 (80 percent) and CO_2 (20 percent) at a reduced pressure of 0.25 atm. The vessel was then sealed at this reduced pressure and helium or xenon (*7*) admitted to produce total pressures from 1 to 7.75 atm. The pressure vessel was held in a reproducible position 47 cm from the target of an x-ray machine, 280 kv (peak), by a support jig that was locked to the body of the machine. The radiation field was made uniform to ±1.5 percent at the level of the petri dishes. The quality of the x-ray beam inside the pressure vessel was 1.1 mm Cu half-value layer and the exposure rate was approximately 190 r/min at the level of the cells, as determined by LiF thermoluminescent dosimeters held in the pressure vessel.

Following irradiation, the four plates used for each experimental point were removed from the pressure vessel and returned to the incubator. Survival was measured by clone formation 12 to 14 days after irradiation. Colonies were stained with methylene blue and scored according to criteria for distinguishing viable from abortive clones (*8*).

Initially, the HeLa cells were irradiated approximately 4 minutes after pressurization with the gases, pressures of the gas mixtures ranging from 1.0 to 7.75 atm. The survival of cells irradiated under a He-O_2-CO_2 mixture at the above pressures was the same as for cells irradiated in air at a pressure of 1 atm. Pressure, per se, does not

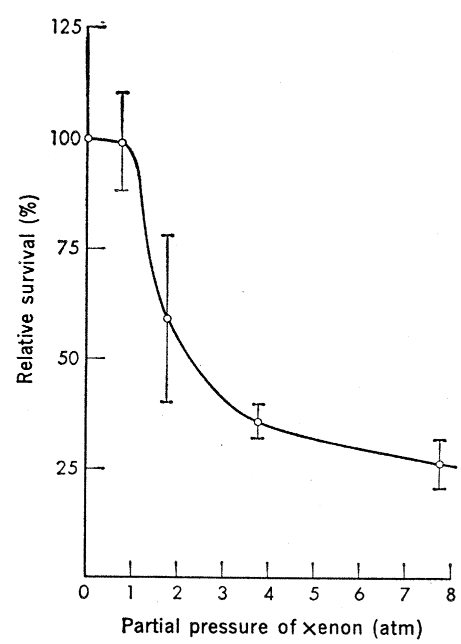

Fig. 1. Survival of HeLa cells in xenon, relative to cells in air, versus the partial pressure of xenon. The x-ray exposure was 430 r. Partial pressures of O_2 and CO_2 were maintained at 0.20 and 0.05 atm, and irradiation was 4 hours after plating. Vertical lines about each mean value represent 95 percent confidence intervals.