conservation." Presumably this fund will be administered by the new National Planning Board.

The United States Geological Survey is scheduled to increase its activities tremendously, especially in the topographic branch, since the topographic mapping of the country is far from being completed and a good topographic base map is a recognized necessity for all research on natural resources.

The South can expect perhaps more than her proportionate share of this new research. The trend toward a chemical development of the South's resources is evident on every hand, as has been shown. Further development will depend upon the limitations set by the new policy, and this looks favorable at the present time. With the expected increased confidence it is reasonable to expect capital to be attracted southward. Let us hope that a scheme will be devised whereby state geological surveys will be materially strengthened financially, so that their long-delayed programs can be accomplished. Many of the funds now being spent for relief work could better be allocated for mineral location and research.

Since the war between the states the mineral industry in the South has been hampered not only by a lack of capital but several things that follow naturally from such a shortage; such as numerous small, poorly developed, widely scattered mines; and an emphasis on metals rather than non-metals. The development of coal, oil and gas in response to the heavy demand has far surpassed the other non-metals, but nonmetallics have suffered most from inefficiencies of mining, milling and marketing. Yet long after metallics have been depleted the non-metallics will remain as strong valuable products.

The newly proposed mineral policy should encourage technological research in metallurgy, ceramics and industrial chemistry, and these researches will doubtless prove the value of many mineral deposits of medium and low grade, hitherto unworkable in the South and elsewhere.

To further this industrial march and to give these minerals the same impetus already acquired by coal, oil and gas, salt and sulphur, it is essential that the entire South be studied as a unit; that markets and centers of production be correlated; that basic freight rates and methods of assessments and taxation receive collective consideration; and that the great fuel supply of the South, coupled with its unexcelled water powers, should be utilized in the fabrication of raw material into finished products carrying higher class freight rates, but reaching new centers of distribution; employing men in a thousand small towns rather than in a few large cities; and offering increased valuations of property as an offset to constantly mounting taxes.[8]

The present slump is only temporary, if we can judge from history. In 70 years (1860–1929 inclusive) the population of the United States increased four times, agriculture production increased about six times, manufacturing increased about 22 times, while the mining output increased 60 times. Therefore, if our standards of living are to improve, as we expect they will, mineral production must also increase.

So in this march of events the South is definitely on its way. Just where we are going is not always quite clear, but let us hope that with the aid of the proposed new national mineral policy, intelligent conservation and a more thorough understanding of the limitations of nature, as well as her bounties, the South may continue to increase her "place in the sun."

[8] "The Undeveloped Mineral Resources of the South." American Mining Congress, 1928.

# THE GEOLOGIC AND THE COSMIC AGE SCALES[1]

## THE AGE OF THE EARTH FROM SEDIMENTATION

THE method of estimating geologic time on the basis of sedimentation was of great value in the development of geology in the nineteenth century because it led to a better understanding of geologic processes and caused geologists to resist the distortion of their developing ideas of geologic history threatened by certain physical theories whose validity was insistently claimed by eminent authorities. The older calculations were, however, low minimal values produced under the influence of limitations urged by physicists, and based on the adoption of the comparatively high present rate of deposition as a constant rate and the neglect of critical considerations of certain factors which demand material time additions to the then accepted figures.

While the sedimentation method has a sound theoretical basis, it is, for the whole geologic record, complex and difficult of application, fundamentally because of varying rates, and the fact that to arrive at dependable approximate average rates for the different periods requires an extensive knowledge of the prevalent conditions during such periods that will be available only at some future date. At the present time we may say that a first rough approximation of specific rates for separate divisions of geologic history, taking into consideration formerly neglected factors, gives results of the same order of magnitude as the method based on radioactivity for the time from the

[1] Abstracts of the six papers of the joint Symposium of the Astronomical Society of the Pacific and the American Physical Society, University of California at Los Angeles, June 26, 1935.

Cambrian to the present. Too little of the history and correlations of the pre-Cambrian have been sufficiently worked out to treat its sedimentary record in the same critical way.

The sedimentary method has, for certain short periods, developed a high degree of accuracy, but is not suited, unaided, to give satisfactory figures for the whole geologic record. Even with the acceptance of the present radioactivity determinations, it must still be used to determine the distribution of time in periods and epochs between the widely spaced points on the radioactivity time scale. It will be most useful to geology if it can be combined with an independent time method to determine its varying rates, for then it will give needed information as to the varying geological and geographic conditions valuable in the interpretation of the different periods of earth history.

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## THE AGE OF THE EARTH FROM RADIOACTIVE DISINTEGRATION AND RELATED PROBLEMS

THE transformations of uranium, actino-uranium and thorium into isotopes of lead of atomic weights 206, 207 and 208, respectively, proceed at rates which have been accurately measured and which are not affected by extremes of temperature or pressure, by chemical reactions nor by the lapse of great periods of time, as is proved by the sharpness of the alpha rings in pleochroic haloes. The accumulation of helium and of the foregoing isotopes of lead gives a time scale of high precision. Reliable age measurements may now be made by the helium method on any small specimen of unweathered, fine-grained, basaltic material. Experiments seeking to extend this technique to coarse-grained granite and other materials are in progress.

The antiquity of nearly every geological period down to the Cambrian has now been determined. In addition, some thirteen pre-Cambrian formations are now dated, the oldest being 1,850 million years old.

The age of the earth can be estimated to lie between 1,850 and 3,500 million years. The ages of 23 iron meteorites, many of which are probably of extra-solar origin, do not belong to the solar system, are uniformly distributed between 2,800 million years and nearly zero, and show no tendency to group about any particular age.

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## THE AGE OF THE EARTH FROM THE CHANGES IN ITS TEMPERATURE AND ELASTIC PROPERTIES

THE results which have been found concerning the age of rocks determine the time which has elapsed since the crystalline crust of the earth has formed. There is a gap which comprises the time between the formation of the earth and the beginning of the geological history. If the earth originated as a cold body, as Chamberlin believed, this time interval may be very large. If the earth was originally gaseous, the time until it formed a solid crust was relatively short, probably less than 100,000 years. In its early history the moon seems to have been very close to the earth, forming tides in the earth's crust which changed the surface layers of the earth to a large extent, so that the rocks which are now close to the surface solidified probably after these disturbances by the moon had decreased. The time elapsed since then can be calculated if the viscosity of the earth is known. Assuming the most probable values, we find times of the order of $10^9$ to $10^{10}$ years; that is, the time when the moon was close to the earth is of the same order as the age found for the oldest rocks. Darwin and others have assumed that the moon originated from the earth. The only fact which seems to contradict this assumption is the high momentum of the moon; as long as this can not be explained, the hypothesis stipulating the origin of the moon from the earth can not be accepted. Jeffreys has found from the mechanics of such an event that in this case the moon must have originated at the time when the earth just began to solidify. In any case, the age of the earth which we find from the age of rocks is that which has elapsed since the moon was very close to the earth, unless the moon is a younger member of our solar system.

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## THE AGE OF THE GALAXY FROM THE DISINTEGRATION OF GALACTIC STAR CLUSTERS AND BINARY STARS

As is well known, in modern astronomical literature, two values for the ages of the stars are found, which are frequently referred to as the short time scale ($10^9$–$10^{10}$ years), and the long time scale ($10^{12}$–$10^{13}$ years). Obviously, both can not be correct, and a choice between the two can be made only after critical examination of the basic computation. We find that the long time scale is without foundation and that the short time scale is compatible with our present astronomical knowledge.

Jeans has been, and still is,[2] the chief advocate of

[2] See discussion on the "Age of the Universe," *The Observatory*, April, 1935.

the long time scale. His five methods of estimating the ages of the stars will be discussed in more detail in a future paper. Two of these methods are erroneous, *viz.*, the method based on the comparison of the distribution of the observed eccentricities in visual binaries and a computed one; and that based on the mass-ratios of the binaries. A third method starts from concepts of stellar evolution which in all probability are incorrect, and two more methods depend on dynamical considerations that are incomplete and bound to lead to numerically incorrect results.

The study of the stability of galactic clusters has given the most reliable astronomical determination of the ages of the stars, and leads to the short time scale. The most complete investigation of this kind is Bok's paper in *Harvard Observatory Circular* 384, 1934; reference is made to Bok's own summary, *loc. cit.*, pp. 39–40.

Provisional computations by the writer on the stability of wide binaries tend to confirm the short time scale.

Finally, we have good reasons to suppose that stellar evolution on a large scale (involving great changes in mass, luminosity, and spectral type) have not taken place since the stars for the first time reached a "stable" state. This is irreconcilable with a long time scale.

It should be borne in mind that the age of the galaxy in its present form, which is equivalent to the average age of the stars, may be considerably less than the age of the universe.

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## THE AGE OF THE UNIVERSE FROM THE RED SHIFT IN THE SPECTRA OF EXTRAGALACTIC OBJECTS

BY the term "age of the universe" we can mean merely the time as measured on some particular conceptual clock back to a cosmological event of special interest or importance. For our present purposes we shall mean the time as measured on an ordinary clock in our own galaxy during which the extragalactic objects would have been observed to carry out the major part of their recession. There is nothing in this point of view contradictory to the idea that time may really be best regarded from a more fundamental point of view as extending from minus infinity in the past to plus infinity in the future.

With the help of the relativistic theory of gravitation, it is possible to investigate the behavior of homogeneous cosmological models, and curves are presented which show the different types of temporal behavior that would correspond to different values of the two parameters $R_0$ and Lambda in the equations. It is emphasized that such models could at best be only a very rough approximation to the actual universe, but that their study may be informing in interpreting the behavior of that portion of the universe which has so far been observed. An essential feature of the models is the instability of any static distribution of extragalactic objects and the consequent expansion or contraction which would be expected. An unessential feature of the models is the appearance of singular states of exactly zero volume which would not be expected to occur in the case of the actual universe which is certainly not perfectly homogeneous.

The expansion of such models would provide a natural and unforced explanation of the extra-galactic red shift. It is to be emphasized, however, that the possibility of other causes for the red shift has not yet been observationally eliminated. For the moment, regarding the red shift as due solely to expansion, we do not now have sufficient data to decide between the different possible types of expansion, but do have enough to reach the provisional conclusion that the major part of the past expansion has taken place during a time scale of the order of $10^9$ to $10^{10}$ years. The rough agreement between this finding and the date for the laying down of radioactive material and for the birth of the planets is to be noted.

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## ATTEMPTS TO RECONCILE THE LONG AND THE SHORT-TIME SCALES IN COSMOGONY

THERE exist extreme advocates of the long and of the short time scale, but neither side can offer an entirely convincing argument. The champions of the long scale calculate the time which the celestial systems needed to reach their present degree of uniformity and equilibrium. In the absence of definite knowledge as to how the universe came into being, it is, however, impossible to say what its initial state was and how much prior conditions in it differed from those we observe at present.

On the other hand, the proponents of the short time scale assume that the universe is now and always was fairly uniform and homogeneous, and compute the time during which it could have existed in this state.

It is clear that the two points of view start from assumptions so radically different that the results at which they arrive are in no way comparable.

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