station and the reactor *DRI*. During the year a cooling system for the reactor was installed, and the power brought up to 1,100 W. Various technical measurements were carried out on the reactor, and training procedures and instructions for courses were revised and improved. The solid-state group continued work on instruments for the study of radiation damage to metals and graphite, and other groups were occupied with planning a new laboratory and its equipment in connexion with the linear accelerator ordered from the United States and with the assessment of the energy and particle balance in a very hot hydrogen plasma.

In the electronics department an analogue computer, the equipment for a 'gas-flow' proportional counter for use at the waste-water treatment plant at Risø, and a fluorimeter for the measurement of uranium content in samples with concentrations of about 10^{-6} , in addition to a number of special pieces of apparatus, have been constructed. The work of

the reactor engineering department was largely concentrated on the study project for the heavy-water-moderated power reactor with an organic cooling medium to be known as *DOR*. The department has been concerned also with constructional and safety problems related to reactor-powered ships.

In addition to its direct educational and training activities in technical and scientific subjects, the report states that the Commission tries to satisfy general public interest in nuclear energy and in the Research Establishment by publications, radio and television broadcasts and exhibitions. A documentary film about Risø is being prepared. Visits to the Establishment are limited to Saturdays, and during January 1–March 31, 1959, about 1,200 persons visited Risø.

The report concludes with a list of the publications by members of the staff of the Commission, and with a detailed map of the layout at the Research Establishment.

AGE OF THE BASE OF THE CAMBRIAN

IN a recent publication¹, Prof. Arthur Holmes has proposed a revision of his 1947 time-scale. This revision was necessitated by the wealth of new age measurements made since 1947, and it is a tribute to Prof. Holmes's insight that his first time-scale, proposed in 1911 when the science of geochronology was in its infancy, has required only relatively minor revisions since that time. In view of Prof. Holmes's past successes in drawing correct conclusions from fragmentary data, it might seem unwise to question his present conclusions regarding the age of the base of the Cambrian system. Furthermore, it is true that imaginative speculation frequently proves more fruitful than sterile scepticism. Nevertheless, in this case, I feel that a critical discussion of the grounds for fixing the age of the base of the Cambrian is in order in the hope that workers may recognize that a problem exists. Otherwise the figure 600 ± 20 million years may prematurely find its way into texts and into the minds of Earth scientists as an established fact of geology.

At the outset, it must be realized that the concept of the base of Cambrian is different from that of the base of the other periods. The base of the Devonian, for example, is defined by the disappearance of characteristic Devonian fossils as one moves down the column and by the appearance of Silurian fossils. In contrast to this, the base of the Cambrian is either defined locally as an unconformity beneath strata containing Cambrian fossils or by the failure to discover lower Cambrian fossils in lower strata. In the first case, there is no reason at all for the local unconformity to have world-wide time significance, and in the latter case, the evidence is of necessity purely negative; the apparent absence of a Cambrian fauna may be due to causes other than age. For purposes of discussion, it is more useful to fix some definable horizon within the Cambrian, for example, the base of the Middle Cambrian and at least for some purposes mentally lump the Lower Cambrian with the Precambrian. This point of view does not significantly alter the discussion of the evidence cited by Holmes; it merely sharpens the definitions employed. This approach relegates to future research

such difficult questions as the time of the first appearance of *Olenellus* and its simultaneity in various regions of the Earth. It will be shown that the data used by Holmes do not yield a firm upper limit to the age of the base of even the Middle Cambrian, and it therefore follows that they do not permit an upper limit to the age of any part of the Lower Cambrian, however it may be defined. (In order to avoid any ambiguity it should be pointed out the expression 'an upper limit to the age' is used to mean that the age is less than a certain number of years. In this expression the word 'upper' is therefore used in a numerical, not a stratigraphical, sense.)

The principal data used by Holmes in placing an upper limit to the age of the base of the Cambrian are those of Kulp (reported by Campana²) and Greenhalgh and Jeffery³ for absite from pegmatites overlain by the Precambrian Adelaide System in South Australia. Since the Adelaide System lies below recognized Lower Cambrian strata, it is clearly pre-Middle Cambrian.

These authors report ages in million years as follows:

	$^{208}\text{Pb}/^{238}\text{U}$	$^{207}\text{Pb}/^{235}\text{U}$	$^{207}\text{Pb}/^{206}\text{Pb}$	$^{208}\text{Pb}/^{232}\text{Th}$
J. L. Kulp	520	600	915	585
Greenhalgh and Jeffery	610	674	895	675

Following Greenhalgh and Jeffery, Holmes interprets these data as a "typical loss of radon pattern", and in accordance with this a probable age of 674 million years is assigned to the sample analysed by Greenhalgh and Jeffery, with 915 million years considered an improbably high upper limit. However, it should be pointed out that there is no age pattern for a single mineral which is diagnostic of loss of radon. There are two independent uranium-lead ages, that calculated from the ratio lead-206/uranium-238 and that calculated from the ratio lead-207/uranium-235. In the data under consideration, the former age is younger than the latter, and this pattern can arise equally well from any of several mechanisms, namely, preferential loss of lead relative to uranium, additions of uranium, gain of radiogenic

lead of some isotopic compositions, or preferential loss of an intermediate daughter product of the uranium-238 series, for example, radon. By simply examining the pattern of discordant ages one can never distinguish between these possibilities. The relative importance of the different possible causes of discordance must be evaluated by independent methods. I am not aware of any experimental data for absite, but measurement of the radon-loss from minerals possessing reasonably well-defined crystal structures has shown such loss to be of minor importance^{4,5}. In contrast to this, there is abundant evidence from intercomparison of uranium-lead ages with ages measured by other methods that loss of radiogenic lead or, equivalently, gain of uranium, is a common cause of discordance in uranium-lead ages. If this more common process is responsible for the discordant data on the sample in question, the limit of 915 million years is a lower limit to the age rather than an improbably high upper limit. The lead-208/thorium-232 age contributes little to the argument since for unknown reasons these ages are almost always badly discordant.

Greenhalgh and Jeffery also report a potassium-argon age of 520 million years on a sample of biotite from the same rock. Even if one postulates loss of radon as the cause of discordance, this result cannot be reconciled in any simple way with the absite data. Taken altogether, the absite and biotite data indicate that for some reason the minerals in question have been open with respect to either the parent or daughter elements, or both, since the time of their original crystallization and their apparent ages are scarcely suitable for fixing a critical point in the geological column.

Some further data bearing on this matter are the results of measurements of Tilton *et al.*⁶ on igneous rocks in the Wichita Mountains of Oklahoma. As pointed out by Holmes, the result of 500–550 million years places at best a limit on the age of a portion of the Upper Cambrian, since there are no Middle or Lower Cambrian strata in the region. It should be further noted that the granitic samples which have been dated are not seen in actual contact with the Cambrian strata and the inference that they are pre-Upper Cambrian is based on the assumption that they are the same age as the neighbouring Carlton rhyolite which is actually overlain by Reagan sandstone of Upper Cambrian age, or on the correlation of these rocks with pre-Reagan granites found in sub-surface drillings.

The remaining evidence cited by Holmes is that based on analysis of uraninite from Katanga, Belgian Congo. The results of age measurements of these samples are reasonably concordant and indicate an age of about 625 million years for the uranium mineralization. As quoted by Holmes, L. Cahen states that the uranium mineralization is later than the Kundelungu formation, which is assigned to the Precambrian by the absence of Cambrian fauna and by the presence of 'Late Precambrian' fossils. Cahen further concludes, as is necessary for the argument, that we can dismiss the idea that the Kundelungu sediments are much older than the uraninites. While this is the best evidence given by Holmes for saying that the age of the base of the Middle Cambrian is less than 600 million years old, the evidence is obviously not clear-cut, in view of the dubious status of Precambrian palaeontology and the uncertainty in the inference that the uranium mineralization does not greatly post-date the Kundelungu sedimentary

rocks. It would be of considerable interest if Dr. Cahen would discuss critically the reasons for his opinions quoted above and by Holmes.

These remarks have been made with the hope of acquainting workers both in the field of geochronology and stratigraphy with this unsolved problem. A start might be made by demonstrating unequivocally that the base of the Middle Cambrian is less than 1,000 million years old. Rocks of this age are found in many parts of the world, but I do not know of any localities where the relationship of dated rocks of this age to the Cambrian is clearly established. If the possibility that rocks of Grenville age (1,000 million years) and their age equivalents in other regions are Upper or Middle Cambrian can be definitely excluded in this way, then one may go to the rarer areas of rocks in the 600–900 million years age-range in order to see if more strict limits can be obtained.

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¹ Holmes, A., *Proc. Edin. Geol. Soc.*, **17**, 183 (1959).

² Campana, B., *Austral. J. Sci.*, **16**, 240 (1954).

³ Greenhalgh, D., and Jeffery, P. M., *Geochim. et Cosmochim. Acta*, **16**, 39 (1959).

⁴ Gilotti, B. J., and Kulp, J. L., *Amer. Mineralogist*, **40**, 481 (1955).

⁵ Starik, I. E., *Geokhimiya*, No. 5, 18 (1956).

⁶ Tilton, G. R., Davis, G. L., Wetherill, G. W., and Aldrich, L. T., *Trans. Amer. Geophys. Union*, **38**, 360 (1957).

WHILE in principle I am in general agreement with Dr. Wetherill, I feel that he over-rates some of the difficulties to which he refers and exaggerates their geochronological consequences.

The "base of the Cambrian" is not a natural phenomenon that can be discovered and objectively investigated. It is a mental concept, entirely dependent on definition and, until agreement is reached, subject to argument and dispute. Geologists are still actively discussing whether the criteria for defining it should be: (a) palaeontological, for example, the first appearance of the earliest trilobites or of other fossils elsewhere associated with them; (b) stratigraphical, for example, the first deposits of the corresponding marine transgression; (c) palaeoclimatological, for example, tillites and other evidence of the glaciations commonly regarded as having occurred towards the close of the pre-Cambrian; or (d) geochronological, a hope for the future which may eventually command widespread assent¹. Meanwhile, most geologists consider (b) and (c) to be inappropriate because the events concerned are likely to have varied from place to place much more widely in time than the appearance of the earliest Cambrian fauna. Adopting the "lowest formation in which the biozone of *Olenellus* or its equivalent is represented" as the base of the Cambrian, I found 600 ± 20 million years to be "a reasonable estimate" for the beginning of the Cambrian Period in the light of the evidence then available². Surely this is neither "imaginative speculation" nor "fixing the age". I see no reason why any geologist, however naïve, should suppose the figure provisionally adopted to be "an established fact". However, referring to "Earth scientists", Dr. Wetherill thinks otherwise, and in so far as there are now many Earth scientists who are not geologists he may be right. If so, his warning to them will serve a very useful purpose.

With regard to the age pattern for the South Australian absite (Greenhalgh and Jeffery's data) it