L. J. Salop

precambrian of the northern hemisphere

DEVELOPMENTS IN PALAEONTOLOGY AND STRATIGRAPHY 3

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PRECAMBRIAN OF THE NORTHERN HEMISPHERE

AND GENERAL FEATURES OF EARLY GEOLOGICAL EVOLUTION

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Developments in Palaeontology and Stratigraphy, 3

PRECAMBRIAN OF THE NORTHERN HEMISPHERE

AND GENERAL FEATURES OF EARLY GEOLOGICAL EVOLUTION

by

L.J. Salop

All-Union Geological Research Institute (V.S.E.G.E.I.), Leningrad, U.S.S.R.

English translation edited by *G.M. Young*

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PREFACE TO THE ENGLISH EDITION

I am pleased that Elsevier has agreed to publish the English version of my book, "Precambrian of the Northern Hemisphere and General Features of Early Geological Evolution". This will undoubtedly enlarge the circle of readers of the book and will permit more active and fruitful discussion of the problems with which it attempts to deal. The text for the English translation was revised and some new data were included. However, I should like to address some additional remarks to the readers:

(1) Precambrian geology is a rapidly developing field in every country. The abundance of new material makes constant revision of ideas necessary. Existing schemes for subdivision of the Precambrian do not meet the requirements of the new data. New stratigraphic terminology is badly needed. In this book I propose some new names for subdivisions of the Precambrian. I am well aware of the fact that new terms initially pose some problems and may even cause some disagreement among geologists. I should like to emphasize, however, that the essence of the proposed subdivision lies not in the names used for the units, but in the natural basis for the subdivision. I hope that the reader will focus his attention on this very important aspect of the problem.

(2) The major conclusions in the book are so-called "empirical generalizations". Some are based on theory but in other cases this remains to be done. I have tried to avoid speculation, so that the conclusions are based on factual evidence derived from the Precambrian rocks of the continents of the Northern Hemisphere. In particular I carefully avoided discussion of the problem of the "new global tectonics" as applied to the Precambrian period of geological evolution. In my opinion, this problem cannot be resolved on the basis of material from the Northern Hemisphere continents alone. Many of the facts presently available admit different interpretations. I hope to devote a separate book to this problem, including material on the Precambrian of all continents.

(3) The continuation of this work is a comparative analysis of Precambrian formations of the continents of the Southern Hemisphere. This work is almost completed and material on the African continent is ready for printing. I think it necessary to state that the major regularities established for the Northern Hemisphere continents are valid for the Southern ones and are thus of global extent. This mainly concerns subdivision of the Precambrian into large natural units (eras/erathems, sub-eras/sub-erathems) and definition of their age boundaries.

In conclusion, I extend my thanks to Dr. G.M. Young for his work in editing the English translation of the book.

Prof. L.J. Salop,
All-Union Geological Research Institute,
Leningrad

PREFACE

It is well known that the Precambrian occupies a period several times longer than the later Phanerozoic. Thorough studies of Precambrian formations, and especially their stratigraphy, are needed to elucidate the general laws of geological evolution. At present there is no internationally accepted stratigraphic scale for subdivision of the Precambrian. Some older formations of different ages are assigned to the same subdivisions (e.g. "Archean" or "Proterozoic"), and coeval strata are commonly described under different names. Geochronological limits of Precambrian "eras" are also variable so that cartography and correlation of Precambrian formations are difficult.

The problems of interregional correlation of Precambrian formations are also of practical value; some exogenic types of deposits (sedimentary and sedimentary—volcanogenic—metamorphic deposits) for example of iron, manganese, uranium, copper, gold and high-alumina raw materials, are associated with older strata of specific composition and age, and even many of endogenic (mostly of metasomatic type) deposits (phlogopite, lazurite, mountain crystal, etc.) are also confined to particular Precambrian formations.

A unified system for subdivision of the Precambrian is badly needed. There are many new geological and geochronological data. These data are considered sufficient to permit delineation of a general stratigraphic subdivision of older formations. A generalized subdivision of the Precambrian is proposed in this book, on the basis of comparative analysis of Precambrian formations of the East European, Siberian and North American platforms and associated fold belts. The less well-known Precambrian formations of peninsular India, and those of Phanerozoic fold belts are also discussed.

This work does not include detailed discussion of the stratigraphy of all regions of the Northern Hemisphere. It is assumed that the reader is familiar with the more important Precambrian sections or can use the included references for their study. We shall consider only the main features of the older strata and will give details only in the case of some new unpublished material, or in the case of some very important problematic data. The treatment of data on each region varies according to the amount of work done in the areas and according to the writer's knowledge of the material. The writer has had little opportunity for first-hand observation of areas outside the U.S.S.R. and has, in many cases, had to rely on published data, and review it using his own experience and knowledge.

Some problems discussed in this book have already been dealt with in earlier publications, but it was felt necessary to review or revise them as new data became available. Precambrian geology is a rapidly developing field so that future work may necessitate some change in the ideas expressed in this book. The writer, however, hopes that the main conclusions will remain valid.

The work on the Upper Precambrian of the East European platform was done in cooperation with K.E. Jacobson, who has studied the subdivision and correlation of the Precambrian deposits of the Russian plate, and their correlation with the Urals sections. K.E. Jacobson wrote some pages of the 7th, 8th and 9th chapters. I thank K.E. Jacobson and also my other colleagues and co-workers: Yu.R. Bekker, Yu.B. Bogdanov, V.K. Golovenok, A.Z. Konikov, K.N. Konyushkov, N.S. Krylov, V.Z. Negrutsa, S.N. Suslova, L.V. Travin and E.A. Shalek for help in this work and for fruitful discussion of problems of Precambrian regional geology.

In this work the rock and mineral ages, according to isotopic analyses, are based on the constants accepted in the U.S.S.R. ($\lambda_K = 0.557 \cdot 10^{-10} y^{-1}$ and $\lambda_{Rb} = 1.39 \cdot 10^{-11} y^{-1}$). The original age data from some original foreign papers are given in brackets. In many countries (with the exception of China and some others) another constant of K-decay is used ($\lambda_K = 0.585 \cdot 10^{-10} y^{-1}$) and in some papers another constant of Rb-decay ($\lambda_{Rb} = 1.47 \cdot 10^{-11} y^{-1}$) is used.

Prof. L.J. Salop,
All-Union Geological Research Institute,
Leningrad

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PART I

INTRODUCTION

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CHAPTER 1

METHODS OF CORRELATION OF PRECAMBRIAN ROCKS

The methods of correlation of Precambrian rocks are dealt with in many works on Precambrian stratigraphy, so that detailed treatment is not warranted here. However, many aspects of these different methods are not well understood and some brief comments are necessary. Three main methods are used in correlation of Precambrian strata: isotopic, paleontological and geological.

Isotopic Methods

The isotopic method of age determination, based on radioactive decay, was initially accepted by some and rejected by others. The first group considered the physical principles to be the absolute truth, and believed that it was possible to solve all problems of age determination and rock correlation by the use of isotopic analyses. They often considered the measured age to be the age of the rock. The other group, in the face of many discrepancies between radiometric and geological data, tended to reject this technique in stratigraphic studies, or accepted it with great caution. At present differences of opinion are fewer because of the development of more sophisticated techniques, and better understanding of both geochemical and geological interpretation of isotopic analyses. However, it is still not certain that in all cases we have a true geological evaluation of radiometric data.

Different isotopic methods and their modifications are used for age determinations of the older formations. These are: potassium—argon (K—Ar), lead isotopes (U—Th—Pb), lead isochron (Pb—Pb), model lead, α-lead and rubidium—strontium (Rb—Sr). Comparative analysis of all these methods is beyond the scope of this work.

All of these methods have their advantages and disadvantages. Initially it was thought that reliable isotopic age determinations would make possible definitive correlation of the older supracrustal formations and that the main task was getting the necessary dates. However, it is only rarely that we can determine the age of sedimentation or even of diagenesis of sedimentary rocks. Such dating appears possible only for sedimentary strata of platforms and miogeosynclinal types, incorporating some potassium-bearing syn- and epigenetic minerals. Even in these cases we cannot be sure that we have the true age and not a "rejuvenated" age related to later processes. It is well known that glauconite, commonly used for sedimentary-rock dating, loses radiogenic argon at relatively low temperatures (about 150°C or even lower). In addition, the potassium content of glauconite varies because of exchange reactions. Under very low-grade metamorphism, glauconite becomes unstable, decomposes, and is replaced by other minerals. Many studies have shown that even fresh, unaltered, glauconite cannot be useful for age dating because of argon diffusion. There are cases where glauconite from unmetamorphosed strata has yielded ages older than glauconite from underlying rocks. For example, the glauconite age of Eocene sandstones from California, taken from the surface, was measured to be 43 m.y. Those from drill cores at depths of 2—4 km in the same deposits, decreased in a regular way from 33 m.y. to 18 m.y. (Evernden et al., 1960). A similar situation was found in glauconite dating of Upper Precambrian rocks of Kazakhstan (Karatau). In this case the glauconite of the upper part of the section, near the contact with fossiliferous Cambrian deposits, yielded an age of 420 m.y. Glauconite from the lower part of the succession yielded lower figures — as low as 350 m.y. (analyses made by L.I. Borovikov and G.A. Murina, personal communication, 1972). It is possible that in these, and similar cases, "rejuvenation" of the age is due to stronger and longer heating of the glauconite-bearing rocks at greater depths, but other explanations are not excluded.

There are many other cases where glauconite from fossiliferous deposits has yielded evidently "rejuvenated" age values. For instance, Cambrian brachiopod- and trilobite-bearing deposits of Alberta (Canada) yielded 413-300 m.y. (several determinations from different horizons). According to the accepted geochronological scale these values correspond to the Early Devonian—Permian (Stevens, 1965). Argon losses in glauconite are evidenced by a wide scatter of ages measured from different samples of the same deposits. Glauconites of the Kar'yernaya Group of the Yenisei mountain range gave ages ranging from 747 to 815 m.y. (five determinations); the Pogoryuy Group of the same area gave ages in the 750—1,630 m.y. range (ten determinations). In general the older the rocks the wider the scatter of glauconite ages obtained from them (Fig.1).

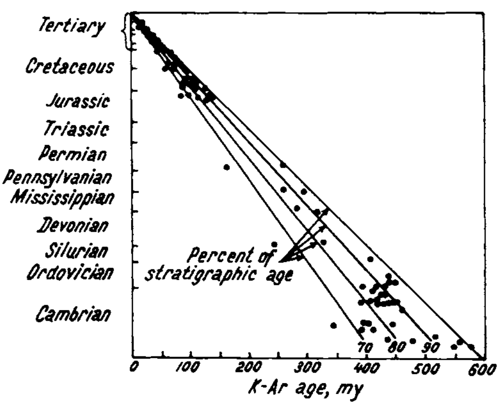

Fig.1. A comparison between K—Ar age determinations on glauconites and stratigraphic classification. After Obradovich (see Thompson and Hower, 1973).

The fact that some glauconite ages increase down-section indicates that the age data are not true. The thermal processes responsible for argon loss could have influenced the whole section, causing general "rejuvenation" of the glauconite ages. In this case, the difference in age of the older and younger deposits would be preserved. The above should be kept in mind when interpreting the dating of sedimentary strata using glauconite. In most cases the age data are "rejuvenated", and may indicate only the upper age limit of the strata. In particular, caution is required in the interpretation of results from older strata (Precambrian) and from altered or faulted rocks. Truer ages are to be expected for horizontal unaltered deposits in the upper parts of platform-cover sections (irrespective of age). Age determinations of geosynclinal strata using glauconite are not reliable. At present all the boundaries of the Riphean subdivisions were determined using glauconite from rocks of the miogeosynclinal complex in the Southern Urals — the Riphean stratotype. The correlation of the platform and miogeosynclinal strata using only age determinations made on glauconite is highly questionable.

"Rejuvenated" K—Ar ages are characteristic not only of glauconites from Precambrian rocks. Rubinshtein (1967), who first proposed the use of glauconite for dating sedimentary rock, came to the conclusion "that in most cases the data for the Paleozoic (and certainly for the pre-Paleozoic!) and Mesozoic glauconites are too young". He even suggested addition of about 15% to the available dates based on glauconite from Mesozoic rocks, but this is not technically justifiable. For Precambrian rocks a rather close approximation to the true age is obtained when using glauconite from the uppermost part of platform sequences.

Many problems arise in interpreting K—Ar age data from hydromicaceous minerals, shales, phyllites and some other similar materials. In addition to "rejuvenation" due to possible argon loss it is commonly impossible to determine whether the data give the age of diagenesis (epigenesis), or the age of primary or superimposed metamorphism. In many cases ages are misinterpreted because of the presence of detrital micas, feldspars and some other minerals.

It is possible to determine the age of unaltered carbonate rocks by the Pb-isochron method, but in the case of metamorphic rocks the interpretation of such data can lead to erroneous results.

Volcanogenic rocks, especially those of acid composition, are more easily dated. Rb—Sr isochron and Pb-isochron (by whole-rock analysis), and Pb-isotopic analysis (on zircon) usually give the age of unaltered or slightly metamorphosed volcanites. K—Ar analysis may give the true age of unaltered volcanics. However, volcanic rocks that appear unaltered under the microscope, may also have suffered argon loss. A good example is provided by the slightly altered acid volcanics (porphyry) of the Akitkan Formation in the Baikal area; K—Ar dating gave an age of 100—550 m.y., whereas Rb—Sr isochron analysis gave their true age of about 1,700 m.y.

Isotopic dating of Precambrian rocks can generally be done mainly on metamorphic and plutonic minerals. These ages indicate the time of metamorphism, metasomatism and intrusions; they reflect events subsequent to the deposition of sedimentary or volcanogenic rocks. In many cases the ages do not necessarily indicate plutonic events that directly followed sedimentation or volcanism, but may reflect later thermal events.

Migration of radiogenic elements and their decay products may take place during metasomatism, deformation, or under the action of various exogenic factors (weathering, solution, exchange reactions, etc.).

All of the above is mainly concerned with K—Ar analysis. Geological and experimental investigations have shown that argon loss from minerals and rocks may take place under low-temperature conditions if they are imposed for a long period. Under these conditions there is no evidence of recrystallization or metamorphic alteration of the rock. Such processes may not be detectable by simple petrographic methods. Thus, this method discloses only the age of rocks and minerals formed on the earth's surface or at relatively shallow depth, and which were not subjected to even slight but prolonged heating or deformation. In most cases K—Ar dating only provides the minimum age of metamorphic and intrusive rocks. This can differ greatly from their true age. Factors affecting the apparent K—Ar age cease to act on uplift of crustal blocks above a critical level which coincides approximately with the 300°C geoisotherm. When uplift of the earth's crust completes the tectono-plutonic cycle, the K—Ar analysis reflects (in a general way) the time of folding, metamorphism and plutonism (Salop, 1963). Relict dating may in some cases indicate the age of metamorphic and plutonic rocks because of local conditions favourable for argon retention in the mineral lattice.

All of these complications in regard to K—Ar analysis are partly applicable to other methods. The difference lies mainly in the fact that argon migrates more easily than some other daughter radioactive elements. K—Ar and Rb—Sr analyses on the same minerals (micas) revealed that argon and strontium migration from minerals in nature may take place simultaneously, but at different rates. In most cases the migration of strontium is slower, but sometimes argon is preferentially retained. The radius of strontium migration is known to be relatively small, and in the case of isochemical metamorphism redistribution of strontium in minerals may take place without a marked change of its content in a relatively small volume of the rock. This is the basis for application of the whole-rock Rb—Sr isochron technique. This method gives the age of the rock and/or the time of early and later metamorphism.

There are great limitations in direct application of Pb-isotope (U—Th—Pb) analysis in solving geochronological problems, for thermal and other processes that continue after mineral formation may cause migration of parent elements, and especially their decay products. Analysis of Pb-isotopes provides evidence of such migration by comparison of different isotopic ratios. Such analyses make possible the use of isochrons so that even discordant figures may give a mineral age by means of various isotopic ratios. In some cases alteration of a mineral or rock may be so profound that it is impossible to determine even the approximate age.

Hart et al. (1968) clearly showed that later thermal events strongly influence the migration of radioactive decay products, and cause "rejuvenation" of isotopic ages. These studies were conducted in the area of the contact aureole of the small Cenozoic Aldor pluton intruded into Precambrian gneisses dated by Pb-isotopic analysis at 1,650 m.y., in an area far removed from the zone of influence of the younger intrusion. In the area of the contact aureole the "ages" of different minerals from gneisses by K—Ar, Rb—Sr and Pb-isotope (according to various ratios) analyses decrease regularly as the Aldor stock is approached. Near the contact the values are similar to those of the intrusion. Only the zircon ages ($^{207}Pb/^{206}Pb$ ratio) remain relatively unaffected. Near the contact the zircon "age" decreases to 1,200 m.y., but at a distance of 100 ft. from the contact the age becomes "normal" (1,650 m.y.). Thermal influence on K—Ar and Rb—Sr dates and on zircon ($^{206}Pb/^{238}U$ ratio) was noted at a distance of about 3,200 ft. from the contact, where available data suggest that the temperature did not exceed 200°C. Thus, even a slight or short-lived increase in temperature near a small intrusive stock may cause a marked "rejuvenation" of isotopic dating. With strong and prolonged elevation of temperatures such as may occur during orogenic cycles, isotopic "rejuvenation" will be more intense and universal.

"Rejuvenation" of Rb—Sr mineral ages was described above. Studies by Pidgeon and Compston (1965) proved that strong contact metamorphism may cause complete homogenization of strontium isotopes in the wall rocks, so that even whole-rock Rb—Sr isochron analysis may not reveal the age of the earlier events.

Thus, direct use of the figures derived by isotopic analyses is commonly difficult or even impossible. We need abundant and varied geochronological data, with a solid basis of geological and geochemical facts. Single determinations, especially by K—Ar analysis, are of little value in dating high-grade polymetamorphic rocks; at best they provide a minimum age limit. Numerous dates from different rocks and minerals are necessary before we can begin to determine "relict" values. K—Ar dating methods normally provide the youngest ages. This is because the possibility of an "older" age is quite rare, as argon will be trapped in a mineral only when the outside argon pressure is higher than that within. In nature this is exceptional (Gerling et al., 1965a).

In cases where the age apparently was increased a check can be made by determining the "age" of cogenetic minerals with different temperature of argon loss. Anomalously old K—Ar rock ages are common in ultrabasic (and partly basic) magmatic rocks due to specific conditions of emplacement and crystallization of the magma (Salop, 1970a). In deeper parts of the crust radiogenic argon, which is expelled from the crystal lattice of potassium-bearing minerals under the effect of high pressure and temperature, may accumulate in open crustal fractures under low-pressure conditions. If magma is intruded into such cavities the crystallizing minerals will trap much of the argon present there (Salop, 1970a). Since such deep fractures commonly control the introduction of ultrabasic magma, the K—Ar dating which yields anomalously old ages is usually found in ultramafic and associated mafic rocks.

The most valuable techniques are the Pb-isotope, Rb—Sr isochron and Pb-isochron methods, but even these may sometimes merely reveal the time of the last high-grade metamorphism when isotopic equilibration took place or when homogenization of isotope distribution took place in cogenetic formations. In such cases it is difficult to determine the true age of the rock. However, the available data may permit an estimation of the time and nature of the main events. In some cases similar or identical isotopic ages are obtained from older basement rocks and an unconformably overlying metamorphic complex. In this case the isotopic age of the older rocks is "rejuvenated" by the later (superimposed) metamorphism.

In many parts of the world the oldest gneiss—granulite complexes and unconformably overlying low-grade volcanic complexes yield identical, or very similar (about 2,600—2,800 m.y.) dates. Granites which were emplaced in the older complex, and younger granites intruding the greenstone strata, give the same age. In rare cases both the older granites and older supracrustal rocks yield an age of about 3,500 m.y. These dates may be regarded as "relict" ages reflecting the period of early metamorphism and plutonism. The more common "age" of the older rocks (2,600—2,800 m.y.) reflects the time of superimposed thermal processes. In the Limpopo belt in South Africa, rocks of the gneiss—granulite complex have a Rb—Sr isochron age of 2,000 m.y. They are transected by the "Great Dike", which, in an area to the north, free from the 2,000 m.y. orogeny, has provided an age of 2,500 m.y. (Rb—Sr isochron). Thus the gneisses and granulites dated in the Limpopo belt are highly "rejuvenated" (Van Breemen et al., 1966), for in adjacent areas these rocks have yielded ages of about 3,500 m.y. Values of about 2,700 m.y. (Van Breemen and Dodson, 1972) were recently reported for gneiss of the Limpopo belt (Rb—Sr analysis).

Geological control on interpretation of radiometric data is essential. It is only with such control that radiometric data will provide a basis for global division and correlation of Precambrian rocks.

Paleontological Methods

Phytolites (stromatolites and microphytolites) occurring predominantly in carbonate-rich Upper Precambrian deposits have recently been used for subdivision and correlation of older strata. This relatively new technique is very popular among Soviet geologists. Unfortunately, this method in some cases has been applied without sufficiently careful analysis. Some empirical regularities in the vertical distribution of stromatolites and microphytolites are not adequately documented. There are many discrepancies between ages based on phytolites and ages based on geological and isotopic criteria. Some examples will be described in dealing with regional stratigraphy.

It is probable that many apparent contradictions are explained by the lack of detailed taxonomy, by incorrect determinations or by misinterpretation of geological and isotopic ages. The diagnostic features of many stromatolites and microphytolites are not fully studied or described. This may lead to subjective identifications of some fossils.

The Soviet workers originally contended that vertical zonation of stromatolites might be established by using high-rank taxonomic units such as "group" or "type". It was suggested that the oldest (Lower Riphean) phytolite complex was characterized by stromatolites of the *Kussiella* group, in particular, the Middle Riphean complex by the *Baicalia* group, the Upper Riphean by the *Inzeria* and *Gymnosolen* groups, and the Vendian complex by the *Patomia* and *Linella* groups. Further investigation, however, evidenced a rather wider vertical range of stromatolite distribution, with some forms occurring at different stratigraphic levels. Thus, the established sequence is expressed by predominance of certain groups at definite levels, and in a general change from one phytolite complex to another with time. The complexes themselves are characterized by a number of stromatolite forms differing in "species" composition.

Phytolite taxonomy has nothing in common with true biological taxonomy, except for the use of Latin names. The major taxonomic units of stromatolites as established by Soviet workers are based on macroscopic differences in external shape. The significance of these features for classification is commonly debatable. Lower-rank taxonomic units ("species") are erected largely on the basis of microstructural features. However, the microstructures are not necessarily primary but may be masked by recrystallization processes, or even produced by them. It is important to note that even small (1 m diameter) stromatolite bioherms may include forms belonging to different stromatolite groups.

We do not understand the mechanisms of stromatolite and microphytolite evolution. These fossils are not plant remains in the literal sense, but are rather carbonate (sometimes originally siliceous) structures — rocks which formed in response to life activity of different species of blue-green algae and bacteria. The role of algae in the formation of stromatolite structures is not clear: do they actively secrete calcite, or does the carbonate precipitate from seawater on the algal mucus to form the so-called "mat"? The occurrence of originally siliceous stromatolites (for instance in the Precambrian Gunflint Formation, which is a chemogenic ferruginous—siliceous unit in Canada; Barghoorn and Tyler, 1965) tends to favour the second opinion. The change in shape of the structures is presumed to be related to evolution of plant remains and gradual increase in their concentration (biomass) with time. It