Isotopic ages of the basic charnockite and khondalite from Kondapalli, Andhra Pradesh, India

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[Taken as read 23 September 1965]

Summary. The isotopic ages of three biotites from the Kondapalli area, Andhra Pradesh, India, have been determined by the ^{40}Ar/^{40}K method. The results (440–524 Myr) indicate that the basic charnockite and khondalite of pre-Cambrian age have been subjected to at least one subsequent metamorphism the age of which must be 440 Myr or younger. The significance of the results is discussed in the light of the available geochronological evidence from Peninsular India.

The hill ranges of Kondapalli (16° 37′ N., 80° $32\frac{1}{2}'$ E.), Krishna district, Andhra Pradesh State, India, form a part of the Eastern Ghats province of the charnockite region (Fermor, 1936) and are known for the occurrence of charnockites in their full variety in association with the basement complex of the khondalitic suite of rocks. Some of the basic charnockites in the Kondapalli area, equivalent to the basic division of the charnockite series (Holland, 1900), show unambiguous intrusive relationship into the khondalites. The terms 'basic charnockite' and 'charnockite' have been used here in the same sense as by Cooray (1962, pp. 242 and 272). In addition to the different types of charnockites, there are grey and pink granitic gneisses of very local occurrence. A large number of pegmatite veins occur cutting across both the khondalites and the charnockites. The general sequence of the Eastern Ghats belt is summarized by Holmes (1955):

	Pegmatites.
Orogenesis and metamorphism	Granitization: migmatites and granites and the manganese-rich Kodurite series. Charnockitization and the charnockite series.
	Calc-gneisses: mainly cafemic granulites.
	Khondalite series.

Krishnan (1960*a*, p. 105), while attempting to correlate the pre-Cambrian formations of Peninsular India, gave the following geochronological succession for the Eastern Ghats:

Cuddapah system.
(?) Granite (fluorine-bearing) 900–1050 Myr.
Charnockite.
Nellore pegmatites 1570–1750 Myr.
Khondalites and manganese sediments 2300–2450 Myr.
Older Gneiss.

TABLE I

Sample	K_2O	Atmospheric contamination	Vol. of radiogenic ^{40}Ar	Apparent age
Biotite from the basic charnockite dyke (P45)	9·26 %	19·5 %	$1{\cdot}65 \times 10^{-2}$ mm³/g	443 ± 8 Myr
		18·0	$1{\cdot}64 \times 10^{-2}$	440 ± 10
Biotite from the khondalite (458)	9·55	28·3	$1{\cdot}61 \times 10^{-1}$	450 ± 5
Biotite from the pegmatite (318)	9·41	9·5	$1{\cdot}80 \times 10^{-1}$	504 ± 5
		6·7	$1{\cdot}88 \times 10^{-1}$	524 ± 3·5

$\lambda_\beta = 4{\cdot}72 \times 10^{-10}\ \text{yr}^{-1}$ $\lambda_e = 0{\cdot}584 \times 10^{-10}\ \text{yr}^{-1}$

As far as the authors are aware, there are no published isotopic ages on any Indian charnockites, though India is the type region of these rocks. To fulfill this need, at least in part, and to investigate the geochronological sequence of the Kondapalli rocks, three biotites, from a basic charnockite, a khondalite, and a pegmatite, have been separated and the isotopic ages determined by the ^{40}Ar/^{40}K method.

The *basic charnockite* (P45, a plagioclase–orthopyroxene–biotite–granulite) dyke of width 25 in. strikes 140° and cuts across the foliation (220°) of the khondalitic gneiss, south-east tip of Balija Gutta, 1¼ miles NNE. of Kotta-Kailaspur village. The dyke has sharp contacts without exhibiting chilled margins. The rock is medium-grained, granulitic, and shows a slight directional orientation of the grains made prominent by parallel arrangement of the biotite flakes. Plagioclase, orthopyroxene, and biotite occur as essential minerals; potassium feldspar, (released?) quartz, ore, apatite, and clinopyroxene form sub-ordinate minerals; bluish-green hornblende, calcite, and scapolite (all secondary) occur in trace amounts together with occasional zircon crystals. Plagioclase (An_{79}) exhibits moderate wavy extinction and a slight or weak zoning of reversed type; the majority of the grains are antiperthitic. Orthopyroxene (En_{53}) is weakly pleochroic, light pink to very light green;

exsolution lamellae are absent. Biotite is of primary crystallization and shows slightly bent cleavage and moderate wavy extinction.

The *khondalite* (458) occurs on the eastern flank of the hill just west of Konduru village. It is essentially a potassium-feldspar–quartz–garnet–biotite–sillimanite–gneiss with minor amounts of opaques, green spinel, secondary calcite, zircon, and monazite. Quartz and feldspar occur in bands alternating with others consisting of garnet, biotite, sillimanite, and opaques. Potassium feldspar shows moderate wavy extinction. Around the large grains of potassium feldspar, quartz occurs in a fine-grained, unstrained, recrystallized form and exhibits normal extinction. Biotite occasionally shows bent cleavage and wavy extinction.

The *pegmatite* (318) occurs at the floor of the eastern face of the Nakkal Banda quarry, 1½ miles SW. of Kondapalli village. It is not seen in contact with either the khondalites or the charnockites and hence it is not certain into which rock type the pegmatite is intrusive. It is a very coarse-grained rock with quartz, plagioclase, biotite, and potassium feldspar as essential minerals, garnet and ore as subordinate minerals and with secondary calcite, myrmekite, and zircon in traces. Plagioclase (An_{35}) occurs in large grains, is not generally antiperthitic, shows feeble undulose extinction and, rarely, reversed zoning. Quartz when recrystallized shows normal extinction. Biotite is extremely pleochroic (from light brownish-yellow to deep brownish-black); wavy extinction and bent cleavage are common. Garnet may form rims around ore or may occur as individual grains occasionally having inclusions of ore and biotite.

Results and discussion

The apparent isotopic ages presented here for the biotites from the basic charnockite and khondalite are the lowest recorded for any Archaean rock or mineral from India (Holmes, 1955, and Sarkar and Saha, 1963) and incidentally younger also than the apparent age of the youngest pre-Cambrian (post-Delhi) pegmatites of 580±20 Myr as given by Aswathanarayana (1959). As the charnockites in general are considered on geological grounds to be of pre-Cambrian age, the present data must indicate that they were subjected to at least one subsequent metamorphism; it is only the last metamorphism that is reflected in these data. Hence it is concluded that while the original crystallization of biotites might have taken place in pre-Cambrian times, the present results could only indicate the magnitude of apparent ages (440–524 Myr) of the deformed biotites; the age of the deformation event or dislocation metamorphism must be 440 Myr or even younger (say 400

Myr). It would appear that this last metamorphism, which took place around the interval 440–400 Myr, corresponds to the latter part of Lower Palaeozoic times on the time scale of Kulp (1960). This 440–400 Myr metamorphism was probably responsible for loss of argon from the biotites of the basic charnockite and khondalite, thus bringing about an almost complete overprinting of the earlier geological events. This sort of overprinting is not unknown and has recently been demonstrated by Fitch, Miller, and Brown (1964) for the Moine and Dalradian rocks of the Scottish Highlands whose age patterns are probably due to overprinting of older metamorphic rocks by a (420–410) ± 10 Myr main Caledonian event.

Mineralogical and petrographic work suggests that the Kondapalli rocks have been subjected to a granulite-facies metamorphism and they in all probability are polymetamorphic. The observed reversed zoning in plagioclases of the charnockites and intense clouding in the plagioclases of the dolerite dykes of this area are suggestive of a change in physical conditions during the evolution of the Kondapalli rock types. In this connexion it is worth stressing that Fermor (1936, p. 51) and Krishnan (1960*b*, p. 124) envisaged that the rocks of the Eastern Ghats belt have been involved in regional deformation in pre-Gondwana times. Which of these episodes is specifically responsible for the argon loss in the dated biotites is difficult to decide in the present state of knowledge, but it is probable that the pre-Gondwana movements (deformation) could have been largely responsible for the present low ages.

Isotopic ages of the radioactive minerals from the pegmatites of different orogenic belts of Peninsular India and Ceylon were given by Holmes (1955), while recently the absolute ages of the minerals and rocks of the Singhbhum region were given by Sarkar and Saha (1963). The dated sequence of pre-Cambrian cycles of Peninsular India and Ceylon may be summarized as follows:

Balangoda group of Ceylon (and probably of Travancore) 485 Myr

$$\text{Delhi orogenic cycle}\begin{cases}580\pm20\text{ Myr}\\735\text{ Myr}\end{cases}$$

Satpura (? Aravalli) cycle 955 Myr ≡ Singhbhum orogeny 905–934 Myr

$$\begin{array}{lll}\text{Eastern Ghats orogenic cycle} & & 1570\text{ Myr}\\\text{Iron-ore orogeny} & & 2000\text{ Myr}\\\text{Dharwar orogenic cycle} & \begin{cases}\text{Upper}\\\text{Middle}\\\text{Lower}\end{cases} & \begin{array}{l}2300\text{ Myr}\\2450\text{ Myr}\\\end{array}\end{array}$$

Holmes (1955) has adopted 1570 ± 70 Myr as the closing age of the Eastern Ghats orogeny, on the basis of the age determination of detrital monazite from Satbhaya in Cuttack district (Orissa), by lead–uranium–thorium and by $^{207}Pb/^{206}Pb$ methods; Holmes discarded the 540 Myr of $^{208}Pb/Th$ age of this monazite as he considered that ^{208}Pb has been preferentially lost in considerable amount. Thus it would seem that the 400–440 Myr metamorphism that effected the Kondapalli rocks did not effect the Satbhaya monazite, assuming this metamorphism was prevalent throughout the Eastern Ghats belt. If these two sets of different ages represent two orogenies then there is a wide field for investigation in particular to determine whether or not any events between 1570 and 430 Myr are recorded in the Eastern Ghats belt.

Holmes (1955) has also given a 485 Myr age for the thorianites, a 540 ± 25 Myr age for the zircons of Ceylon and a crude age of 490 Myr for the cheralite from Travancore; he concluded that all these ages probably represent the same cycle. The present data on the Kondapalli biotites suggests the existence of this cycle in the Eastern Ghats belt as well. In fact Holmes (1955) has pointed out that it is possible for a branch of the Eastern Ghats belt (from north of Madras) to continue under the sea floor as an arc that comes to the surface again in the north-east and eastern parts of Ceylon; he further stated that the general sequence of Ceylon, omitting the doubtfully older gneisses, is practically identical with that of the Eastern Ghats belt, but with the addition of an important series of younger pegmatites. However, Holmes believed that the charnockites of Ceylon are very much older than 1050 Myr (which is the uncorrected age of zircon from beach sands derived in part from the charnockites), which he thinks is consistent with its geologically well-documented correlation with the rocks of the Eastern Ghats belt. Vitanage (1959) established that the pegmatites that cut the Vijayan rocks of Ceylon have apparent isotopic ages of the order of 500–600 Myr, whereas the Highland Series (assumed to be a continuation of the Eastern Ghats belt) was given a rough age of 1700 Myr (quoted from Cooray, 1962). Unfortunately the ages of the charnockites of the type area near Madras, which will be of the greatest use in elucidating the Eastern Ghats orogenic cycle, have not yet been determined. It is, however, unlikely that the age of the Madras charnockites will be significantly different from that of the Kondapalli basic charnockite.

It is not safe to compare the lead isotopic ages of the radioactive minerals, such as monazite from the beach sands or from the pegmatites representing the closing stages of an orogeny, with the absolute K/Ar ages of the biotites from the rock formations, even assuming that both types of minerals come from the same orogenic belt. But the possibility that a perfect agreement can exist for these two sets of data in a given region is disclosed by the recent studies of Sarkar and Saha (1963). These authors have given the K/Ar ages of the muscovites from the schists of the Chaibasa stage as 905 and 934 Myr representing the Singhbhum orogeny; these values are in such close agreement with the isotopic age of lead (955±40 Myr) from the uraninite of Singar in Gaya district, Bihar (Holmes, 1955), that they have correlated the Satpura cycle of Holmes with the Singhbhum orogeny.

It was surmised by Holmes and others that the Satpura belt, on the structural and tectonic evidence, is younger than the Eastern Ghats belt. The ages published so far from these two belts have substantiated this view and it has been claimed that the relative ages obtained from the tectonic evidence are consistent with the ages of the radioactive minerals. This principle now appears to be at variance with the isotopic ages obtained for the Kondapalli rocks. The Eastern Ghats belt (1570± 70 Myr of Holmes) stabilized much later than the Iron-ore orogenic belt (2000 Myr) as reported by Sarkar and Saha (1963), but before the Singhbhum orogeny (905, 934 Myr); the present results indicate that the Eastern Ghats belt was reworked (around 400–440 Myr), not only much later than the Iron-ore orogenic belt but even later than the Singhbhum (Satpura) orogeny. This conclusion can be accepted for two reasons: The ages obtained in both the cases are the K/Ar ages of the micas from the rocks—a situation that is ideal for comparison; and there is no evidence of any recrystallization of the mica in the mica schists of the Chaibasa stage after the close of the Singhbhum orogeny, as emphasized by Sarkar and Saha (1963). It is in this context that the present results are of significance in throwing new light on the geochronological sequence of the pre-Cambrians of Peninsular India.

Acknowledgements. We are grateful to Prof. W. A. Deer, F.R.S., for his constant advice and for critical reading of the manuscript. We also thank Dr. F. J. Fitch for discussion and comments on this paper.

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