K-Ar age of Ukra glauconites from the Kutch Basin, India

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The present paper reports the K-Ar ages determined on glauconitic samples collected from the Ukra Member of the Mesozoic Bhuj Formation in two different sections, one located on the Ghuneri-Ghaduli road near Katesar Mahadeo temple and the other at the base of the Ukra hill in the northwestern part of the Kutch Mainland area.

Three glauconite samples viz., $Ukra_{KT}$-1, $Ukra_{KT}$-4 and $Ukra_{UH}$-3 have yielded K-Ar ages of 107.9 ± 3.4 Ma, 105.5 ± 3.3 Ma and 103.5 ± 3.4 Ma, respectively. The sample $Ukra_{KT}$-1 treated with 0.5N HCl and analysed in duplicate has yielded a mean age of 104 ± 2.3 Ma while the sample $Ukra_{KT}$-4 treated with 0.1N HCl has given an age of 106.5 ± 3.3 Ma. The ages of the treated and untreated glauconites are indistinguishable within 2σ uncertainty with a mean of 105.2 ± 1.3 Ma, which has been interpreted as the depositional age of the Ukra Member of the Mesozoic Bhuj Formation. The study has further indicated that mild acid treatment (up to 0.5N HCl) does not lead to any loss of radiogenic argon in the glauconites and can be helpful in purification of the samples.

1. Introduction

Dating of stratigraphic sequences encountered in sedimentary basins is of paramount importance in the context of petroleum exploration, as it provides basic parameters for integrated basin analysis. K-Ar method is one of the most potential geochronological techniques available for dating rocks of sedimentary origin and has found wide applications in petroleum exploration. Authigenic minerals such as illites and glauconites formed within the sedimentary sequences provide excellent avenues for application of this geochronological technique, especially for inferring the time of deposition/young diagenetic events (Clauer *et al* 1986; Bonhomme 1987) and the time of petroleum migration and gas emplacement in the reservoirs (Sommer 1975; Aronson and Burtner 1983 and Lee *et al* 1985).

The lithological rock types in which authigenic glauconite is most common are calcareous sandstones and impure granular limestones etc. It may also occur as detrital glauconite in a wide range of sedimentary rocks, particularly if calcareous, since it is highly stable in alkaline conditions (Fairbridge 1967). The formation of glauconite is favoured by a low or even a negative sedimentation rate (Muller 1967). Such conditions together with other favourable environmental conditions, may be provided during a marine transgression, because of which the glauconite is commonly found associated with unconformities and other stratigraphic breaks (Goldman 1921). The two most commonly suggested processes of glauconitization are: (1) the "*layer lattice theory*" of Burst (1958a and b) and Hower (1961), which requires the presence of degraded micaceous clay minerals acting as a substrate for the newly formed Fe-rich glauconitic materials, and (2) the crystallization of automorphous crystallites in pores of any coprolite-like substrate, which is accompanied by progressive alteration and replacement of the substrate, as suggested by Odin and Matter (1981). In the latter process, the first automorphic particles formed are thought to be Fe-rich and K-poor smectites, which evolve later into K-rich glauconitic mica by incorporating K from the sea water. The transformation may take up to about one million years and depends on the availability of potassium and iron and on low accumulation rates.

In the present paper, we report the first K-Ar ages determined on the glauconites belonging to the Ukra

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Member of the Mesozoic Bhuj Formation from the Kutch basin of India.

2. Geologic setting

The Kutch sedimentary basin, extending from the Great Rann of Kutch in the north to the Kathiawar (Saurashtra) peninsula in the south, is typically a pericontinental embayed basin occupying a rifted graben (Biswas 1991). This pericratonic rift basin is characterised by well defined transgressive/regressive sequences which lasted till the end of Lower Cretaceous and a rugged topography featuring highlands of exposed Jurassic and Cretaceous rocks amidst the vast plains of alluvium covered Rann. The basin extends into offshore with a wide shelf platform and is filled with over 3000 m thick Mesozoic sediments followed by a thin ($\approx$ 900 m) Tertiary sequence (Biswas 1991). The Mesozoic rocks are exposed in six highland areas of Kutch (Mainland, Wagad, Pachham, Khadir, Bela and Chorar) whereas the Tertiary strata are exposed only in the bordering plainland (figure 1). In the Kutch Mainland area, a complete and thicker succession ranging from Middle Jurassic to Early Cretaceous is exposed. The Mesozoic sediments in this area are divided into four lithostratigraphic units viz. Jhurio, Jumara, Jhuran and Bhuj Formation ranging in age from Bathonian to Albian (Biswas 1977).

The generalised Mesozoic lithostratigraphy of Kutch Mainland is given in table 1. The Bhuj rocks are exposed extensively in the mainland, occupying about three-fourth of the total area of the Mesozoic outcrops, and are divided into Ghuneri, Ukra and Upper Member in western Kutch. The environment of deposition of Mesozoic sediments have been dealt at length by Krishna *et al* (1983), Howard and Singh (1985) and Biswas (1991). The Ukra Member of the Bhuj Formation, consisting mainly of fossiliferous glauconitic shale and sandstone, is a marine lithosome developed locally within the formation (Biswas 1977). Krishna *et al* (1983) and Howard and Singh (1985) have described the Bhuj Formation as a coastal shallow marine deposit based mainly on trace fossils and gross lithological characteristics. Biswas (1991) has further

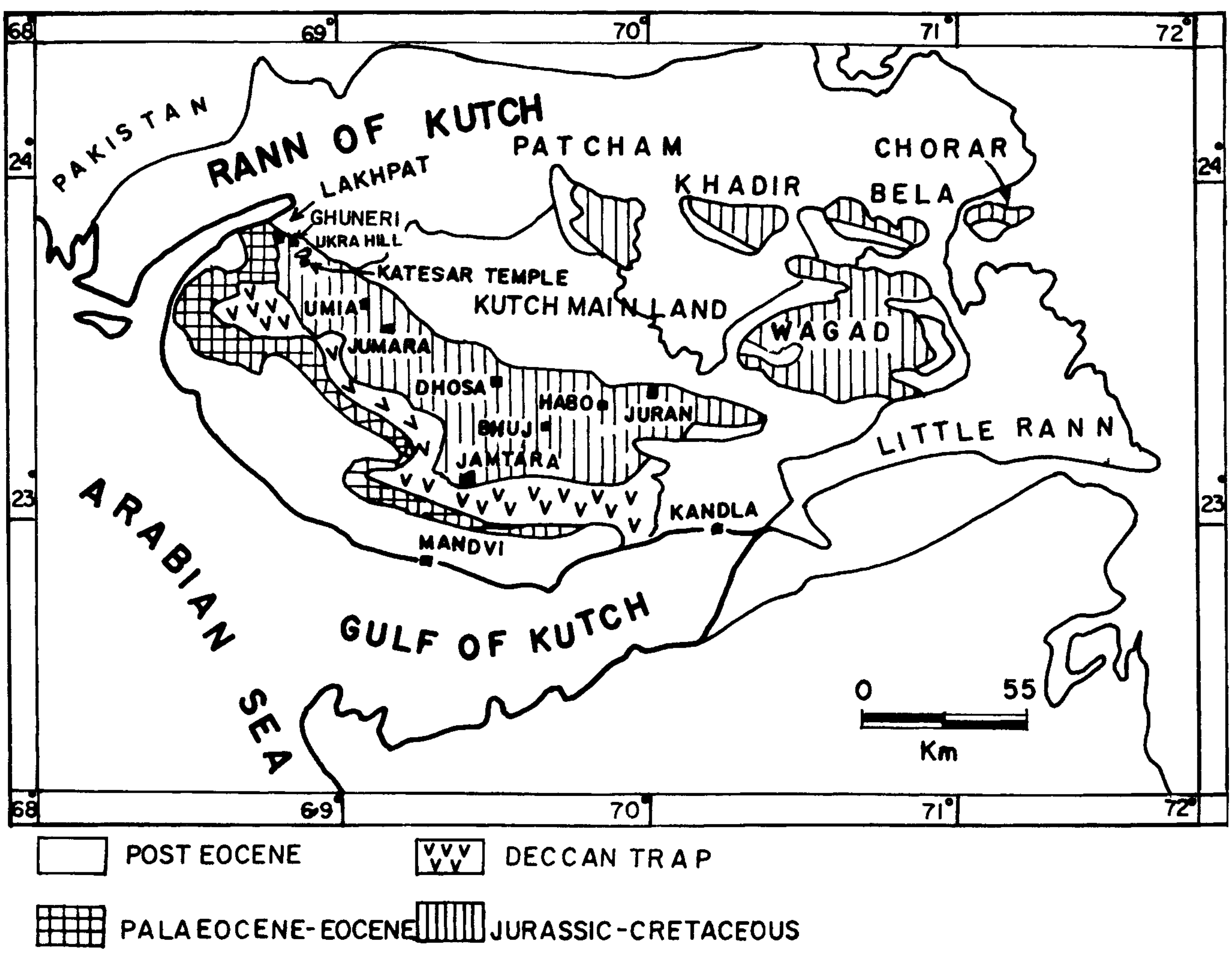

Figure 1. Simplified geological map of Kutch (Modified after Biswas 1977).

Table 1. *Generalised lithostratigraphy of Kutch Mainland area (after Biswas 1991).*

AGE	FORMATION	MEMBER	LITHOLOGY
NEOCOMIAN-ALBIAN	BHUJ	UPPER	CROSS BEDDED SANDSTONE WITH KAOLINITIC CLAYSTONE BEDS AND SANDY IRONSTONE BANDS
		UKRA	DEVELOPED ONLY IN WEST GLAUCONITIC SANDSTONE AND SHALES, FOSSILIFEROUS
		GHUNERI OR LOWER	RHYTHMIC SEQUENCE OF SANDSTONE-SHALE-IRONSTONE BANDS ABUNDANT, PLANT FOSSILS
	·DISCONFORMITY		
	JHURAN	KATESAR	CROSS BEDDED SANDSTONE WITH CALC. BANDS, LOCALLY FOSSILIFEROUS, DEVELOPED IN WEST ONLY
KIMMERIDGIAN TO TITHONIAN		UPPER	THINLY BEDDED SANDSTONES CALCAREOUS, FOSSILIFEROUS
		MIDDLE	MAINLY SHALES FOSSILIFEROUS
		LOWER	SHALE/SANDSTONE ALTERATION, FOSSILIFEROUS
	·DISCONFORMITY		
OXFOR-DIAN	JUMARA	DHOSA OOLITE	SHALES WITH OOLITIC LIMESTONE BANDS, FOSSIL.
CALLOVIAN		MIDDLE	SANDSTONE IN THE EAST, LIMESTONE WITH GOLDEN OOLITE IN THE WEST
		LOWER	OLIVE GREEN SHALES, FOSSILIFEROUS
	JHURIO	UPPER	BEDDED LIMESTONE
BATHONIAN		MIDDLE	SHALE INTERBEDDED WITH GOLDEN OOLITIC LIMESTONE
		LOWER	INTERBEDDED LIMESTONE/ SHALES
PRECAMBRIAN BASEMENT			

suggested marine tongue in a deltaic sequence signifying transgressive break in a prograding delta for this Member. The presence of glauconite in the Ukra Member indicates deposition in littoral to neritic zone under reducing conditions.

3. Sample details

The type section of Mesozoic Bhuj Formation is exposed on the banks of the Rukmavati river near the village Jamtara (23°06′20″ : 69°28′17″) and is disconformably overlain by the Deccan Trap. The lower contact with the Jhuran Formation is gradational and is defined by the boundary between marine and non-marine rocks. The occurrence of the Ukra Member, which forms the middle part of the Bhuj Formation, is restricted and is best exposed at two places, one along the roadside near the Katesar Mahadeo temple on Ghuneri-Katesar road and the other at the base of the Ukra hill (23°45′30″ : 68°51′55″) near village Ghuneri, east of Lakhpat. Glauconite samples used in the present study were collected from both the localities. Four samples ($Ukra_{KT}$1–4) were collected from the bottom to the top of the Katesar temple section, consisting of about 90 cm thick friable glauconitic sandstone, which is underlain by a red ferrugenous band. Additionally, four samples were also collected from and around the main Ukra hill ($Ukra_{UH}$1–4). One of these samples i.e. $Ukra_{UH}$-4 was collected from a location about 300 m SW of the hill while the remaining three samples i.e. $Ukra_{UH}$1–3 were collected from the base of the Ukra hill.

4. Methodology

Glauconite rich portions from selected samples were crushed in a mortar and pestle and were sieved in the range of 50 to 100 mesh. The sieved samples were repeatedly washed with triple distilled water and were subjected to ultrasonic treatment for cleaning the cracks developed during the growth of glauconitic minerals. The highly evolved glauconite sometimes shows a thin external film covering the grains. This film is composed of less evolved glauconitic minerals (Lamboy and Odin 1975) and can easily be removed by ultrasonic treatment. Routinely, we used two agitations of 5–10 minutes duration each with a careful washing with triple distilled water between each agitation. After ultrasonic treatment, the samples were dried at low temperature of about 60°C. Initial separation of glauconite was done using the magnetic barrier separator (Model LB-1) as per the procedure standardized in house which was followed by heavy liquid separation. The final purification was done under an optical microscope by removing the impurities through hand picking.

Potassium was measured on a Systronic *Mediflame 127* flame photometer. The accuracy of K-measurement, monitored using a glauconite standard GL-O (Odin *et al* 1982), was found to be better than ±1.5%. The amount of ^{40}K was calculated from the known isotopic abundance of K, i.e. $^{40}K/K = 0.0001167$ (Steiger and Jager 1977). Argon isotopic analyses were performed under static condition on a Micromass 1200 Noble Gas Mass Spectrometer as per the procedure, standardised by Rathore *et al* (1993). The samples were pre-heated overnight at about 80°C to remove adsorbed atmospheric argon. Total duration involved in the extraction and purification process of the argon from the sample was approximately two hours. The measured isotopic abundances were extrapolated to time "t_0", i.e. the time when the gas was introduced into the mass spectrometer. Every sample was preceded and followed by a hot blank, which was

Table 2. *Analytical data and calculated K-Ar ages of glauconites from the Ukra Member of Bhuj Formation, Kutch Basin.*

Sl. No.	Sample No.	Sample Location	K (wt %)	Total ^{40}Ar (x 10^{-7} cc STP g^{-1})	Rad ^{40}Ar (x 10^{-7} cc STP g^{-1})	Age (± 2σ) Ma
1	$Ukra_{KT}$-1N	Katesar Temple	5.42	304.56	234.08	107.9±3.4
2	$Ukra_{KT}$-1A	Katesar Temple	5.42	291.42	226.36	104.4±3.2
3	$Ukra_{KT}$-1AD	Katesar Temple	5.42	301.84	224.39	103.6±3.2
4	$Ukra_{KT}$-4N	Katesar Temple	5.64	281.16	238.11	105.5±3.3
5	$Ukra_{KT}$-4B	Katesar Temple	5.64	284.93	240.43	106.5±3.3
6	$Ukra_{UH}$-3N	Ukra Hill	5.91	259.63	244.51	103.5±3.4
7	GL-O$	-	6.46	298.408	243.086	94.3±2.8

Note: N - Untreated Sample, A - Sample treated with 0.5N HCl, B - Sample treated with 0.1N HCl, D-Duplicate Analysis and $ - Glauconite standard with a reported age of 95.03±1.11 Ma (Odin et al. 1982) carried out following the same procedure as that of the sample. An average of pre and post-hot blank was used for the blank corrections. The typical ^{40}Ar blank in the present study was 5.6×10^{-9} cc STP.

5. Results and discussion

The analytical data on three glauconite samples, two from Katesar road section near Mahadeo temple and one from Ukra main hill, are given in table 2. Errors are quoted at 2σ level. Three untreated samples, viz., $Ukra_{KT}$-1, $Ukra_{KT}$-4 and $Ukra_{UH}$-3, have yielded K-Ar ages of 107.9 ± 3.4, 105.5 ± 3.3 and 103.5 ± 3.4 Ma, respectively. These ages are indistinguishable within 2σ error and give a mean age of 105.6 ± 1.9 Ma. Some of the glauconite samples were also treated with 0.1 N and 0.5N HCl to see the effect, if any, of the acid treatment on K-Ar ages. One of the samples, $Ukra_{KT}$-1, treated with 0.5N HCl and analysed in duplicate ($Ukra_{KT}$-1A and $Ukra_{KT}$-1AD) to check the consistency of the results, have yielded a relatively lower but concordant ages of 104.4 ± 3.2 and 103.6 ± 3.2 Ma, respectively, which are indistinguishable from that of the untreated sample within the experimental error (table 1). Another sample, $Ukra_{KT}$-4, treated with 0.1N HCl, has yielded an age of 106.5 ± 3.3 Ma (table 2) which is in concordance with the age of the untreated sample i.e. 105.5 ± 3.3 Ma. These results indicate that mild acid treatment (up to 0.5N HCl) does not lead to any argon loss and can safely be used for purification of glauconites, especially for dissolution of carbonate impurities. It is also apparent that all the analysed glauconites, both treated and untreated, yield mutually indistinguishable ages within 2σ error with a mean of 105.2 ± 1.3 Ma. A glauconite standard (GL-O), analysed during the study to check the accuracy of the measurements, has yielded an age of 94.32 ± 2.8 Ma (table 2) against its reported age of 95.03 ± 1.11 Ma (Odin *et al* 1982).

The reliability of isotopic dates, both by Rb-Sr and K-Ar method, of glauconites for the determination of stratigraphic ages has often been questioned due to lack of precise knowledge of the apparent age of this mineral at the time of deposition. Additionally, the glauconites are commonly suspected of containing detrital precursors, of undergoing post depositional loss of radiogenic ^{40}Ar and ^{87}Sr, and of experiencing post depositional modifications in their K and Rb content (Clauer *et al* 1992). Therefore, for correct interpretation of isotopic dates obtained from glauconites, a very careful and detailed sedimentological study must be carried out which may help in understanding the genesis of the glauconites.

We carried out XRD analysis of the glauconites, used for dating in the present study, to know their characteristics as well as genesis. The XRD patterns thus obtained are shown in figure 2, which also includes that of the glauconite standard, i.e. GL-O (Odin *et al* 1982) for the purpose of comparison. Characteristic peaks of mineral glauconite at 10.11, 4.511, 3.324 and 2.57 Å are present in all the samples. A careful study of the XRD patterns suggests that the glauconites under investigation are evolved (Odin and Matter 1981) and fall in the category of well ordered, non-swelling, and high potassium type mineral glauconite in sensu stricto (Burst 1958 a,b). The patterns are also similar to those obtained by Bentor and Kastner (1965) for class I mineral glauconites having well ordered 1M polymorphic form which is typical of low temperature formation of the lattice and which is also suggestive of authigenic formation of the mineral (Velde 1965).

Glauconites with very poor potassium content often give too high radiogenic ^{40}Ar for their probable age (Owens and Sohl 1973). Ghosh (1972) measured argon content in four glauconites with various K contents (0.77 to 4.55%) from the Weches Formation of Middle Eocene of the Gulf Coast Province and found the ages ranging from 136 to 46.5 Ma and that the probable age (ca. 40–45 Ma) was only approached by the most K-rich sample, which had reached only a slightly evolved stage. Adams (1975) has also reported similar age behaviour in the Early Miocene glauconites from New Zealand. It has, therefore, been inferred that argon is inherited from the initial substrate in the glauconite, and this inheritance decreases as the potassium content of the glauconite increases.

Odin (1982), on the basis of agreement between isotopic dates and stratigraphic ages of glauconites from different regions e.g., Guinea, California and Senegal, suggested that even for glauconites developed from a ^{40}Ar-rich substrate, the initial argon ratio becomes normal whose potassium content is equal to or greater than 6.5% K_2O. Therefore, the glauconites with $\geq 6.5\%$ K_2O are approximately in equilibrium with the depositional environment and provide a stratigraphically meaningful K-Ar age. However, if the initial substrate is free from radiogenic argon, for example a carbonate, then its initial apparent age is zero and it is supposed to give a meaningful age whether the evolution has reached a nascent, a slightly evolved or an evolved stage. All the samples used in the present study have K_2O content more than 6.5%. Further, Odin (1982), suggested an inverse age relationship with potassium content during the process of glauconitization. However, in the present study the age difference between the analysed samples is not appreciable and cannot be distinguished within experimental error. Based on the mean age obtained for the glauconites, we therefore, assign an average stratigraphic age of 105.2 ± 1.3 Ma to the Ukra Member, which had earlier been assigned biostratigraphic age of Lower Albian to Aptian (Pascoe 1959; Krishnan 1968; Biswas 1971; 1977). Recently, based on ammonoid studies, Krishna (1994) has suggested Late Aptian (Australiceras) to Early middle Albian (Lemuroceras)

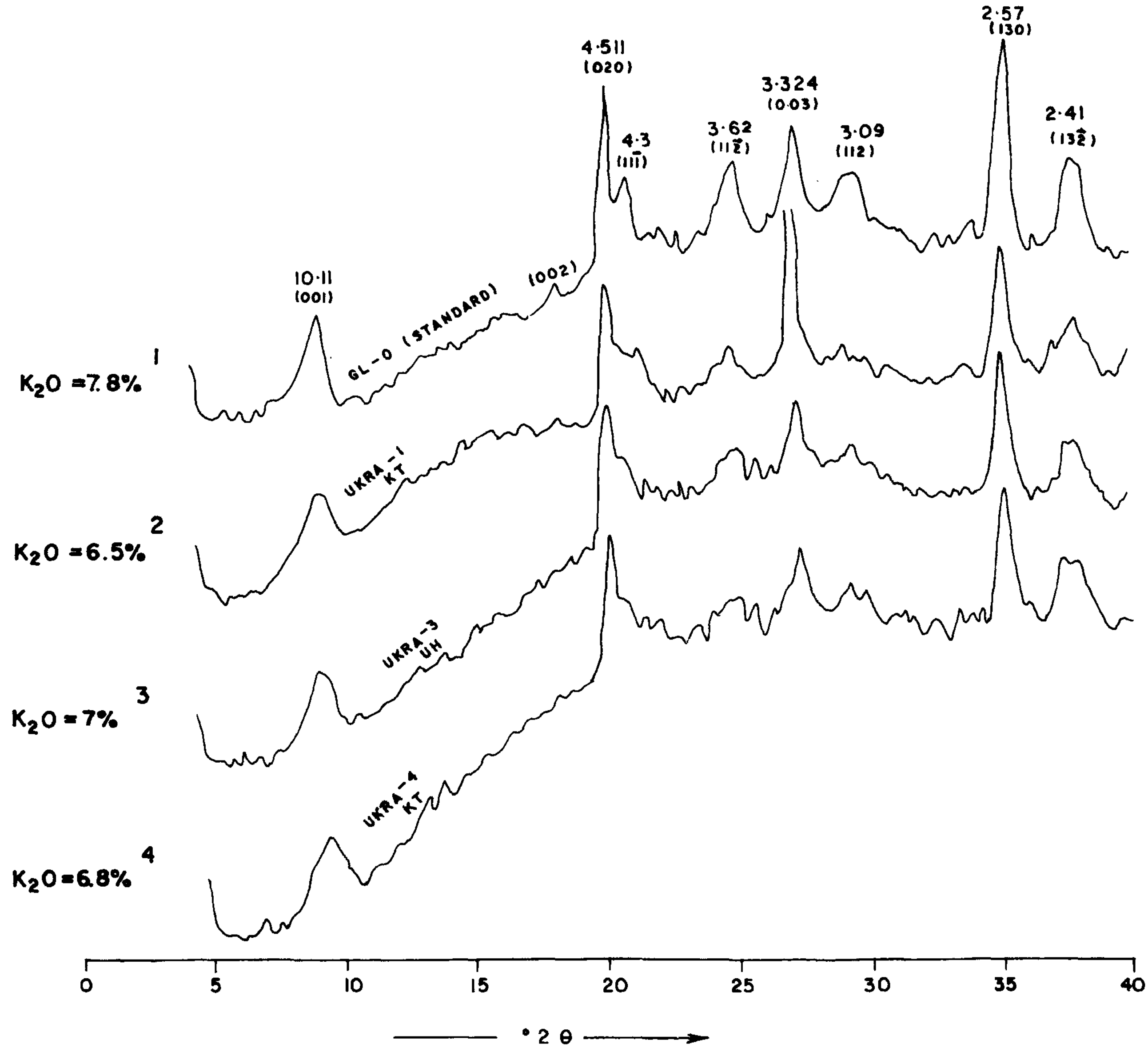

Figure 2. X-ray diffractograms of powder mounts of glauconites of Ukra Member, Kutch.

age for the Ukra Member. No reliable radiometric age is available for this Member except for a fission track (F-T) age of 112 Ma for the basal glauconite of this member reported by Krishna (1994). However, due to greater uncertainties involved in the F-T ages, the lone reported age of 112 Ma should be accepted cautiously. The K-Ar ages obtained in the present study from two different sections of the Ukra Member are indistinguishable and provide the first quantitative age estimation to this Member. The mean age of 105.2 ± 1.3 Ma obtained in the present study has been interpreted as the formation/deposition age of the glauconites of the Ukra Member.

6. Conclusions

We report the first K-Ar ages on the glauconites from the Ukra Member of the Mesozoic Bhuj Formation of the Kutch Basin, India. The studied samples from two different sections, i.e. one near the Katesar Mahadeo temple on Katesar-Ghaduli road and the other from the Ukra main hill, have yielded concordant ages with a mean age of 105.2 ± 1.3 Ma. This age, interpreted as the time of glauconitization, can be considered as the average stratigraphic age of the Ukra Member. The study has further indicated that mild acid treatment (up to 0.5N HCl) on the glauconites does not cause any loss in radiogenic argon and may be helpful in purification of the samples.

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