Interpretation of Potassium-Argon isotopic data related to metamorphic events in South-Western Alps

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Interpretation of Potassium-Argon Isotopic Data Related to metamorphic Events in South-Western Alps

by *Michel G. Bonhomme**, *Pierre Saliot*** and *Yves Pinault**

Abstract

Potassium-argon data have been determined on fractions smaller than 2 microns along the Avignon-Briançon traverse in two stratigraphic horizons: the Rhetian and the Oxfordian. The non-metamorphic Rhetian suffered a late diagenesis at 155 ± 9 M.Y. The non-metamorphic Oxfordian shows the stratigraphic age: 163 ± 6 M.Y. and inheritage of ^{40}Ar. The K-Ar apparent ages of fine fractions generally decrease with increasing metamorphic grade as is shown by the increasing crystallinity of illites. In the polymetamorphic alpine history an additional factor governing the K-Ar system is the chemical composition of the micas, as it represents the thermodynamic conditions which occured during crystallization. All the studied samples, except the radiolarite boulders of Oligocene deposits at Barrême, have suffered the effects of the phase of relatively high temperature. The K-Ar system of the radiolarites was preserved and show the age of the phase of high pressure, i.e. 85,4 ± 3,5 M.Y.

Résumé

L'analyse potassium-argon a été effectuée sur des fractions inférieures à deux microns prélevées le long du profil Avignon-Briançon dans deux horizons stratigraphiquement bien définis, le Rhétien et l'Oxfordien. Le Rhétien non métamorphique a subi une diagenèse tardive à 155 ± 9 MA. L'Oxfordien non métamorphique montre l'âge stratigraphique: 163 ± 6 MA et la trace d'héritage isotopique d'argon. L'âge mesuré dans la zone de métamorphisme croissant décroît. L'indice de cristallinité de l'illite, retenu comme premier critère d'intensité du métamorphisme, se révèle insuffisant. Dans un lieu donné, le critère déterminant pour la géochimie isotopique de l'argon donc pour l'âge est la composition chimique des phyllites analysées, représentative des conditions thermodynamiques ayant régné lors de leur formation. Ainsi, à cause de leur chimisme particulier, les phengites des galets de radiolarite de l'Oligocène de Barrême ont conservé l'âge de leur formation lors de la phase de haute pression, soit 85,4 ± 3,5 MA.

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A. Introduction

The paper reports the results of analyses by potassium-argon method of two particular features of the evolution of the southwestern Alps: the influence of increasing metamorphism on the apparent ages of sedimentary formations; and the age of boulders from the ophiolitic series deposited in the Oligocene basin at Barrême.

The general geological outline of the Western Alps has been defined by DEBELMAS and LEMOINE (1970), TRÜMPY (1973), DEBELMAS (1974 and 1975), and FREY et al. (1974) who summarized geochronological results. The results presented in this paper have been obtained from samples from the Briançon-Avignon profile. The tectonic and paleogeographical aspects of the central part of this profile have recently been reassessed in great detail by CARON (1977).

1. PETROGRAPHY

The study of mineral paragenesis originating from the alpine metamorphism in the Western Alps (e.g. KIENAST and VELDE ‹1970›, SALIOT ‹1973 and 1978›, BOCQUET et al. ‹1974›) has led to a global scheme of metamorphic evolution. The effects of that evolution in sedimentary formations have been studied by DUNOYER de SEGONZAC (1969), ARTRU (1972), Barlier (1974) and ABBAS (1974).The petrographic analysis of the Oligocene boulders in Barrême has been presented by DE GRACIANSKI et al. (1971).

The results indicate essentially three metamorphic domains:
- blue schist paragenesis with jadeite, lawsonite and glaucophane mainly in the so-called «séries piémontaises»;
- greenschist facies paragenesis which are superimposed onto those of glaucophane facies, mainly in the more western units;
- and parageneses of very low grade metamorphism can be observed toward the West, between those already mentioned and the non-metamorphic domain.

The three metamorphic assemblages are related to three successive periods of intense deformation which can be observed in the Avignon-Briançon traverse of the Alps:
a) During a period of high pressure and low temperature conditions the jadeite, lawsonite and glaucophane paragenesis was generated. Geological evidence indicates an age for this episode of upper Albian to upper Cretaceous and possibly even Paleocene (LEFEVRE and MICHARD,1976).
b) Greenschist facies conditions with lower pressure and relatively higher temperature prevailed during the late Paleocene to early Oligocene time. How-

ever, in the central part of the «Schistes lustrés» zone, high pressure conditions were maintained and lawsonite and glaucophane recrystallized.

c) The last period of metamorphism occured during the lower Miocene to Pliocene. It caused very low grade metamorphism in the Champsaur sandstones (zeolite facies).

However, the distinction of these episodes in time is not well defined. In fact, the mineral crystallizations and recrystallizations appear as a continuous process marked by pulses (CARON, 1977, and LEFEVRE and MICHARD, 1976).

2. GEOCHRONOLOGY

There are relatively few papers concerned with the geochronology of the south-western Alps: BERTRAND (1970), DAL PIAZ et al. (1972), SCHEURING et al. (1974), HUNZIKER (1974), BOCQUET et al. (1974) and DELALOYE and DESMONS (1976).

From summarizing the previous publications, it follows that:

- the high pressure episode took place 100 to 80 M. A. ago;
- the high temperature metamorphism occurred 40 to 34 M. A. ago;
- the post-oligocene phase, the least well defined, has an age between 30 and 15 M. A.

B. Sampling

As the previously mentioned studies were devoted mainly to the innermost part of the chain, it was considered important to analyze the variation of the age of the clay fraction in the same sedimentary horizon along a profile going from the non-metamorphic zone to the most highly metamorphosed zone. The same type of work has been done by FREY et al. (1973) on glauconitic sediments from central Switzerland. The youngest phases of metamorphism cause a partial or total loss of radiogenic products and thus prevent the correct dating of the previous tectonic phases (see HUNZIKER, 1974, and BOCQUET et al. 1974). Dating the pebbles of the Oligocene basin in Barrême might provide a solution to this problem as they have not suffered the effects of this latest metamorphic episode.

Because of these considerations, it was decided to undertake a geochronological study along:

(1) a West-East profile in the Rhetian, from the eastern border of the French Massif Central towards Sestriere (Italy) where the easternmost outcorp of undoubted Rhetian occurs. This profile follows an increasing grade of metamorphism from a region where metamorphism is absent up to an area, in the «Schistes lustrés» zone, where greenschist facies conditions were reached.

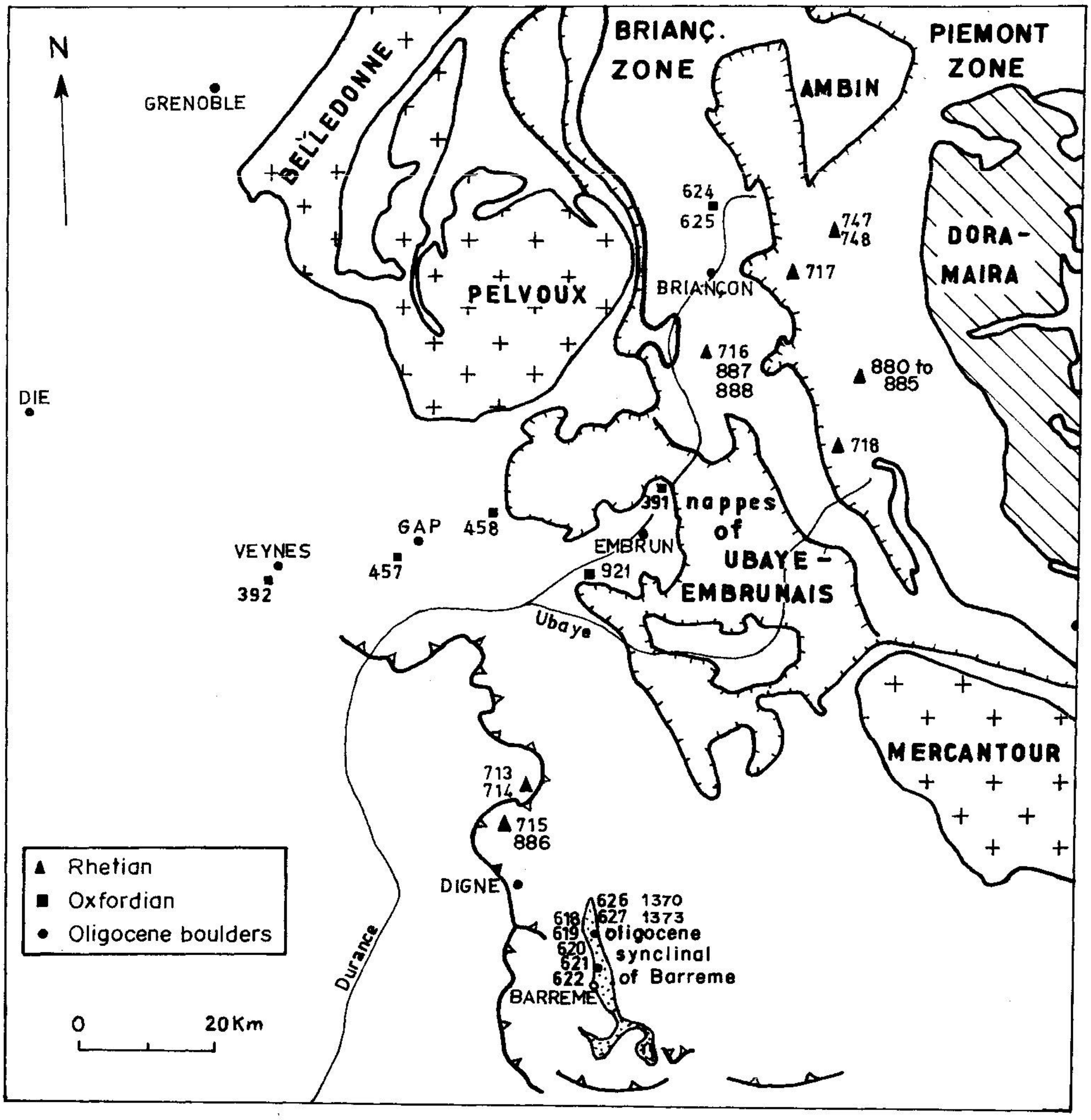

Fig. 1 Western Alps geological sketch map and sample localisation.

(2) a similar profile in the upper Jurassic (Terres Noires) from Veynes to the north of Briançon.

(3) additional pebbles in the northern part of Oligocene basin of Barrême. They are representative of various facies of the metamorphosed ophiolitic series, and include samples of radiolarite.

The sample localities are shown in figure 1.

C. Experimental

The instrumentation and analytical techniques are described in detail by PINAULT (1974) and BONHOMME et al.(1975).

The analysed samples are granulometric fractions. Two types of fractions were studied: the fraction finer than 2 microns in the sedimentary or slightly metamorphosed rocks, the sieved fraction of the total rock selected between 250 and 500 microns from the pebbles. The less than 2 microns fraction, extracted by the method described in «Mise au point collective» (1979), is representative of the true clay fraction. The fraction between 250 and 500 microns is considered as representative of the total rock. The size limits have been chosen because they are sufficiently coarse to minimize argon loss during the crushing and small enough not to be disturbed through sample inhomogenity using sample amounts of only 0,5 g.

Potassium determinations were made by atomic absorption spectrometry (KREMPP, 1969).

Argon was determined by isotopic dilution using a ^{38}Ar volume calibrated with inter-laboratory standards. Gases were extracted by inductive heating using an aperiodic supply (KIEFFEL, 1973), then purified twice by cold traps and titanium sponge at 800 °C. Isotopic ratios were determined in the mass spectrometer under static conditions. Many of the argon analyses were repeated in order to assess equipment isotopic accuracy.

The constants used are those of the Sydney International Geological congress (STEIGER and JAEGER, 1977).

40 K/K	= 0,001167%	(GARNER et al., 1976)
λ_β	= 4,962 10^{-10} an^{-1}	(BECKINSALE and GALE, 1969)
$\lambda_\varepsilon + \lambda_\varepsilon'$	= 0,581 10^{-10}an^{-1}	(GARNER et al., 1976)

The interlaboratory standards gave the following contents of radiogenic argon:

biotite	4B	5.37 ± 0,07 (lσ)	10^{-6} cc STP/g	11 analyses
muscovite	4M	6.23 ± 0,14 (lσ)	10^{-6} cc STP/g	11 analyses
glauconite	Gl-O	24.92 ± 0,15 (lσ)	10^{-6} cc STP/g	22 analyses
muscovite	P207	28.15 ± 0,78 (lσ)	10^{-6} cc STP/g	5 analyses

D. Results and discussion

Analytical results are presented in Table I.

1. RELATIONS BETWEEN STRATIGRAPHY AND GEOCHRONOLOGY DATA

a) The Rhetian

- Results

The age obtained on the two samples of the Rhetian in Corbes on the eastern border of the French Massif Central is 155 M.A. This result is much younger than the results of 190-195 M.Y. (HOWART, 1964) and 208 M.A. (ARMSTRONG and MCDOWALL, 1974) for the top of the Rhetian. The ages calculated on the two samples from Barles are almost the same, namely 142 M.A. and 156 M.A. A 40Ar/36Ar-40K/36Ar-diagramm (MCDOUGALL and STIPP, 1969; RODDICK and FARRAR, 1971) (figure 2) shows a fairly good alignement for three of these four samples with an initial ratio $(40Ar/36Ar)_0 = 305 \pm 91$ ($\pm 2\sigma$). The calculated age is 155 ± 9 M.A. ($\pm 2\sigma$) (fig. 2).

- Discussion

ESQUEVIN and MENENDEZ (1972) reported three similar Rb-Sr ages for the fine fractions of Carboniferous samples collected in the Mistral 1 drill hole offshore of Languedoc. They attributed the isotopic redistribution to an anchimetamorphic transformation of the illites without being sure if the age was really reflecting this event.

BELLON et al. (1973) obtained an age of 167 M.A. for the fine anchimetamorphic fraction of a Saxonian pelite from Lodève basin (the stratigraphic age: 240

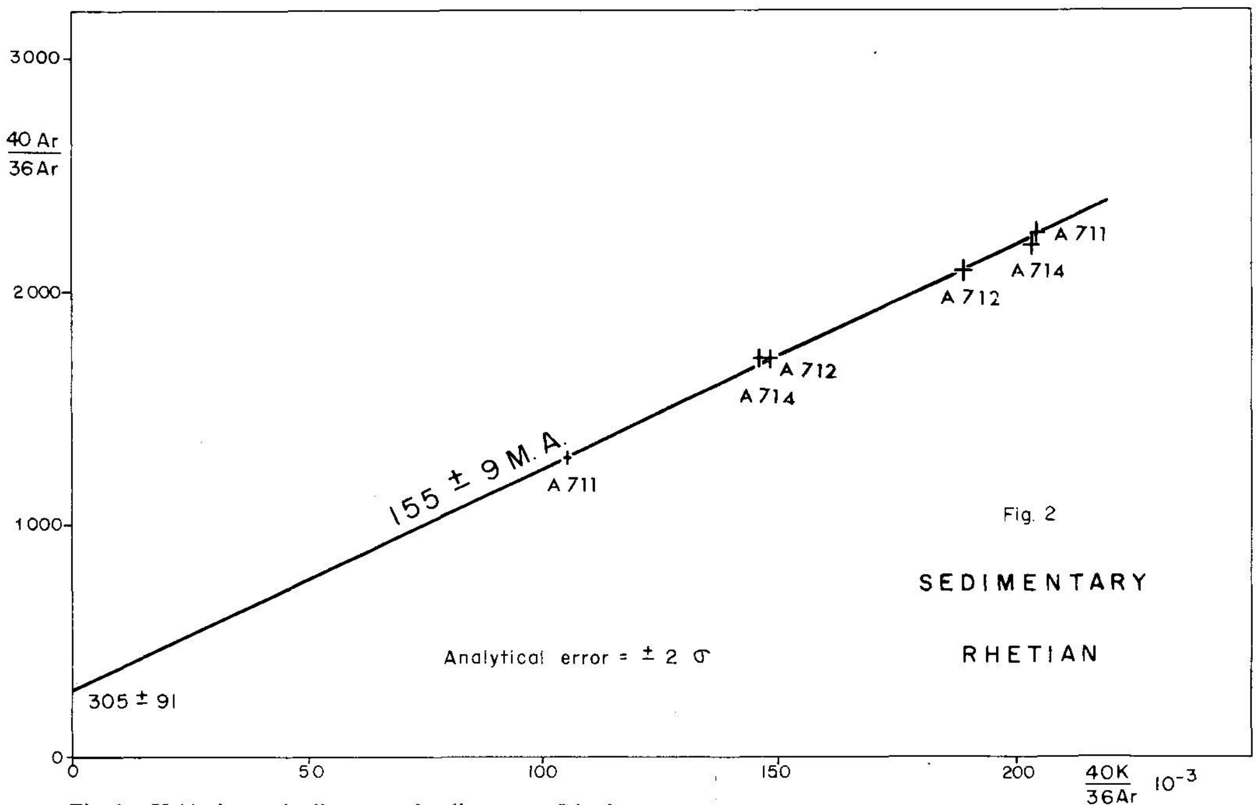

Fig. 2 K/Ar isotopic diagram of sedimentary Rhetian.

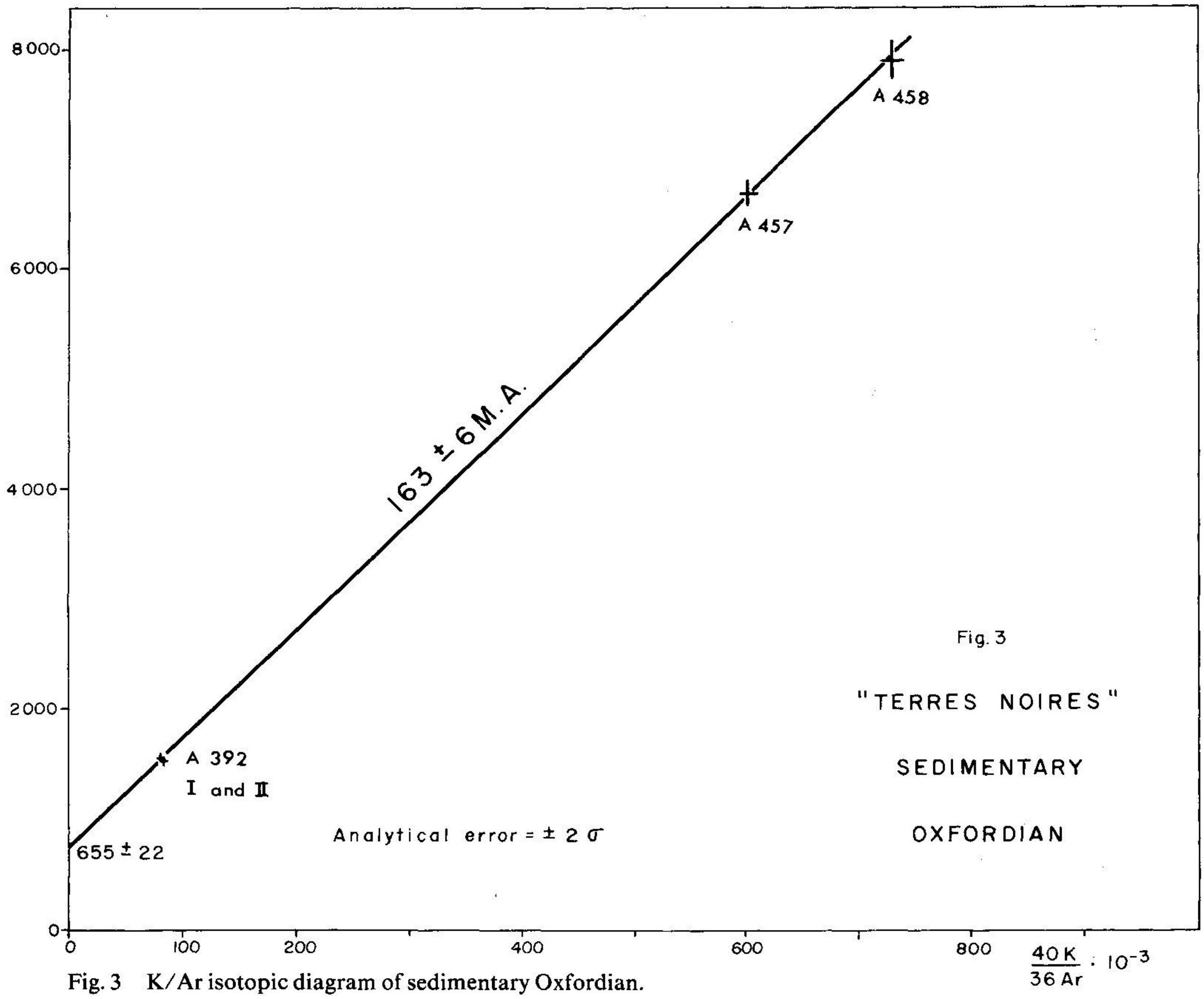

Fig. 3 K/Ar isotopic diagram of sedimentary Oxfordian.

M. A.), collected a few meters from a recent basaltic intrusive formation. However, the proximity of that intrusion could have led to both a mineralogical transformation and a partial argon loss.

Thus the ages obtained on sedimentary formations older than Lias in the western peri-mediterranean basin are too young. Such deviations from the sedimentary age are generally related to late diagenesis or low-grade metamorphism. As there is no tectonic or metamorphic episode of that age known in the area, (ROUIRE and ROUSSET, 1973, MATTAUER and PROUST, 1962) the age of 155 M. A. might be attributed to a late diagenesis.

b) The case of the Jurassic «Terres Noires»

The conventional ages obtained on the non-metamorphic «Terres Noires» formation show too old values for the upper Jurassic. For instance, in Veynes, the age is 230 M.A. On a 40K/36Ar-40Ar/36Ar-diagramm, the 4 points of the 3 samples fit on a straight line the slope of which indicates an age of 163 ± 6 M.A. with 40Ar/36Ar intercept of 655 ± 22. (fig. 3) Such an initial ratio confirms excess 40Ar heritage, due to the presence of detritus. The clay mineral fraction includes kaolinite and thereby suggests that also the fine fraction is detritic (ARTRU, 1972, BARLIER, 1974, CLAUER, 1976). Other instances of such argon isotopic anomalies in the clay fraction have been observed by BONHOMME et al. (1978). In case of argon isotope equilibration during sedimentation, the slope of the line at the time of sedimentation is equal to zero. Thus the slope of the line is a measure of the time of sedimentation. The age of 163 M.A. for the «Terres Noires» is compatible to the age of deposition. ARTRU (1972) indicates that the end of sedimentation of the «Terres Noires» facies took place before the middle Oxfordian, i.e. 155 M.A. following HOWARTH (1964), 163 M.A. according to ARMSTRONG and MCDOWALL (1974) or 155 M.A. following ODIN (1975). Our result is well included between the limits of error.

2. ARGON ISOTOPIC GEOCHEMISTRY AND PROGRESSIVE METAMORPHISM

As demonstrated by KUBLER (1966) and DUNOYER DE SEGONZAC (1969), a relation exists between the intensity of weak metamorphism and the width at half the height of the 10 Å peak of illite, i.e. the so-called crystallinity index. On the figure 4, the ages of the analysed illites have been plotted versus their crystallinity index. With the apparatus used in Strasbourg, the limit between diagenesis and anchimetamorphism is put et 5,75 and the limit between anchimetamorphism and epimetamorphism is placed et 3,5. The reference lines at 155 M.A. for the Rhetian and at 163 M.A. for the «Terres Noires» allow to distinguish the samples free of alpine influence from those which were affected by the alpine metamorphism.

- Results

Figure 4 shows that the age of the fine fractions decreases markedly when the illite crystallinity increases. The better the crystallinity, the lower the index. The age is already modified before the limit between diagenesis and anchizone is reached as may be seen, for instance, in sample 713 in the Rhetian. Due to smaller $\frac{I_{1002}}{I_{001}}$ ratio, A 713 is more sensitive to diagenetic transformation than A 714. Its smaller crystallinity index also shows that it has been more affected by diagenesis. The diminution of the apparent age corresponds to a diminution of the $\frac{40\,Ar\,rad}{40K}$ ratio, that is, either to a loss of radiogenic argon, or to a gain of potassium. The illite part of the fine fraction, assuming that it contains all the potassium, shows a 20% increase of the potassium concentration. This corresponds to the

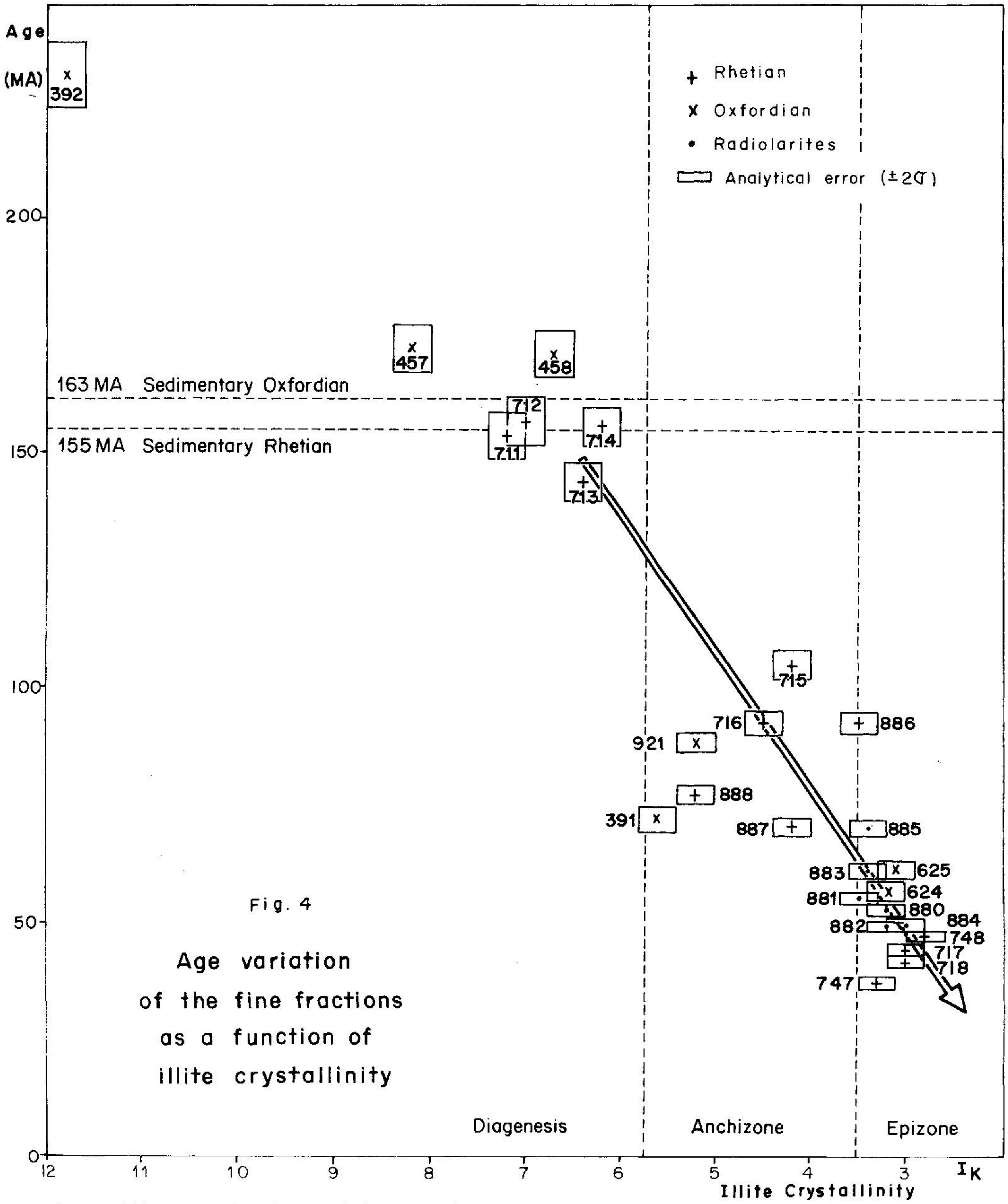

Fig. 4 K/Ar conventional age variation versus illite crystallinity.

observed transformation from sedimentary illite to metamorphic phengite and is not sufficient to account for the actual diminution of the apparent age. The decrease of the crystallinity index and the decrease of the age do not show a simple correlation. The points scatter widely. For instance, the fine fractions with crystallinity indexes between 3 and 3,5 (the analytical uncertainty on the index measurement is ± 0,2) have ages between 95 and 38 M.A. The six fine fractions, collected on the Gondran crest, within a distance of less than 100 m., and within an horizon of nearly one meter, give ages between 72 and 51 M.A. for a cristallinity index of between 3 and 3,5.

- Discussion

The great variation of the ages for similar crystallinity indexes shows that the crystallinity is not the only factor which governs the behaviour of the potassium-argon system.

ESQUEVIN and MENENDEZ (1972) and BONHOMME (1976) have been able to relate the argon loss and ability for strontium isotopic homogeneization to the chemistry of the aluminous or ferro-magnesian illites, as determined by the ratio of the heights of the 5 Å and 10 Å peaks, $\frac{I_{002}}{I_{001}}$ (ESQUEVIN, 1969). That ratio is lower than 0,25 for the ferro-magnesian illites, and greater than 0,4 for the aluminous ones. The more ferromagnesian types with a biotitic character, are generally more affected by rejuvenation than the more aluminous ones with a muscovitic character. This relation, however, is not applicable to illites which suffered the complex history of alpine metamorphism.

To further persue these relations, two fine fractions of Sestrière material have been studied in detail. Their characteristics are:

Sample	Crystallinity index	$\frac{I_{002}}{I_{001}}$	Age (M.A.)
A 747	3,3	0,50	38,2 ± 1,2
A 748	2,8	0,60	48,8 ± 1,3

These results confirm that the two above mentioned relations are not valid.

The microprobe analysis and the petrographic study done by one of us (P.S.) demonstrated that the two samples contain a phengitic mica which is to a high degree substituted by a magnesian celadonite: the analytical technique and accuracy are explained in detail in SALIOT (1978). The results are as following:

747 (1) $(Si_{3,520}Al^{IV}_{0,480}O_{10})$ $(Al^{VI}_{1,490}Fe^{2}_{0,040}Mg_{0,450})$
$(K_{0,876}Na_{0,017})(OH)_2$

748 $(Si_{3,500}Al^{IV}_{0,500}O_{10})$ $(Al^{VI}_{1,500}Fe^{2}_{0,030}Mg_{0,450})$
$(K_{0,850}Na_{0,016})(OH)_2$

This type of phengite is normally encountered in the «Schistes lustrés» with mineral associations indicative of high pressure, and in certain carbonate rocks of the «Briançonnais» domain as defined by DEBELMAS and LEMOINE (1970). The sample 748 does not contain any other mica. However in sample 747, there are two successive phengitic phases present. Microscopic examination revealed that lawsonite is pseudomorphosed by calcite and white mica. It is a classical transformation in carbonate rocks (see also CARON, 1974). The newly-formed micas of the pseudomorphose have a different composition:

747 (2) $(Si_{3,310}Al^{IV}_{0,690}O_{10})$ $(Al^{VI}_{1,630}Fe^{2}_{0,015}Mg_{0,370})$
$(K_{0,827}Na_{0,049})(OH)_2$

In these micas, the substitution of the phengitic component is less important and might characterize a late metamorphic phase with different pressure and temperature conditions. Such phengites are common in the «Briançonnais» and in the Pelvoux massif.

The age of 49 M.A. of sample 748 may result either from a partial loss of the radiogenic argon which has accumulated since the first closure of the micas, probably related to the first phase of alpine metamorphism, dated at 80-100 M.A. (see references in the introduction), or may approximate the real age of the micas. The age of sample 747 may be similarly interpreted. Nevertheless, detailed study revealed the existence of a metamorphic event which post-dates the formation of high pressure phengites. The micas formed during that second episode coexist with micas of the first phase. Thus, the age will be intermediate between the dates of the two episodes unless the old phengites have lost all their radiogenic argon or the fine fraction extraction technique has considerably enriched the mixture in micas of the second generation. In that case, the age of 38 M.A. would represent an age close to the time of mica formation. The formation of $Si_{3,3}$ micas would then have occured less than 38 M.A. ago. Although lawsonite was «muscovitized» with a corresponding potassium gain, the analyses of the first generation phengites clearly show that their alkaline content has not changed. If we assume that the sample A 748, which did not suffer a modification of its potassium content, has not completely lost its radiogenic argon, then its apparent age would lie between 37 and 80-100 M.A. This implies that the age of the micas of the second generation has to be younger than 49 M.A., that is, probably of the order of the age of A 747, i.e. 38 M.A.

This example illustrate the difficulty in interpreting correctly «the age» of fractions less than 2 microns, collected in polyphased metamorphic systems. The $\frac{^{40}Ar\ rad}{^{40}K}$ ratio is the result of many factors with opposing and complementary effects such as: the tectonometamorphic phases, the degree of illite crystallinity, the $\frac{Fe + Mg}{Al}$ ratio as indicated by the $\frac{I_{002}}{I_{001}}$ ratio, the grain size. PURDY and JÄGER

(1976) attributed the difficulty of interpreting the potassium-argon ages of micas to some of these factors and concluded that K-Ar system closed at 350°. CLAUER (1976) showed that crystallization and recrystallization of clays occur in Sr isotopic equilibrium with the environment. Probably the same applies for argon. In the Alps, the recrystallization of micas, a common phenomenon (CARON, 1977), normally resets the K-Ar clock. During low-grade metamorphism, temperature generally reaches less than 350 °C. Thus, without recrystallization, the radiogenic argon would only be partially outgassed. Furthermore, the argon pressure of the fluid phase remains rather high and is enriched in argon 40. As a consequence of the various amounts of radiogenic argon outgassed, the 40Ar/36Ar is variable. The recrystallization will occur in an environment in which the ratio of the 40Ar/36Ar pressure is higher than that of atmosphere and variable. Under these conditions, the minerals will already have an «apparent age», at the time of closure of the K-Ar system. Thus, if the rock system remained open to allow the complete escape to the argon 40 and if the minerals completely recrystallized would one obtain a meaningful K-Ar age. If the 40Ar did not escape but equilibrated with the other argon isotopes one obtains a meaningful age from the slope of the linear array of the data points in a 40Ar/36Ar-40K/36Ar-diagram.

3. DATING THE OPHIOLITIC PEBBLES OF BARREME OLIGOCENE BASIN

The pebbles of the ophiolitic suite were deposited during the Oligocene in Barrême and thus escaped the third phase of alpine metamorphism.

The ages obtained on ophiolitic total rocks lie between 30 and 38 M. A. (Table I). The radiolarite boulders show total rock ages of nearly 80 M. A. (fig. 5) The lack of effects of the third phase is verified: there is no age younger than 30 M. A.

The petrography of the four dated ophiolitic samples, a variolite, a prasinite, an amphibolite and a diabase, shows that they contain two alpine parageneses: the first with glaucophane corresponding to the high pressure episode, the second with chlorite due to a lower pressure episode. It might be assumed that the argon loss during the second phase was complete. However, the effect of the second phase was not observed on the radiolarites. In a 40K/36Ar-40Ar/36Ar-diagramm, they fit on a straight line which shows an age of 85,4 ± 3,5 M. A. with a 40Ar/36Ar initial ratio of 291 ± 12. The structural and metamorphic framework was the same for the two types of rocks. Thus, that complete retention of the radiogenic argon must be attributed to the peculiar chemistry of the radiolarites. A microprobe analysis of the very small phengite, not visible under the microscope, gave the following formula:

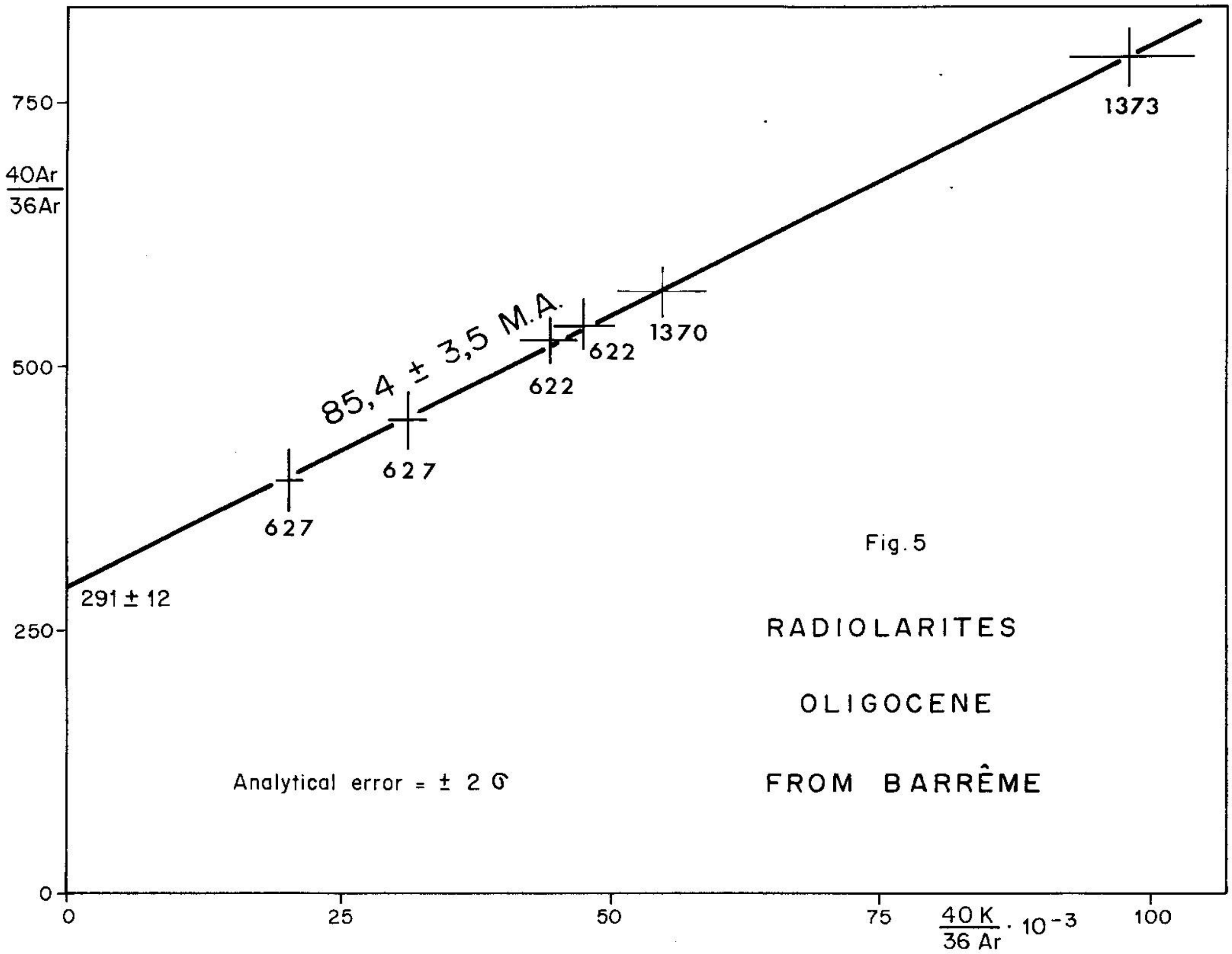

Fig. 5 K/Ar isotopic diagram of radiolarite pebbles in Barrême oligocene basin.

$(Si_{3,610}\overset{IV}{Al}_{0,390}O_{10})$ $(\overset{VI}{Al}_{1,140}\overset{2}{Fe}_{0,380}Mg_{0,380})$
$(K_{0,846}Na_{0,030})(OH)_2$

The special technique for microprobe analysis of these very fine minerals is also described in Saliot (1978).

The phengite included in the radiolarites is really a high pressure phengite. The rock contains more than 99% quartz, small amount of hematite and phengite. The isotopic result suggests that the rock has not been open during the second phase. The reason of that peculiar isotopic behaviour has probably to be sought in the mineralogical composition, which enabled these rocks to remain closed systems since the first crystallization of the phengites.

Thus, the age of 85 M.A. would be considered as the age of the high pressure event.

TABLE I - Potassium-Argon isotopic data.

N° Sample (1)	Illite (%)	Chlorite (%)	Interlayered (%)	Diverse (%)	I_K (2)	$\frac{I_{002}}{I_{001}}$ (3)	K_2O (%)	$\frac{^{40}Ar\ rad}{^{40}Ar\ tot}$ (%)	^{40}Ar rad (10^{-6} cc/g)	$\frac{^{40}K}{^{36}Ar} \times 10^{-3}$	$\frac{^{40}Ar}{^{36}Ar}$	t_{MA} (± 2σ)	Locality
RHETIAN													
A 711	100				7,2	n.d.	7,88	76,9	41,96	105,2	1284	158 ± 5	Corbes
								86,5	41,70	203,6	2196	157 ± 4	
A 712	100				7,0	n.d.	7,72	85,7	41,45	189,0	2086	159 ± 4	"
								82,6	42,20	146,3	1707	162 ± 5	
A 713	100				6,4	n.d.	7,52	85,0	37,03	193,7	1978	147 ± 4	Barles
								86,9	37,28	225,4	2267	148 ± 4	
A 714	100				6,2	n.d.	7,81	82,6	41,96	148,8	1706	160 ± 4	"
								86,8	42,28	204,5	2248	161 ± 4	
A 715	100				4,2	n.d.	8,00	86,8	88,45	311,9	2252	107 ± 3	Maupas
								89,7	28,66	411,1	2892	108 ± 3	
A 886	90	10			3,5	0,37	8,17	93,2	25,61	751	4447	94,8 ±2,2	"
A 716	80	20			4,5	n.d.	6,43	74,5	19,65	160,9	1164	92,5 ±2,6	Ascension
								85,5	20,65	310,9	2067	97,1 ±2,4	
A 887	95	5			4,2	0,32	7,69	83,0	18,12	352,0	1772	71,2 ±1,9	"
A 888	75	25			5,2	0,30	6,84	81,9	17,80	269,9	1663	79,1 ±2,0	"
A 717	70	30			3,0	n.d.	6,88	73,2	10,07	315,5	1111	44,9 ±1,3	Charvie
								75,2	10,29	341,6	1197	45,9 ±1,3	
A 718	50	40		Paragonite 10	3,0	n.d.	5,85	59,2	8,07	177,0	727	42,3 ±1,5	Cristillan
								56,9	8,24	157,9	689	43,2 ±1,6	
A 747	85	15			3,3	0,50	7,74	68,7	9,61	298,4	950	38,2 ±1,2	Sestrière
A 748	85	15			2,8	0,60	7,19	78,1	11,46	377,5	1357	48,8 ±1,3	"
TERRES NOIRES			Illite-Smectite										
A 392	35	20	10-14Sm 35	Kaolinite 10	11,8	n.d.	3,62	79,8	29,61	81,3	1469	238 ± 7	Veynes
								79,7	29,49	81,5	1467	237 ± 7	
A 457	45	35	id. 20		8,2	n.d.	4,55	95,5	27,28	603	6664	177 ± 5	S.W. Gap
A 458	50	35	10-14Sm regular 15		6,7	n.d.	4,48	96,3	26,63	730	7944	176 ± 5	N.E. Gap
A 391	45	30	id. 25		5.6	n.d.	5,73	59,9	13,98	103,2	741	74,2 ±2,6	NE Embrun
								64,5	13,86	126,9	838	73,6 ±2,4	

A 625	75	25			3,1	0,55	6,34	77,8	13,13	285,3	1388	63,2 ± 1,7	N.Briançon
								84,0	13,06	428,6	1853	62,9 ± 1,6	
A 624	75	25			3,2	0,58	6,74	63,2	12,53	155,5	806	56,8 ± 1,9	"
								76,9	13,11	288,6	1286	59,4 ± 1,7	
A 921	55	40	10-14 Sm regular 15		4,8	n.d.	5,58	91,3	16,09	592	3377	87,1 ± 2,2	S.W.Embrun
RADIOLARITES													
A 880	95	5			3,2	0,38	8,25	86,6	14,57	628	2257	54,9 ± 1,3	Gondran Crest
A 881	90	10			3,5	0,33	8,12	87,1	15,11	591	2228	56,9 ± 1,4	"
A 882	90	10			3,2	0,11	6,83	82,2	11,25	479	1691	56,4 ± 1,3	"
A 883	90	10			3,4	0,25	7,91	84,5	16,20	444,1	1896	62,5 ± 1,6	"
A 884	90	10			3,0	0,36	6,63	69,4	10,98	227,2	956	50,7 ± 1,5	"
A 885	90	10			3,4	0,36	7,00	84,8	16,53	392,4	1925	71,9 ± 1,8	"
BOULDERS	Petrographic type												
R 618	Variolite						0,31	33,6	0,362	73,2	448	35,9 ± 3,0	North-East Barrême
								53,2	0,350	170,5	638	34,7 ± 2,3	
R 619	Prasinite						0,49	28,6	0,544	60,9	416	34,2 ± 2,7	"
								17,3	0,486	35,2	354	30,5 ± 3,6	
R 621	Diabase						0,15	8,4	0,181	12,6	320	37,1 ± 9,4	"
R 626	Lawsonite amphibolite						0,41	28,2	0,496	54,7	414	37,2 ± 3,1	"
								27,5	0,483	54,2	410	36,2 ± 3,0	
R 622	Radiolarite						0,26	43,5	0,756	44,6	526	88 ± 7	"
								44,7	0,741	47,8	537	86 ± 7	
R 627	"						0,27	33,9	0,742	31,4	449	83 ± 8	"
								24,2	0,716	20,3	392	83 ± 9	
R 1370	"						0,272	47,7	0,739	55,1	565	82 ± 7	"
R 1373	"						0,328	62,7	0,914	98,8	793	84 ± 6	"

(1) A : fine fraction
R : total rock

(2) Ik : crystallinity index

(3) n.d. : not determined

Conclusion

Potassium-argon dating of the non-metamorphic «Terres Noires» gives an age corresponding to lower Oxfordian, i.e. the time of the end of deposition of that formation. The data demonstrate the presence of excess 40Ar in the clay minerals and the homogeneity of the 40Ar/36Ar in the sedimentary evironment.

The non-metamorphic Rhetian showed an age of 155 M.A., an age which was also observed on older formations in the same region. The result does not correspond to the age of deposition. It might be attributed to a late diagenesis.

The age of the fine fractions of both Rhetian and «Terres Noires» from areas with increasing grade of alpine metamorphism show an overall correlation between argon loss and illite crystallinity. The detailed crystallochemical analyses of two samples which do not strictly follow the general pattern lead us to conclude that, locally, the decisive factor is the mineral chemistry. In addition to these considerations, the situation is further complicated by the effects of the peculiar argon isotope geochemistry.

The Oligocene pebbles in Barrême confirmed that the ophiolitic suite has suffered two metamorphic episodes before being eroded. The radiolarites preserved the age of the first phase, due to their peculiar paragenesis. That high pressure phase is dated at 85 M.A.

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