

Title	Potassium-Argon Dating and Palaemagnetic Study of Selected Dykes and Lava Flows Deves, Valay Area(Massif Central, France)
Author	Sunardi, E. / Boven, A. / Hus, J. / Punzalan, L. / Pasteels, P.
Citation	Journal of geosciences Osaka City University 39; 1-17.
Issue Date	1996-03
ISSN	0449-2560
Type	Departmental Bulletin Paper
Textversion	Publisher
Publisher	Faculty of Science, Osaka City University
Description	

Placed on: Osaka City University Repository

Placed on: Osaka City University Repository

Potassium - Argon Dating and Palaeomagnetic Study of Selected Dykes and Lava Flows from The Devès, Valay Area (Massif Central, France)

^aE. SUNARDI, ^bA. BOVEN, ^cJ. HUS, ^bL. Punzalan and ^bP. PASTEELS

(with 7 Figures and 2 Tables)

Abstract

Potassium-Argon dating, supplemented with palaeomagnetic analyses, have been undertaken on lava flows and dykes from the Devès plateau (Massif Central, France) in order to establish an improved Quaternary chronostratigraphy. The present work is restricted to localities close to the Lac du Bouchet maar and its surroundings on the Devès plateau, namely, at St-Didier-d'Allier along the Allier river on its western margin and at Darsac, near to the Puy basin along its eastern margin.

Different specimens from the lava flow of the Lac du Bouchet, sampled in the vicinity of the maar, display an intermediate to reverse polarity. These results do not correspond to the prevailing polarity within the Brunhes magnetochron to which the lava should belong, on the basis of its radiometric age determination between 0.4 and 0.5 Ma. These results, however, may allow a possible correlation with the Emperor Reversed Polarity Subchron. Measurements on the same flow at greater distances from the maar crater itself, where it would be less prone to tilting effects, will be more meaningful in determining its polarity with more confidence.

Polarities and K-Ar ages of the two dykes from Monchamp and Raye-Fait have been determined; they allow location of these volcanic events within the magnetic polarity time scale. Baked contact tests made on the dated lava flow of St-Didier d'Allier allowed us to ascertain firmly its polarity. However, at Darsac, the polarity determined on the dated lava flow does not correspond to the signature recorded by its baked contact.

Key Words: K-Ar, palaeomagnetism, Lac du Bouchet, Devès, Massif Central France, Emperor Reversed Polarity Subchron.

1. Introduction

The Massif Central in France is a suitable region in Europe for studying the continental Pliocene and Pleistocene. Within its tectonically induced and morphologically delineated basins, a huge accumulation of volcano-sedimentary deposits has been registered throughout the end of the Tertiary up to the Quaternary. The main interest of the morphologically well-expressed plateau of the western Devès, which belongs to the Velay area, is the interlayering of various volcanic materials with fluvio-lacustrine, fossil-bearing deposits.

The major part of the chronostratigraphy of the Devès plateau is based on numerous field observations, supported by an extensive database of radiometric ages. Most datings

^a Geosciences Department, Faculty of Science, Osaka City University, Osaka, Japan

Permanent address: Geology Department, Padjadjaran University, Bandung, Indonesia

^b Laboratory of Geochronologie, Vrije Universiteit Brussel, Pleinlaan 2, B-1050, Brussels, Belgium

^c Centre de Physique du Globe, 6381 Dourbes-Viroinval, Belgium

are K-Ar ages and are often apparent ages only. These dating results, obtained in each of its volcanic provinces, especially in the Quaternary time-span, await further control measurements and additional $^{40}\text{Ar}/^{39}\text{Ar}$ results on selected minerals in order to clarify the various chronostratigraphical problems of the Plio-Pleistocene.

Numerous studies have been undertaken on the Devès plateau itself (BOUT 1974; COUTHURES, J., 1982; PASTRE, J.-F., 1987; FOURIS M., 1989; TEULADE 1989; THOUVENY, N., 1990). The area is characterized by intense strombolian fissural activity which resulted in the stacking of alkali-olivine flows on the Hercynian basement. Associated with these is a contemporaneous phreatomagmatic eruption leading to numerous maar-eruption systems. The latter define a closed environment, protected from further erosion and meteoric weathering, and they are natural registration structures (unfortunately difficult to be dated) throughout the Quaternary. They are to be considered as unique "natural" laboratories in which a multidisciplinary team of Quaternary Scientists (geologists, paleontologists, geochronologists, palynologists, paleomagnetists, archaeologists, and others) have contributed to the establishment of an improved chronostratigraphical framework of the Quaternary. Part of the present work has been undertaken by a multidisciplinary team within the frame of the Euromaar project.

Because the lacustrine sedimentation originates exclusively from the inner slope of the crater, it records in a more or less continuous way the environmental changes throughout the Quaternary (BONIFAY 1987). Moreover, the presence, of pyroclastic markerbeds associated with an acid dynamic volcanism among the lacustrine deposits in some maars of the Devès plateau allows some long-distance correlation with the Mt. Dore (Massif du Sancy) volcanism. (TEULADE 1989).

The study of lacustrine deposits in the Maars of the Devès plateau has provided, for the first time, a continental sedimentary sequence of significant length and with paleoecological information (pollen, macrorests and diatomites). It ranges from the Eemian interglacial, through the Prewürm (including two forestial interstadials) and the Pleniwürm glacial period, up to the present. This allows establishment of a reference sequence for the Middle and Upper Pleistocene of the Medio European area (REILLE 1989).

Fossil-rich deposits enclosing the typical "Early, Middle and Late-Villafranchian" mammalian faunas, formerly grouped in the misleading stratigraphical term "Villafranchian" and thought to be the continental equivalent of the marine Calabrian (AZZAROLI 1988), are found in specific biotopes. These latter are found within maar deposits or along the margins of the Devès plateau in the volcano-sedimentary basins of the Haut-Allier and the Puy, respectively, preserved by their effusive volcanism. These sites have been intensively studied and used for the establishment of a biochronostratigraphical time-scale of the continental Plio-Pleistocene in the Central Massif; they could, most probably, be extended to a larger European area (numerous contributions by BOUT, P., 1960; BONIFAY, M.F., 1986; AZZAROLI, A., 1988).

Ongoing research on the geomagnetic secular variation as recorded in lacustrine deposits has gained confidence within the world of Quaternarists, as some reproducible

information with a high resolution could be extracted from the paleomagnetic record of the Lac du Bouchet Maar in the Velay area, covering a time sequence up to the last interglacial/glacial cycle (last 120 000 years) (CREER 1986, 1990; THOUVENY, N., 1990). Reconstitution of the evolution of the palaeorelief has been attempted on the basis of geomorphological study of the lava flows (G. Kieffer, 1971).

2. Objective of the Present Study

The present study was carried out within the general context as discussed previously, and is supported by our field observations which were restricted to three areas. These were situated at the centre of the Devès plateau (Lac du Bouchet and its surroundings), to the west of the plateau along the Allier river (St-Didier-d'Allier), and along its eastern margin near to the Puy basin at Darsac (see Figures 1 and 2). The Lac du Bouchet is a maar volcano with a well-preserved morphology. A lava flow was sampled along the north-western crater rim of the Lac du Bouchet Maar. The lava outcrops as a steep wall along the inner crater of the maar and is thought to have been cut by the subsequent maar eruption. Based on its morphology, the lava flow is interpreted as emanating from the neighbouring scoria cone of Mt-Recours, to the north-west of the maar. Two other scoria cones south of Lac du Bouchet, at Monchamp and Raye-Fait, were selected because of the presence of dyke intrusions which may belong to the same

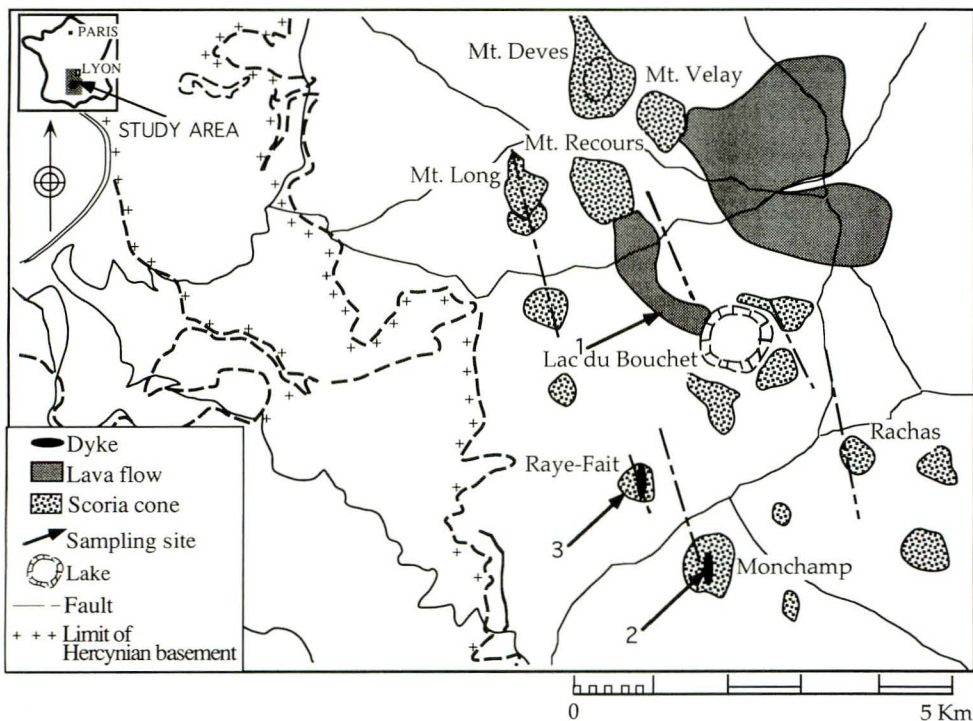


Fig. 1. Detailed map of the study area in the vicinity of Lac du Bouchet, with sampling locations.

magmatic feeding system as the one connected to the Lac du Bouchet. Another maar, among the numerous ones, is located at Darsac on the eastern edge of the Devès plateau and St-Didier-d'Allier along the Allier river on its western margin. Within an exceptional outcrop along the railway, cut through its tuff ring, a small dyke is injected perpendicularly to the dip of the base surge layers from the tuff ring.

Laboratory techniques have been limited to K-Ar datings and palaeomagnetic analyses made on the same samples. Both techniques, taken on their own, do sometimes lead to irreconcilable conclusions, but when interpreted together do allow a better evaluation of the obtained results. Ages and polarities have been obtained on the lava flows of Lac du Bouchet, of St-Didier d'Allier, Darsac and on dykes of Monchamps and Raye-Fait respectively. The results are tabulated in Table 2. Stability of the measured magnetization has been checked through baked contact tests at the sites of St-Didier d'Allier and Darsac.

Attempts have been made to determine the onset of sedimentation within the Lac du Bouchet Maar, based on K-Ar datings and palaeomagnetic measurements on its lava rim, and through Ar-Ar dating of a feldspar separate from a cinerite layer at a depth of 42.43 m of a core, taken from the Lac du Bouchet lacustrine deposits. This material was found unsuitable, consisting largely of older reworked feldspars, or unstable feldspars which yielded disturbed Ar-Ar spectra. Test measurements have also been made on dyke intrusions related to the fissural volcanism of the Devès plateau and found in the scoria cone of Monchamps (in the vicinity of the Lac du Bouchet), as well as in the tuff ring of the maar of Darsac. Stability of the magnetization has been checked through baked contact tests in the sites of St. Didier d'Allier and Darsac. Comparison of the dating results on rocks with known magnetic polarity with the general polarity time-scale will be discussed briefly.

3. Geological Setting of the Effusive Volcanism

The Devès plateau of Western Velay, with an area of 850 km², is the most extensive basaltic plateau in the Massif (see Fig.2). It trends NW-SE and is bordered by the Allier (West) and Loire (East) rivers. The distribution of the alkali-olivine lava flows, which are stacked upon each other in some instances, is influenced by the topography of the underlying Hercynian basin. The latter culminates as a NW-SE trending crest, which defines the principal alignment of the volcanoes. The crest is not axial but is displaced to the west, resulting in a greater dip of the paleotopography towards the Loire. The latter basin was formed since the Paleogene because of rifting of the Puy Basin.

The lava flows, upon reaching the Loire and Allier, respectively, have filled paleovalleys and, due to relief inversion, may now be observed sticking out morphologically.

The basalt-crystalline Hercynian basement interface (at about 1100 m altitude) along the Allier is a rather monotonous contact (as seen in St. Didier d'Allier, the selected site in the frame of this study) or is more differentiated (at about 950 m) along the Loire, where a contact is seen with the Oligocene sediments that accumulated in the

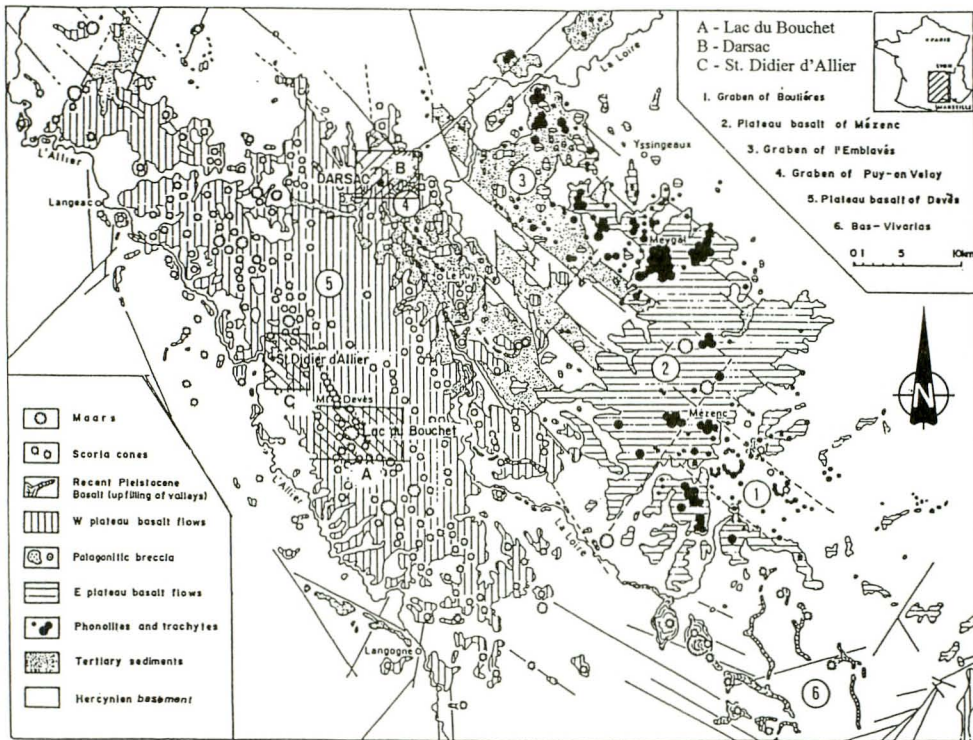


Fig. 2. Geological map of the Western Devès, Velay area (After GOER A de., MERGOIL, J, 1971) with location of the study area.

Puy basin. The whole structure is surmounted by scoria cones (Monchamp and Raye-Fait, for example, in the selected site) and pierced by more than 40 explosion craters (Lac du Bouchet for example, also a selected site), testifying to the importance of phreatomagmatic activity synchronous with strong fissural effusive volcanism. The latter had originally been assumed to be the final stage of volcanism in the Velay area (BOUT 1974) but is now shown to be spread throughout the whole timespan of the Velay volcanism. The volcanism of the Devès plateau ranges from 3.5 to 0.7 Ma (cited from BOUT, 1974, in THOUVENY and BONIFAY, 1984) or from 3 to 0.6 Ma (FOURIS, 1989), and is mainly of fissural origin. A relatively old volcanism is confined in the Langeac basin along the Allier valley, where a basalt at the base of the flow d'Espaly is dated at 7.1 – 10.7 Ma (MERGOIL 1987).

The lavas from the Devès plateau are alkali-olivine-basalts, a term which should preferably be used instead of alkali-basalt. Moreover, they are distinct from olivine basalts because of their high concentration of alkalis, especially Na, in relation to Al and Si, and have more affinities to a normative nepheline composition. These basalts occur either as lavas or as dykes. Their texture is porphyritic, with a fine-grained, hypocrySTALLINE groundmass. Vesicular structure is common. Olivine is the essential phenocryst in these undersaturated basalts. Some basalts contain xenoliths of peridotites

or pyroxenites and xenocrysts of olivine and spinel (BABKINE *et al.* 1965, BOIVIN 1982).

The petrographical differentiation of these lavas is based on the presence of more than 5 to 10 per cent modal nepheline, but remains rather ambiguous. Nepheline can generally not be detected under the microscope as it occurs in the very fine-grained or partly glassy groundmass.

No chemical analyses were performed by us but sufficient data are available in the literature. The chemical composition of the lava flow for Lac du Bouchet (after JARDIN, L., 1973), is as follows: SiO₂: 46.47%, TiO₂: 2.50%, Al₂O₃: 13.43%, Fe₂O₃: 6.70%, FeO: 4.50%, MnO: 0.18%, MgO: 10.50%, CaO: 9.40%, Na₂O: 4.10%, K₂O: 1.80%, H₂O+: 0.00% H₂O-: 0.23%, Total: 100.01%.

Chemical classification is recommended as it allows differentiation of the varieties of alkali-olivine-basalts. The classification of IRVINE and BARAGAR (1971), which differentiates ankaramites, nephelenites, basanites, alkali basalts and hawaiites, is recognised. Other usable classifications are the total Alkali versus Silica diagrams (TAS) of le MAITRE (1989) and COX *et al.* (1979), which are very similar to the often used K₂O versus SiO₂ diagram. Indeed, both Na₂O and K₂O essentially behave erratically until the advanced stages of crystallization. On the basis of IRVINE and BARAGAR (1971), the lavas of the Devès plateau plot within the fields of hawaiite, basanite and foidite.

4. Laboratory Treatment

K-measurements were performed on a Varian-Techtron AA-10 Atomic Absorption Spectrometer, solutions being obtained through tri-acid digestion of powdered aliquots; the extracted argon was measured on other aliquots with a MAT240 mass spectrometer operated in the static mode. Peak intensities were calculated on the basis of the ion-proportionality method. Their readings, expressed in volts, were converted in mlSTP of gas on the basis of measurements made on the K-Ar standard BB6 with known amounts of radiogenic argon. Argon extraction from the samples was achieved by induction heating of a molybdenum crucible under an ultra-high vacuum, at about 1600°C. Purification of the released gasses was achieved by two Ti-Zr getters and two SAES getters working at different temperatures.

The sampling of geological materials for palaeomagnetic studies involves both the removal of the samples from their natural environment and their marking in such a way that their original field orientation is known. Orientation can, in principle, be carried out either by the sun or magnetic compass methods. In our study, after orientation and numbering, intact samples were removed from the site by chisel and hammer. The sampling of the baked contacts, on the other hand, was more delicate in comparison to hard-rock sampling. Before removing the sample, a horizontal plane was first scraped with a knife and controlled for horizontality with a level. A magnetic compass was used to mark the magnetic north. Detailed information concerning the sampling localities, number of specimens, coordinates, type of sample and method of sampling is given in Table 1. All measurements of NRM (natural remanent magnetization) were done with

Table 1. Sampling scheme of the paleomagnetic samples.

SAMPLING LOCALITY	NUMBER OF SPECIMENS	COORDINATES		TYPE OF SAMPLE	METHOD OF SAMPLING
		N	E		
Monchamp	8	44°52'49"	3°47'06"	dyke	sun compass
Raye-Fait	6	44°53'43"	3°46'42"	dyke	sun compass
Lac du Bouchet	6	44°53'43"	3°41'35"	lava	sun compass
Darsac	8	44°08'18"	3°43'35"	baked contact	magnetic compass
	4	45°08'20"	3°43'35"	lava	sun compass
St.Didier d'Allier	2	44°58'01"	3°41'35"	baked contact	magnetic compass
	7	44°58'01"	3°41'35"	lava	sun compass

either a JR-4 spinner magnetometer or a PAR SM-1 spinner magnetometer, depending on the magnetization intensities. The susceptibility was measured with a KLY-1 magnetic susceptibility bridge. All equipment for palaeomagnetic analyses mentioned here are used routinely at the Centre de Physique du Globe in Dourbes, Belgium.

The two routine "cleaning" techniques used are alternating field demagnetization and thermal demagnetization, in which magnetic and thermal energy respectively, are used to randomize the moments of particles carrying secondary natural remanent magnetizations. In our experiment, standard stepwise thermal demagnetization procedures were followed, with temperature increments of 35°C or 45°C up to temperatures of 665°C and 645°C. All the samples were heated using a Schontedt Model TSD-1 thermal specimen demagnetizer furnace. In addition, alternating field demagnetizations tests were run on specimens in order to remove the spurious remanent magnetization from the stable primary magnetization. All the specimens were progressively demagnetized in alternating fields, with peak values up to 800 Oersted by using a Schontedt GSD-1 AC geophysical specimen demagnetizer.

5. Potassium-Argon and Palaeomagnetic Data

5.1. Potassium-Argon dating results

K-Ar results are summarized in Table 2. Four different aliquots (three whole-rock and one matrix split) from the same lava flow of Lac du Bouchet yielded different amounts of radiogenic argon, leading to a wide range of apparent ages between 0.46 to 0.79 Ma. The removal of the phenocrysts and suspected xenocrysts is a routine procedure as they may carry excess argon. In the present instance, the possible presence of excess argon in the phenocrysts of some of the aliquots, if not in all, is, therefore, to be considered.

As can be seen in Table 2, one measurement obtained on a whole-rock aliquot yields an apparent age definitely greater than in the three other aliquots. The three other splits, although a priori are still possible carriers of excess argon, yielded comparable concentrations of Ar^{40} rad. A part of the excess argon must, therefore, be present in at least some occasional grains which ended up accidentally in one split and not in the others. Excess argon has often been described in connection with ultramafic inclusions

Table 2. Ages and polarities of lavas and dykes from the Devès plateau.
 * for polarity: I Intermediate, N Normal and R Reversed

Locality	Sample No.	Rock Type	Sample Type	Percentage of K(wt.%)	⁴⁰ Ar rad (%)	⁴⁰ Ar rad (10 ⁷ mlSTP/g)	Age (Ma±d)	Polarity*
Lac du Bouchet	V-90-14(1)	lava	whole rock	1.01	7.2	0.31	0.79±0.05	I-R
	V-90-14(2)	lava	whole rock	1.01	10.8	0.181	0.46±0.05	I-R
	V-90-14(3)	lava	whole rock	1.01	15.6	0.207	0.53±0.05	I-R
	V-90-14(4)	lava	matrix	1.01	7.6	0.207	0.53±0.05	I-R
Monchamp	V-90-5	dyke	matrix	1.04	2.14	0.502	1.24±0.46	N-R
Raye-Fait	V-90-6(1)	dyke	matrix	1.47	4.58	0.406	0.71±0.13	R
	V-90-6(2)	dyke	whole rock	1.47	9.1	0.698	1.22±0.09	R
Darsac	V-90-21	lava	matrix	1.59	45.83	2.062	3.33±0.10	R
St. Didier d'Allier	V-90-59	lava	matrix	1.55	28.17	0.684	1.13±0.06	R

in basalts (FUNKHOUSER and NAUGHTON 1968; McDUGALL and Stipp 1969). On the other hand, early crystallizing minerals such as pyroxenes and olivines are also known for carrying excess argon, which alters K-Ar dates (CASSIGNOL and GILLOT, 1982). Similarly, Fuhmann and LIPPOLT (1987) identified excess argon enrichment in mafic phenocrysts. In the present instance, we observed that this excess argon would more precisely be associated with olivine phenocrysts. These make about 25 per cent of the total rock sample in this lava. Some whole-rock samples do not however, display excess argon problems while others suffer from it. The effects on the whole-rock age determinations are, therefore, not easy to determine, as the amount of excess argon varies as well between different outcrops as, perhaps, within one occurrence, and between different phenocrysts. It is difficult to evaluate which proportion of a rock sample is actually carrying excess argon at the moment of an eruption. The phenomenon is, nevertheless, important enough to be taken into consideration. Interpretation of apparent ages and deduction of the best age estimate for the emplacement age of a lava suffering from excess argon should, therefore, be made with caution. The average of the apparent ages on split numbers 2,3 and 4 may be considered as a most probable (but still too old) age estimation for the phreatomagmatic eruption of the Lac du Bouchet maar. This maar must, therefore, be younger than 0.4 to 0.5 Ma, which is at variance with the K-Ar dating results reported in CREER 1989 (0.8001±0.04 Ma and 0.8701±0.06 Ma). The estimated onset of sedimentation within the Lac du Bouchet, about 0.4 to 0.5 Ma from our data, coincides with an age estimate based on sedimentation rates of 0.24 to 0.26 mm/year, as reported in CREER *et al.* (1989), if we assume that these prevailed within the same range throughout the entire filling of the maar, whose total

thickness is 100 meters or less. Palynological information throughout the lacustrine sedimentation record (REILLE and BEAULIEU, 1990) also supports the presently obtained estimate of K-Ar ages. The well-preserved geomorphology of the maar, the scoria cones and the lavas in the Lac du Bouchet surroundings, as compared to the other volcanic apparatus in the Devès plateau, is other evidence that allows us to place its eruption among the latest events in the effusive history of the Devès plateau covering a time-span from 3 to 0.4 Ma years.

5.2. Paleomagnetic Results

5.2.1 Lac du Bouchet

The palaeomagnetic study was attempted mainly in order to cross-check the K-Ar dating. The six specimens sampled from the lava flow of Lac du Bouchet yield a different directional behavior (Fig.4). However, the stable characteristic remanence after cleaning has inclinations and declinations ranging between $I = -15$ to $+46$ and $D = +103.0$ to -177.0 , respectively. The obtained polarity does not correspond to that inferred from the geomagnetic time scale of MANKINEN and DARLYMPLE (1979, Figure 3) for samples with an age estimate of 0.4 to 0.5 Ma or younger. It is possible that this lava flow reflects the short polarity interval corresponding to the Emperor Subchron. This subchron has been recognized at several places. It was first reported by Ryan (1972,

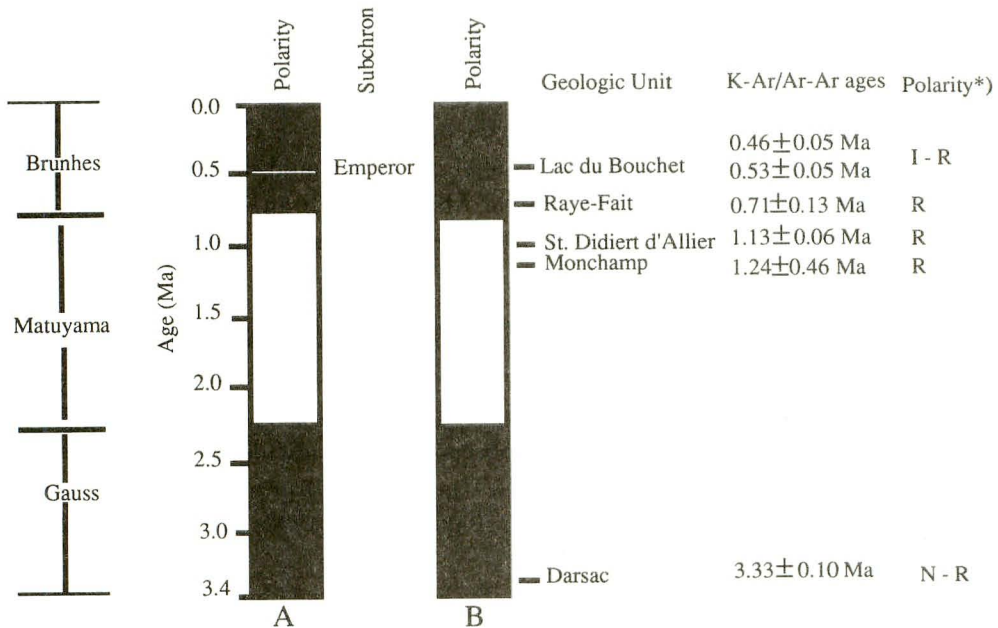


Fig. 3. Comparison between the Geomagnetic Polarity Time Scales. A. After MANKINEN and DARLYMPLE (1979), with revision of boundary ages after CHAMPION *et al.* (1981) and IZETT and OBRADOVICH (1994). B. Present work. For polarity : I Intermediate, N Normal, R Reversed

in JACOBS, J.A.,1984) in cores from the Caribbean and Pacific, with an age between 0.4 to 0.5 Ma. Later, WILSON and HEY (1981, in JACOBS,J.A.,1984) collected a series of marine magnetic profiles across the Galapagos spreading center and found consistent short wavelength anomalies which they interpreted as the Emperor Event at 0.49 to 0.5 Ma with a duration of about 10,000 yr.. CHAMPION *et al.* (1981) also found evidence of a brief (5 to 10,000 yr.) reversed period of the field about 0.4610 ± 0.05 Ma ago, in cores cutting through a sequence of basalt flows in the Eastern Snake River Plain, Idaho. They suggested that this reversal is the same as the Emperor Event and the Ureki event of KOCHEGURA and ZUBAKOV (1978). WILSON and HEY (1981) also suggested that this event was probably a global phenomenon and was the youngest reversal documented by three independent techniques.

The sampled lava flow of Lac du Bouchet could thus correspond with the Emperor Subchron, based on its K-Ar age and its polarity. However, to reach a definite conclusion on this, more research is needed. Foremost in importance is to sample the lava flow farther away from the maar in order to exclude the possible tilting effect on its polarity direction.

5.2.2. Monchamp

The samples from the dyke of Monchamp show mixed polarities with a predominant reversed polarity (Fig.5). All the specimens have a consistently large declination but a scattered inclination. Taking into consideration the topographical situation of the dyke, the random polarities could be caused by lightning effects. These may cause intense heat and produce a thermal remanence at the impact spot and an isothermal remanence farther away from the impact. Hence, no polarity can be irrevocably assigned to this intrusion, merely on the basis of the obtained palaeomagnetic results. The K-Ar on a matrix aliquot yields an age of 1.2410 ± 0.46 Ma. This would confirm an emplacement age for the dyke of Monchamp during the Matuyama chron, in agreement with the majority of the palaeomagnetic results which indicate a reverse polarity.

5.2.3. Raye-Fait

All specimens of the dyke of Raye-Fait, with an apparent age of 0.711 ± 0.13 Ma, have reversed polarities (Fig. 6), a consistently large declination but a scattered inclination. The latter is probably due to fault movements, and most likely to tilting along the NE-SW trending fault plane observed perpendicular to the strike of the dyke. Recently, proposed revisions of the age of the Brunhes/Matuyama transition (IZETT,G.A., and OBRADOVICH J.D. 1994; BAKSI *et al.* 1992) would place the dyke emplacement within the Brunhes chron.

However, K-Ar ages may be in error by as much as about 10 per cent in many instances, as proved by the fact that the age assignment for the limit which is now being criticized had been established merely on the base of K-Ar ages.

5.2.4. Darsac

The lava flow of Darsac gave similar palaeomagnetic results (Fig.7). However, the baked contact specimens (normal polarity) do not correspond to the signature recorded by the lava itself (reversed). This can result from insufficient baking whereby the real signature was improperly printed. The K-Ar age obtained on a whole rock aliquot yields an age of 3.331 ± 0.10 Ma, confining its emplacement within the Gauss chron.

5.2.5. St. Didier d'Allier

The lava flow taken from St.Didier d'Allier yields a K-Ar age of 1.131 ± 0.06 Ma, and gave remanence directions, after cleaning, that are clustered in the southern hemisphere (Fig.7). Even the baked contact agrees fairly well with the direction of the lava. The agreement of the polarity of the flows and associated baked contacts as well as its emplacement firmly support the idea of a reversal of the Earth's magnetic field during the reversed Matuyama chron.

6. Conclusion

Potassium-Argon dating and palaeomagnetic studies have been undertaken on lava flows and dykes from the Devès plateau, Massif Central France. The present work has been restricted in space by selecting the localities of Lac du Bouchet and its surroundings on the Devès plateau, St. Didier d'Allier along the Allier river on its western margin and Darsac along its eastern margin near to the Puy basin.

Three among the four obtained ages on the basanitic ankaramite of Lac du Bouchet show a better reproducibility between the Ar measurements on whole rock and matrix aliquots. This reproducible figure is thus considered as being probably representative. This would infer an age estimation of the phreatomagmatic eruption at around 400,000 to 500,000 years. After cleaning, the NRM of seven oriented samples of the lava flow of Lac du Bouchet show a different behavior. However, their stable remanence have an intermediate to reversed direction. The negative polarity of the lava flow may correspond to the Emperor Subchron.

Two dykes were sampled at Monchamp and Raye-Fait and one lava flow at Darsac. The samples from Monchamp show mixed polarities, with a predominant reversed polarity. The K-Ar dating on a matrix aliquot yields an age of 1.241 ± 0.46 Ma. This would confirm an emplacement age for the dyke of Monchamp during the Matuyama chron. The samples of the dyke of Raye-Fait yield consistent results; they have a reversed polarity with a consistent large declination but a scattered inclination. The latter is probably due to tectonic movements and probable tilting, if compared with the mean NE-SW trend of faulting perpendicular to the strike of the dyke. The K-Ar dating of the dyke of Raye-Fait gives an apparent age of 0.711 ± 0.13 Ma; this would place the dyke emplacement within the Brunhes chron. The lava flows of Darsac and St. Didier d'Allier yield a K-Ar age of 3.331 ± 0.10 Ma and 1.131 ± 0.06 Ma, respectively. The stability of the magnetization has been checked through baked contact

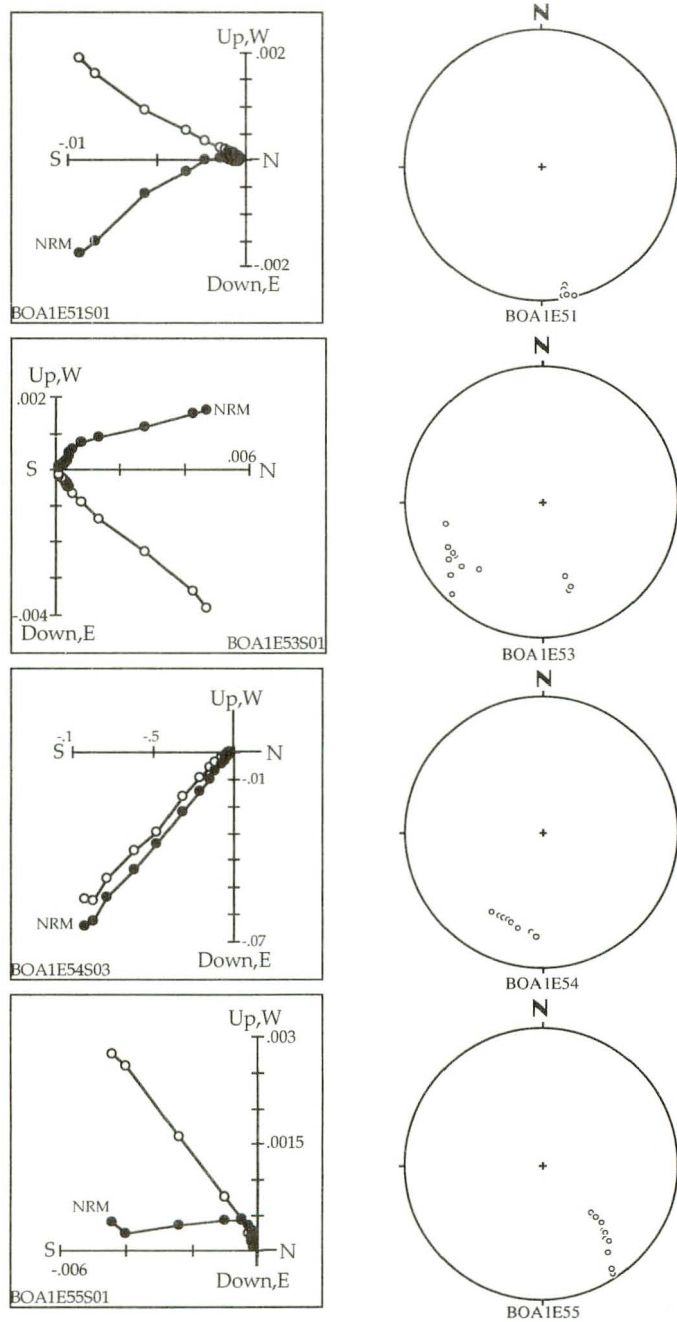


Fig. 4. (right) Equal-area projection of the remanence directions after cleaning of specimens from Lac du Bouchet. Open circles on the lower hemisphere, crosses on the upper hemisphere. (left) Variation of magnetization during demagnetization; diagrams illustrate reversed polarity (BOA1E51, BOA1E54, BOA1E 55) and intermediate polarity (BOA1E53). Solid (open) data points indicate vector end points projection onto the horizontal (vertical) planes. The scale on the axes is in Gauss.

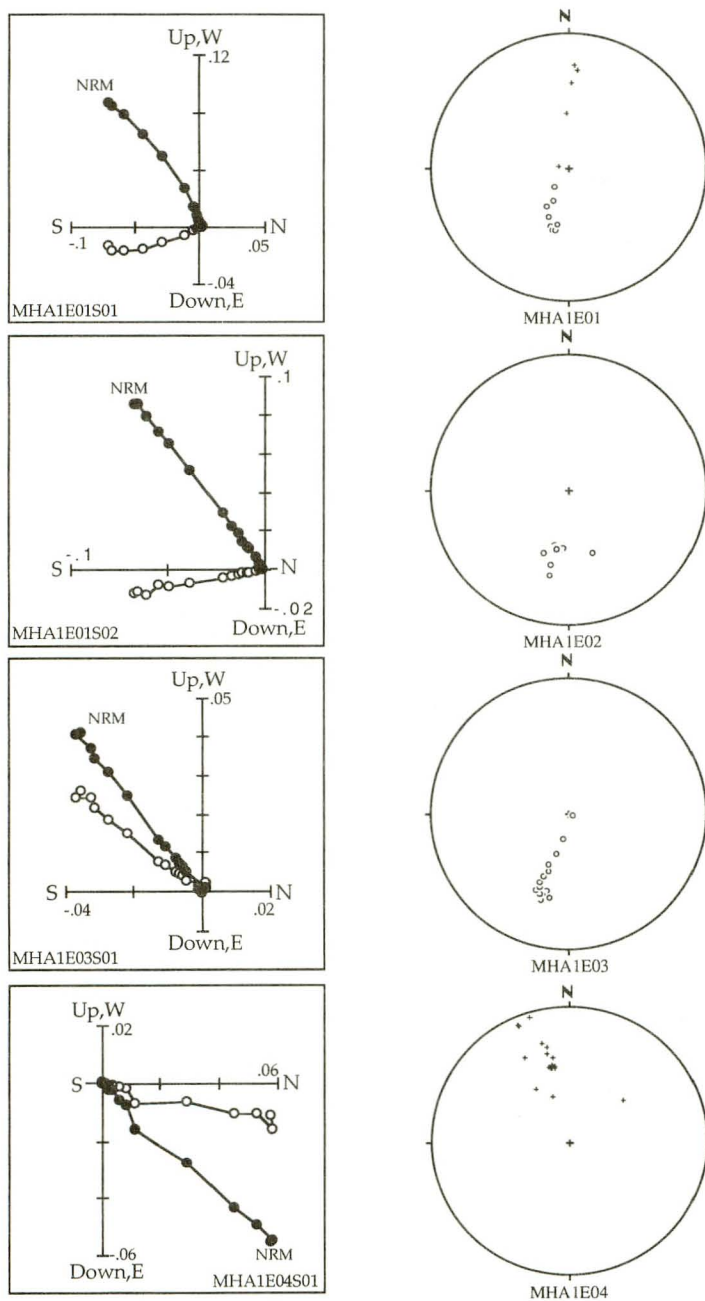


Fig. 5. Same as Fig 4, specimens from Monchamp. Mixed polarity (MHA1E01), reversed polarity (MHA1E02, MHA1E03), normal polarity (MHA1E04).

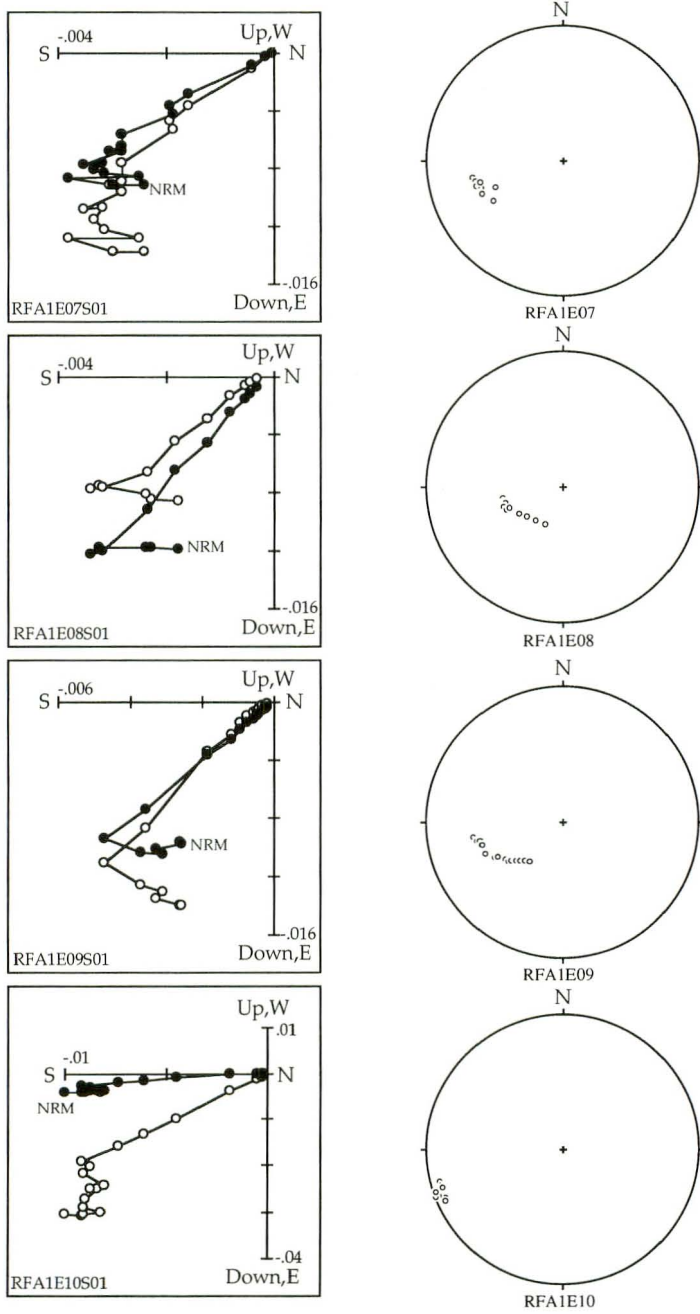


Fig. 6. Same as Fig 4, specimens from Raye-Fait. All specimens have reversed polarity, a consistent large declination but a scattered inclination.

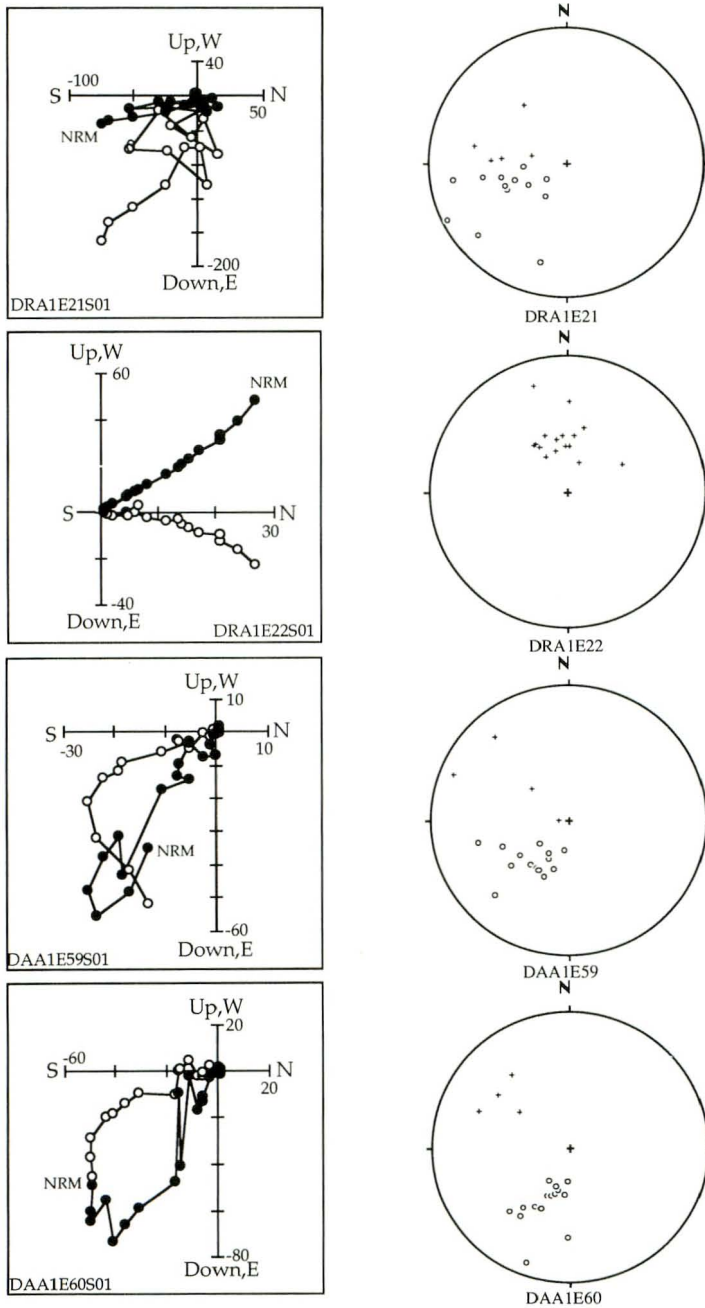


Fig. 7. Same as Fig 4, specimens from Darsac (DRA) and St. Didier d'Allier (DAA). Samples for Darsac have mixed polarity and for St. Didier d'Allier have reversed polarity.

tests at the sites of St. Didier d'Allier and Darsac. The direction of the remanence of the baked contact from St. Didier d'Allier agrees fairly well with those of the lava flow. On the other hand, the magnetic properties of the lava of Darsac do not correspond to the signature recorded by the lava itself.

Acknowledgments

Data on this paper have been presented as partial fulfillment of a thesis for the degree of Master of Science in Quaternary Geology in IFAQ at the Vrije Universiteit, Brussel, Belgium, obtained by the first author. Guidance within the fields of K-Ar dating and palaeomagnetic investigation from sampling up to laboratory treatments have been obtained from the co-authors. We thank Prof. Hisao Kumai of the Department of Geosciences, Faculty of Science, Osaka City University, for his criticism of the manuscript and for valuable comments.

References

- AZZAROLI, A. *et al.*, 1988, Late Pliocene to Early Mid-Pleistocene mammals in Eurasia: Faunal succession and dispersal events, *Paleogeogr. Paleoclimato. Paleocol.*, **66**, p. 77 – 100.
- BAKINE, J., CONQUÉRÉ, F., VILMONT, J.-C., and PHAN, K.D., 1965, Les spinelles des basaltes de Monistrol d'Allier (chaîne du Devès, Haute-Loire), *Bull. Soc. franc. Minér. Crist.*, **88**, p. 447–455.
- BAKSI, A.K., HSU, V., MC. WILLIAMS M.O., and FARRAR, E., 1992, $^{40}\text{Ar}/^{39}\text{Ar}$ dating of the Brunhes-Matuyama geomagnetic reversal, *Science*, **256**, p.356–357.
- BOIVIN, P., 1982, Interactions entre magmas basaltiques et manteau supérieur. Arguments apportés par les enclaves basiques de basaltes alcalins: exemple du Devès (Massif Central français) et du volcanisme quaternaire de la région de Carthagne (Espagne), Thèse de Doctorat d'Etat, Université Blaise Pascal, Clermont Ferrand.
- BONIFAY, E and TRUZE, E., 1987, Dynamique sédimentaire et evolution des Lacs de maars: L'exemple du Velay, Documents du C.E.R.L.A.T., Memoire No. 1, p.29–64.
- BONIFAY, M.F., 1986, Intérêt des études taphonomiques au Pléistocène ancien: soleiphac et Ceysseguet (Blansac, Haut-Loire), *Bull. Mus. Natn. Hist. Mat., Paris 4e ser.*, 8, section C, n. 2, p.269–281.
- BOUT, P., 1960, Le Villafrancien du Velay et du Bassin Hydrographique Moyen et Supérieur de l'Allier, *Imprimerie Jeanne D'Arc Le Puy (Haute-Loire)*, 337p.
- BOUT, P., 1974, Le maar de Saint-Geney's près Saint-Paulien (Haute-Loire), Considérations générales sur les maars du Velay et d'Auvergne, (In *Problèmes du volcanisme en Auvergne et Velay*), p. 257–280, Imprimerie Watel, Brioude.
- CASSIGNOL, C and GILLOT, P.Y., 1982, Range and effectiveness of unspiked K-Ar dating, (In *Odin, G., ed: Numerical dating in Stratigraphy*), 159–179, 5 figs, 7 tabs., Chichester, John Wiley and Sons.
- CHAMPION, D.W., DARLYMPLE, G.B. and KUNTZ, M.A., 1981, Radiometric and paleomagnetic evidence of the Emperor reversed polarity event at 0.46±0.05 myr. in basalt lava flows from the Eastern Snake River, Idaho, *Geophys. Res. Lett.*, V. 8, n. 10, p.11667–11680.
- COUTHURES, J., 1982, Contribution a la chronostratigraphie de formation Plio-Pleistocene du Massif Central (France), Thèse de Doctorat d'Etat, Université Pierre et Marie Curie.
- COX, K.G., BELL, J.D., AND PANKHURST, R.J., 1979, *The interpretation of igneous rocks*, Allen and Unwin Ltd., London.
- CREER, K.M., SMITH, G., TUCHLOKA, P., BONIFAY, E., THOUVENY, N. and TRUZE, E., 1986, A preliminary paleomagnetic study of the Holocene and Late Würmian Sediments of Lac du Bouchet (Haute-Loire), *Geophys. J.R. Astr. Soc.*, **86**, 143–164.
- CREER, K.M., THOUVENY, N. and BLUNK, I., 1990, Climatic and geomagnetic influences on the Lac du Bouchet paleomagnetic SV record through the last 110,000 years, *Phys. Earth Planet. Inter.*, **64**, p.314–341.
- DARLYMPLE, G.B. and LANPHERE, M.A., 1969, *Potassium-Argon Dating*, W.H. Freeman and Company, San Francisco, 258 p.

- DALRYMPLE, G.B., 1969, $^{40}\text{Ar}/^{36}\text{Ar}$ Analyses of Historic Lava Flows, *Earth. Planet. Sci. Lett.*, **6**, 47–55.
- DEREK, V. AGER, 1980, *The Geology of Europe*, McGraw Hill Book Co. (UK) Limited, p.240–249.
- FOURIS, M., 1989, Les sites Villafranchiens du Devès et les basaltes se la valée de l'Allier: application de la methode K-Ar, Thèse de Doctorat de l'Université Blaise Pascal, 206p.
- FUHRMANN, U. and LIPPOLT, H.J., 1987, Excess Argon and dating of Quaternary Eifel volcanism: III Alkali Basaltic rocks of the Central West Eifel/FR Germany, *N. Jb. Geol. Palaont. Mh.*, Stuttgart, H4, 213–236, 5 figs, 6 tabs.
- FUNKHOUSER, J.G. and NAUGHTON, J.J., 1968, Radiogenic helium and argon in ultramafic inclusions from Hawaii, *J. Geophys. Res.*, **73**, 4601–4608.
- GOER A. DE., MERGOIL, J., 1971, Structure et dynamique des edifices volcaniques tertiaires et quaternaires. Symposium J. Jung. Geologie, geomorphologie et structure profonde du Massif Central francais. Edit Plein Air Servicess, Clermont-Ferrand
- IRVIN, T.N. and BARAGAR, W.R.A., 1971, A guide to the classification of the common volcanic rocks, *Can. J. Earth Sci.*, **8**, p.23–48.
- IZETT, G.A. and OBRADOVICH, J.D., 1994, age constraints for the Jaramillo Normal Subchron and the Matuyama-Brunhes geomagnetic boundary, *JGR*, Vol **199**, N B2, p.2925–2934.
- JACOBS, J.A., 1984, *Reversals of the Earth's Magnetic Field*, Adam Hilger Ltd., Bristol, 224p.
- JARDIN, L., 1973, Les enclaves bassiques et ultrabassiques dans les basaltes alcalins de la channe du Devès (Haute Loire). These 3e Cycle, Univ. Lyon, pp.1–120.
- KANEOKA, I and AOKI, K., 1978, $^{40}\text{Ar}/^{39}\text{Ar}$ Analyses of phlogopite nodules and phlogopite bearing peridotite in S. African Kimberlites, *Earth Planet.Sci.Lett.*, Amsterdam, **40**, 119–129.
- KIEFFER, G., 1971, Aperçu sur la morphologie des régions volcaniques du Massif Central, In Symposium Jean Jung: Géologie, géomorphologie et structure profonde du Massif Central français, Plein Air Service, Clermont Ferrand, p.511–527.
- KOCHEGURA, V.V. and ZUBAKOV, V.A., 1978, Paleomagnetic time scale of Ponto-Caspian Plio-Pleistocene deposits, *Paleogeogr. Paleoclimato. Paleoecol*, **23**, p.151–160.
- LE MAITRE, R.W., 1989, *A classification of igneous rocks and glosary terms*, Blackwell Sci. Publ., Oxford, London.
- MANKINEN, E.A. and DARLYMPLE, G.B., 1979, Reversed geomagnetic polarity time scale for the interval 0–5 my BP., *J. Geophys. Res.*, **84**, p.615–626.
- MCDUGALL, I., POLACH, H.A., and STIPP, J.J., 1969, Excess radiogenic argon in young subaerial basalts from Auckland volcanic field, New Zealand, *Geochim. Cosmochim. Acta*, vol.**33**, 1485–1520.
- MERGOIL, J., 1987, Les volcans du mont Denise., Son histoire, ses volcans, Cahiers du C.P.I.E. no. 2, série géologie, Le Puy.
- PASTRE, J-F., 1987, Les formations Plio-Quaternaires du bassin de l'Allier et le volcanisme régional (Massif Central, France), Thèse de Doctorat d'Etat, Université Paris VI.
- REILLE, M. and DE BEAULIEU, J.L., 1988, History of the Wurm and Holocene vegetation in Western Velay (Massif Central France): A comparison of pollen analysis from three corings at Lac du Bouchet, *Rev. Paleobotany and Palynology*, **54**, p.233–248.
- , 1989, The Velay Maars (Massif Central France): Key sites for the middle and upper Pleistocene pollen sequences, *Quaternary Type sections: Imagination or Reality?*, Rose and Schluochter eds., Balkema, Rotterdam, p.79–89.
- , 1990, $^{40}\text{Ar}/^{39}\text{Ar}$ dating of Quaternary plagioclase: examples from the Taupo volcanic zone, Abstract in Seventh Int. Conf. Geochronol. Chosmochronol. Isotope Geol., Canberra, Australia, p.80.
- TEULADE, A., 1989, Tephrologie des formations Cendro-Ponceuses en milieux lacustres Quaternaires, Thèse de Doctorat de l'Université d'Aix-Marseille II.
- THOUVENY, N and BONIFAY, E., 1984, New chronological data on European Plio-Pleistocene faunas and hominids occupation sites, *Nature*, **308**, No.5957, p.355–358.
- THOUVENY, N., 1990, Les variations du champ magnétique terrestre dans le dernier cycle climatique, Thèse de Doctorat d'Etat, Université d'Aix Marseille II.