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Snapshot of the Matuyama-Brunhes reversal process recorded in $^{40}\text{Ar}/^{39}\text{Ar}$ -dated lavas from Guadeloupe, West Indies

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[1] We obtain new $^{40}\text{Ar}/^{39}\text{Ar}$ ages for three lavas that record part of the Matuyama-Brunhes geomagnetic field reversal process on Guadeloupe. These lavas record a reversed-transitional-reversed magnetostratigraphy and yield a weighted mean isochron age of 785.2 ± 5.2 ka (2σ analytical uncertainty) relative to an age for the Fish Canyon sanidine standard of 28.201 Ma. This age is of greater accuracy than ages obtained previously by K-Ar dating. These lavas may record directional fluctuations occurring between the Matuyama-Brunhes precursor and the final directional reversal. Such variations have been observed in some globally distributed coupled paleomagnetic and oxygen isotope marine sedimentary records of the Matuyama-Brunhes reversal. Previous paleointensity estimates from these lavas indicate reduced, but fluctuating field strength during this time.

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1. Introduction

[2] Constraining the temporal evolution and surface morphology of the geomagnetic field during reversals will lead to a better understanding of geodynamo processes and conditions at the core-mantle boundary. Many paleomagnetic studies on lava and sedimentary sequences have sought to reveal details

of the reversal process and they provide valuable information on temporal changes in direction and intensity at the Earth's surface [e.g., Channell and Kleiven, 2000; Brown *et al.*, 2009]. To correlate these variations globally and assess the complexity of the geomagnetic field during reversals reliable magnetic measurements from volcanic rocks must be accompanied by accurate radioisotopic dating.

[3] Attaining greater precision and accuracy in radioisotopic dating has been given recent impetus through calibration of $^{40}\text{Ar}/^{39}\text{Ar}$ standard ages [e.g., Kuiper *et al.*, 2008; Rivera *et al.*, 2011] and ^{40}K decay constants [Min *et al.*, 2000; Renne *et al.*, 2011] against the astronomical time scale. In addition, numerical inversion methods applied to paleomagnetic data from sedimentary and volcanic sequences have been used to create temporally continuous global models of reversing fields [e.g., Leonhardt and Fabian, 2007]. This approach provides one way to assess the temporal and spatial evolution of the transitional magnetic field, e.g., possible growth of flux patches at the core-mantle boundary and their implication for the initiation and development of the reversing field [Amit *et al.*, 2010]. However, such interpretations depend critically on the accuracy and uncertainty of dated lavas for constraining and verifying the age of specific features along derived model time series.

[4] The Matuyama-Brunhes (MB) reversal is the most recent geomagnetic field reversal and is recorded at a number of globally dispersed volcanic sites [Kristjánsson *et al.*, 1988; Baksi *et al.*, 1992; Quidelleur and Valet, 1996; Singer and Pringle, 1996; Valet *et al.*, 1999; Quidelleur *et al.*, 2002, 2003; Singer *et al.*, 2005; Gratton *et al.*, 2007; Brown *et al.*, 2009; Leonhardt *et al.*, 2009; Camps *et al.*, 2011; Mochizuki *et al.*, 2011]. Previous studies have obtained a combination of paleodirections, paleointensities, and radioisotopic ages (K-Ar or $^{40}\text{Ar}/^{39}\text{Ar}$); however, few have dated lavas recording transitional directions [Singer and Pringle, 1996; Singer *et al.*, 2005; Camps *et al.*, 2011]. Although constraints on the age of key features that may be related to the MB reversal process recorded in volcanic sequences have been improved [e.g., Singer *et al.*, 2005], the precision of many radioisotopic dates remains low, inhibiting interpretation of paleomagnetic field structures.

[5] We will frequently use the terms “reversal process” and “final directional reversal.” This is to separate the underlying driving mechanism of the reversal (and all related surface changes in direction and intensity), from one particular surface field characteristic of the reversal process: the period over which directions switch definitively from reversed to normal polarity. This distinction is made as the MB reversal process may start some time before the final directional reversal occurs [Singer and Pringle, 1996; Leonhardt and Fabian, 2007]. In addition, a decrease in intensity

may begin before the onset of major directional changes. This has been observed in some volcanic sections, e.g., Steens Mountain [Prévot *et al.*, 1985]. Most reversals generated in numerical dynamo simulations are associated with a sustained period of dipole decay before the final directional reversal [Coe *et al.*, 2000; Amit *et al.*, 2010]. It is therefore worthwhile to determine the timing of variations in direction and intensity preceding the final directional reversal as they may be an expression of the reversal process.

2. Sampling Locations

[6] Four andesitic lavas were sampled on the island of Basse-Terre, Guadeloupe (Figures 1 and 2). These lavas were previously sampled by Carlut *et al.* [2000] (hereafter referred to as C00), Carlut and Quidelleur [2000] (hereafter referred to as CQ00), and Brown *et al.* [2009] (hereafter referred to as B09). Based upon K-Ar Cassignol-Gillot ages [Samper *et al.*, 2007, 2009], the island can be split into five broad volcanic complexes (Figure 1b): the Basal complex (2.79–2.69 Ma); Septentrional Chain (1.8–1.15 Ma); Axial Chain (1.02–0.44 Ma); Monts Caraïbes Massif (0.56–0.45 Ma); and Grande Découverte volcanic complex (0.20 Ma–present). Samples were collected at two locations in the Axial Chain complex as part of the study of B09: (1) Morne Marigot quarry (16.088°N, 298.241°E), a rare exposure of flat-lying superposed andesitic lavas, and (2) a river cut section ~500 m to the southwest of the quarry and ~20 m below the base of the quarry. Three flows were sampled in the quarry (G01, G02, and G03) and are identical to the flows with the same name in B09. Flows G01, G02, and G03 correspond, respectively, to flows GU9, GU10, and GU11 in C00 and CQ00. G03/GU11 is the uppermost flow stratigraphically. The isolated flow to the southwest is the same as flow GD in B09. Further details can be found in C00 and B09 and the samples used specifically in this study are described more fully in B09. We use B09 flow names.

3. Radioisotopic Dating

3.1. Previous K-Ar Results

[7] C00 and CQ00 used the Cassignol-Gillot “unspiked” K-Ar method to determine the ages of lavas G01, G02, and G03. Ages were calculated

Figure 1. (a) Location of Basse-Terre, Guadeloupe, in the Lesser Antilles. Localization of main faults as shown in *Samper et al.* [2007]. (b) Location of Morne Marigot sampling site on Basse-Terre. Dashed lines define five broad volcanic complexes as described by *Samper et al.* [2007]. Elevation data from the consortium for spatial information (<http://srtm.csi.cgiar.org>) [*Reuter et al.*, 2007].

Figure 2. VGP positions from C00 (red) and B09 (blue) from Guadeloupe flows. Errors are $dm - dp$ ellipses. Star is location of Guadeloupe. Lines between VGPs are great circles and are a guide to the order of the VGPs; they do not indicate the path of the VGP.

using *Steiger and Jäger* [1977] decay constants and isotopic ratios. Weighted mean ages for G01 and G03 were calculated using an inverse- 1σ weighting and analytical uncertainties were published at 1σ . Recalculating these dates and their 2σ uncertainties using the inverse-variance of the analytical uncertainty [Taylor, 1997] gives a mean age of 777 ± 16 ka for G01 and 783 ± 31 ka for G03. CQ00 reported a single age of 781 ± 36 ka (2σ) for G02. However, the use of the interlaboratory standard GL-O to calibrate the ^{40}Ar signal makes comparison with results from other laboratories problematic [Charbit *et al.*, 1998]. For further experimental details and results of the individual experiments see C00 and CQ00.

3.2. New $^{40}\text{Ar}/^{39}\text{Ar}$ Ar Experiments

[8] Eighteen $^{40}\text{Ar}/^{39}\text{Ar}$ incremental heating experiments at the University of Wisconsin-Madison were made on specimens from GD, G01, G02, and G03. Groundmass samples free of phenocrysts were prepared by crushing, sieving to isolate the 250–350 μm fraction, density separation using methylene iodide and hand-picking under a binocular microscope [Jicha *et al.*, 2012]. Purified groundmass separates were weighed and then wrapped in 99.99% copper foil packets placed into Al disks with Fish Canyon sanidine (FCs) standard to monitor neutron fluence. The Al disks were irradiated for 1 h at the Oregon State University Training, Research, Isotopes, General Atomic (TRIGA) reactor in the Cadmium-Lined In-Core Irradiation Tube (CLICIT). J values were uniform within analytical uncertainty across individual Al disks, and the precision of the J values averages $\pm 0.10\%$ (2σ). The uncertainty in age determined for each specimen reflects only analytical sources of error at the 2σ level, unless otherwise noted. ~ 200 mg groundmass packets were incrementally heated in a double-vacuum resistance furnace following the procedures of Jicha *et al.* [2012]. Argon isotopes were measured using a Mass Analyzer Products (MAP 215-50) mass spectrometer and the isotopic data was reduced using ArArCalc software version 2.5 (<http://earthref.org/ArArCALC/>). We use an atmospheric $^{40}\text{Ar}/^{36}\text{Ar}$ value of 295.5 ± 0.5 [Steiger and Jäger, 1977]. As noted by Renne *et al.* [2009] the majority of ages determined by K-Ar and $^{40}\text{Ar}/^{39}\text{Ar}$ methods are insensitive to the isotopic composition of atmospheric argon. Complete analyses, including reactor constants, mass discrimination, and J values are in given in supporting information.

3.3. $^{40}\text{Ar}/^{39}\text{Ar}$ Ar Results

[9] Ages are calculated relative to an age of 28.201 ± 0.046 Ma for FCs [Kuiper *et al.*, 2008] and a value for $\lambda^{40}\text{K}$ of $5.463 \pm 0.107 \times 10^{-10}$ year $^{-1}$ [Min *et al.*, 2000]. These values are used in the current geologic time scale [Schmitz, 2012] and provide a level of accuracy that supersedes previously published K-Ar results. As the total uncertainties on the astrochronologic age models against which our $^{40}\text{Ar}/^{39}\text{Ar}$ ages are compared are difficult to assess, we report all ages with 2σ analytical uncertainties only (includes J uncertainty). Using the calibration of Kuiper *et al.* [2008] limits systematic contributions to the total uncertainty to less than $\pm 0.25\%$. This translates to an added uncertainty (in addition to the analytical contributions reported) of, at most, approximately ± 2 ka at the MB boundary. However, for most of the $^{40}\text{Ar}/^{39}\text{Ar}$ ages discussed here, the systematic contribution to the total uncertainty is less than 1 ka.

[10] From 18 experiments 15 gave concordant plateau ages (Figure 3 and Table 1). It was not possible to obtain reliable plateaus from the normally magnetized G03 flow; two experiments gave discordant age spectra (Figure 4). Total fusion ages of 793 ± 16 and 782 ± 16 for G03 are indistinguishable from the K-Ar age of 783 ± 31 ka from C00, but the $^{40}\text{Ar}/^{39}\text{Ar}$ experiments suggest that the eruption age for this lava cannot be precisely constrained. One experiment from GD gave discordant age spectra.

[11] Isochron ages are preferred as they combine estimates of analytical precision plus internal disturbance of the sample without assumptions about the trapped argon component [e.g., Singer and Pringle, 1996]. This results in larger, more conservative, uncertainties compared with plateau ages. The final isochron age for each flow is the age of the combined isochron. At the 95% confidence level lavas GD, G01 and G02 have: (1) weighted mean isochron and plateau ages of the individual flows that are indistinguishable; and (2) mean isochron ages that are indistinguishable between flows.

4. Discussion

4.1. Previous Directional and Paleointensity Results

[12] B09 determined a reversed-transitional-reversed-normal (R-T-R-N) magnetostratigraphy

Figure 3. Age spectra, K/Ca spectra, and isochrons obtained from incremental heating experiments on GD, G01, and G02 lavas. For illustrative purposes isochrons of several experiments on each lava were normalized to a common neutron fluence parameter, J . 2σ is analytical uncertainty.

for lavas GD-G01-G02-G03 (Figure 2). This sequence broadly agrees with results from C00 for flows G01, G02, and G03 (Figure 2). For flows G02 and G03, we note the two 95% error ellipses calculated for each flow using the directions of B09 and C00 do not overlap (Figure 2). The source of this discrepancy is unknown and the published data of C00 do not allow us to investigate this further. In both B09 and C00, the upper three flows record a T-R-N polarity sequence regardless of differences in the mean directions calculated in the two studies.

[13] Flow mean microwave absolute paleointensity estimates from GD and G01 [B09] and flow means calculated from combined thermal [CQ00] and microwave estimates for G02 and G03 [B09] using all available data (Table 2) are variable, but lower than the present field (virtual dipole moment of $7.9 \times 10^{22} \text{ Am}^2$; see B09). For G02, when all data are considered (rather than using the selection criteria of B09), the thermal Thellier mean is $9 \mu\text{T}$ lower than the microwave mean with nonoverlapping 1σ uncertainties (overlapping at 2σ). For G03 the difference is less: $4.5 \mu\text{T}$ and lying within 1σ uncertainty of the microwave mean. Based upon the available data it is not possible to discern if one or both data sets are biased. Flows G01 and G02 record the lowest intensity values and are

coincident with the two directions that show a departure from fully reversed or normal directions. Only G01 and G03 pass the within flow consistency criteria ($\leq 5 \mu\text{T}$) of *Tauxe and Staudigel* [2004]. We therefore treat interpretations using these paleointensity data with caution.

4.2. Comparison With Sedimentary Records

[14] A number of coupled marine isotope-paleomagnetic records span the MB; however, few have high enough sedimentation rates to capture the reversal process in detail and many lack a high-resolution isotopic age model. A suite of five high sedimentation rate, high-resolution coupled isotope-paleomagnetic records from the North Atlantic [Channell *et al.*, 2010] are some of the most detailed recordings of the MB reversal. In addition, they are some of the closest marine paleomagnetic records to Guadeloupe (Ocean Drilling Program (ODP) Site 1063 is nearest at $\sim 2000 \text{ km}$). As the field may be globally nonuniform in its morphology and the timing of reversal features may differ between locations [Clement, 2004; Wicht, 2005; Brown *et al.*, 2007; Leonhardt and Fabian, 2007], a comparison with cores close to Guadeloupe may minimize any offset in the timing of the final directional reversal recorded at different locations. Channell *et al.* [2010] calculated a

Table 1. Summary of $^{40}\text{Ar}/^{39}\text{Ar}$ Incremental Heating Results From the Two Lowest Flows at Morne Marigot Quarry (G01 and G02) and the Isolated, but Stratigraphically Lowest Flow GD^a

Sample	N	$^{40}\text{Ar}/^{36}\text{Ar}_i (\pm 2\sigma)$	MSWD	Isochron Age (ka) ($\pm 2\sigma$)	$^{39}\text{Ar}\%$	MSWD	Plateau Age (ka) ($\pm 2\sigma$)
GA0207B	6 of 8	297.9 ± 10.6	0.11	757.7 ± 92.1	85.9	0.13	778.1 ± 24.2
Flow G02	6 of 8	294.5 ± 7.5	0.27	804.2 ± 74.5	85.2	0.23	794.9 ± 20.0
	6 of 8	290.0 ± 8.9	0.33	831.2 ± 83.7	84.8	0.56	780.8 ± 23.2
	8 of 8	296.6 ± 5.5	1.02	780.5 ± 51.3	100.0	0.83	788.3 ± 32.7
GA0205A	7 of 8	293.7 ± 6.3	0.58	794.2 ± 29.5	99.8	0.54	788.0 ± 20.1
Flow G02	7 of 7	296.7 ± 4.5	0.43	775.9 ± 40.1	100.0	0.41	782.5 ± 30.9
	8 of 8	294.3 ± 3.9	0.85	790.6 ± 29.4	100.0	0.79	785.1 ± 23.7
Combined isochron and weighted mean plateau ages:				789.7 ± 15.7			786.1 ± 9.0
GA0101B	7 of 8	292.1 ± 5.7	0.07	795.7 ± 36.1	96.8	0.29	777.9 ± 20.7
Flow G01	7 of 8	293.7 ± 5.4	0.60	795.4 ± 39.2	96.5	0.57	784.8 ± 22.5
	6 of 8	292.7 ± 8.4	1.00	799.7 ± 52.1	87.6	0.89	783.0 ± 17.7
	7 of 7	296.3 ± 3.5	0.09	793.4 ± 35.8	100.0	0.11	799.4 ± 24.8
Combined isochron and weighted mean plateau ages:				798.0 ± 18.3			785.0 ± 10.5
GD0103B	9 of 9	295.7 ± 1.1	0.74	785.3 ± 15.4	100.0	0.67	785.6 ± 15.3
Flow GD	7 of 8	295.6 ± 2.5	1.21	780.0 ± 8.8	99.9	1.01	780.1 ± 7.6
	8 of 8	294.8 ± 5.0	0.43	787.2 ± 12.9	100.0	0.38	786.1 ± 10.4
	8 of 8	295.6 ± 5.4	0.55	794.9 ± 26.9	100.0	0.40	795.3 ± 20.7
Combined isochron and weighted mean plateau ages:				783.3 ± 5.8			783.6 ± 5.5
Total weighted mean*:				785.2 ± 14.7			784.4 ± 2.5
Total weighted mean:				785.2 ± 5.2			784.4 ± 4.3

^aResults in stratigraphic order (GD—oldest; G02—youngest). Isochron ages (in bold) are preferred as they provide a more conservative determination of the age. All ages calculated using the decay constants of *Min et al.* [2000] ($\lambda^{40}\text{K} = 5.463 \pm 0.107 \times 10^{-10} \text{ year}^{-1}$). J-values calculated relative to 28,201 Ma for the FCs standard [Kuiper et al., 2008]. N is the number of incremental heating steps. MSWD is the mean squares weighted deviate; $^{40}\text{Ar}/^{36}\text{Ar}_i$ is a measure of extraneous ^{40}Ar compared with $^{40}\text{Ar}/^{36}\text{Ar}_i = 295.5$ for atmospheric argon [Steiger and Jäger,

1977]. Weighted means ($\bar{x}_w$) and standard deviations (σ_w) are calculated using the inverse of the analytical variance ($w_i = \frac{1}{\sigma_i^2}$): $\bar{x}_w = \frac{\sum x_i w_i}{\sum w_i}$ and $\sigma_w = \frac{1}{\sqrt{\sum w_i}}$ [Taylor, 1997], with the exception of * where the standard deviations are calculated using the weighted mean ages of the three flows.

Figure 4. Age and K/Ca spectra obtained from incremental heating experiments on two samples from G03. Both yield discordant spectra.

Table 2. Directional and VDM/VADM Results From C00, CQ00, and B09 for Four Flows From Morne Marigot, Basse-Terre, Guadeloupe. n/N = Number of Selected Specimens/Number of Measured Specimens; *I* = Inclination; *D* = Declination; α_{95} = 95% Circular Confidence Limit [Fisher, 1953]; *k* = Precision Parameter [Fisher, 1953]; *dm* = 95% Confidence Limit for VGP Latitude and *dp* = 95% Confidence Limit for VGP Longitude [cf. Butler, 1992]^a

Flow	Directions										Paleointensity	
	n/N	<i>I</i> (°)	<i>D</i> (°)	α_{95} (°)	<i>k</i>	VGP Lat. (°)	VGP Lon. (°)	<i>dm</i> (°)	<i>dp</i> (°)	n/N	VDM/VADM ($\times 10^{22}$ Am ²)	1 σ ($\times 10^{22}$ Am ²)
<i>G03—783.0 ± 31.0 ka^b</i>												
B09	4/5	24.2	353.8	3.8	579.5	83.1	179.1	4.1	2.2	8/11	4.1/4.3	1.2/1.2
C00 and CQ00	9/10	31.4	340.7	3.8		71.5	213.7	4.3	2.4	2/6	2.9/3.1	
Mean:										10/17	3.8/4.1	1.2/1.3
<i>G02—789.7 ± 15.7 ka^c and 781 ± 36 ka^b</i>												
B09	7/8	−61.9	192.3	9.5	40.9	−61.0	136.9	14.8	11.5	4/9	2.4/3.8	0.8/1.2
C00 and CQ00	6/9	−57.0	162.0	9.1		−63.3	85.3	13.3	9.6	4/6	1.0/1.5	0.2/0.3
Mean:										8/15	1.7/2.6	0.9/1.5
<i>G01—798.0 ± 18.3 ka^c and 777 ± 16 ka^b</i>												
B09	4/6	11.6	253.2	17.1	29.9	−14.4	218.8	17.3	8.8	5/14	1.3/1.3	0.4/0.4
C00	8/8	1.7	241.0	11.0		−27.5	217.9	11.0	5.5			
<i>GD—783.3 ± 5.8 ka^c</i>												
B09	7/7	−31.4	168.6	8.8	47.8	−79.0	34.3	9.9	5.5	2/8	5.1/5.7	-

^aNote corrections to *dm* and *dp* shown in the appendix of B09. *k* was not shown in C00 or CQ00. For G02 and G03 mean VDM/VADM and 1 σ are combined estimates from CQ00 (classical Thellier) and B09 (microwave); GD and G01 estimates are from B09 (microwave). It was not possible to calculate combined mean directions for flows G01, G02, and G03 using B09 and C00 data sets as specimen-level directions were not shown in C00 and only specimen-level directions from Thellier experiments on G02 and G03 were shown in CQ00. All age errors are shown at 2 σ analytical uncertainty.

^bRecalculated K-Ar ages from C00 and CQ00 (see section 3.1).

^cCombined ⁴⁰Ar/³⁹Ar isochron ages from this study (see section 3.3 and Table 1).

mean age of 773.1 ± 0.8 ka (2 σ) for the midpoint (virtual geomagnetic pole (VGP) path crossing the equator) of the MB final directional reversal recorded at these sites. For the same cores they estimated VGPs departed from a range associated with “normal” secular variation at 775.3 ± 1.4 ka (2 σ). In addition they estimated the astronomical age of the MB precursor [Hartl and Tauxe, 1996] to be 794 ka. (See Channell *et al.* [2010] for details on the construction of the oxygen isotope age models and for a discussion of the chronology of other coupled isotope-paleomagnetic records recording the MB reversal.)

[15] The temporally continuous global model of the MB reversal of Leonhardt and Fabian [2007] generated a global minimum in dipole energy at 774.5 ka. This is coincident with the majority of the local final directional reversals generated by the model. This estimate is slightly older than the mean age of the midpoint of the reversal calculated by Channell *et al.* [2010]; however, the chronology of the model is only based on the age model of ODP Site 664 [Valet *et al.*, 1989; Raymo *et al.*, 1997; Lisiecki and Raymo, 2005] and the mean ⁴⁰Ar/³⁹Ar age of a sequence of lavas on Maui recording part of the MB reversal process [Singer *et al.*, 2005].

[16] The weighted mean age of the combined isochron ages from flows GD, G01, and G02 is 785.2 ± 5.2 ka (the small uncertainty of this age results from the relatively high precision of the combined isochron age of flow GD). If we assume the R-T-R directional fluctuation recorded by these lavas occurred over a time shorter than the analytical uncertainties of the individual age determinations, then this age is our best limit on the timing of this behavior. This age would place the directional variation between the MB precursor and the onset of the main directional reversal recorded in the North Atlantic sediments of Channell *et al.* [2010]. In addition, this directional change would precede the global minimum in dipole energy generated in the model of Leonhardt and Fabian [2007].

[17] High sedimentation rate cores from the North Atlantic [Channell and Lehman, 1997; Channell and Kleiven, 2000; Channell *et al.*, 2004, 2010] and the South Atlantic [Yamazaki and Oda, 2001] recorded complex directional variations (multiple VGP loops) as part of the final directional reversal. In particular, Channell *et al.* [2010] noted a directional fluctuation at ~ 781 ka in the North Atlantic sedimentary record of ODP Site 984 [Channell and Lehman, 1997; Channell *et al.*, 2004]. It

precedes the final MB directional reversal and has VGPs that reach between 20° and 30° latitude. This fluctuation (and subsequent directional variability) is coeval with a low in relative paleointensity and is compatible, within uncertainty, with the timing of directional and intensity changes recorded in the lower three Guadeloupe lavas (GD, G01, and G02). The MB model of *Leonhardt and Fabian* [2007] generated a similar fluctuation for some locations between 784 and 775 ka.

[18] Directional variability preceding the MB final directional reversal has been noted in other marine sedimentary records. These include North Atlantic ODP Site 1063 [*Channell et al.*, 2010], South Atlantic ODP Site 1082 [*Yamazaki and Oda*, 2001], Celebes and Sulu Sea ODP Sites 767 and 769 [*Oda et al.*, 2000], western Pacific cores MD982187 and PS40 [*Suganuma et al.*, 2010], Boso Peninsula, Japan [*Tsunakawa et al.*, 1999], and the Olorgesailie sedimentary Formation, Kenya [*Tauxe et al.*, 1992].

[19] *Coe and Glen* [2004] suggested that for at least some reversals complex directional behavior may be characteristic of the reversal process. Directional variability preceding and as part of the final directional reversal have been observed in sedimentary records of the Jaramillo reversals [*Channell and Lehman*, 1997; *Channell and Kleiven*, 2000; *Clement*, 2004], Cobb Mountain reversal [*Clement*, 2000], and Gauss-Matuyama reversal [*Glen et al.*, 1999] and in volcanic sequences recording the Steens Mountain reversal [e.g., *Jarboe et al.*, 2011] and C27n-C26r reversal [*Risager et al.*, 2003]. The three Guadeloupe lavas dated in this study may capture snapshots of similar complex directional variations coincident with a reduction in field strength preceding the final directional reversal. This may be a feature common to some reversals.

5. Conclusions

[20] We have obtained new $^{40}\text{Ar}/^{39}\text{Ar}$ ages for three lavas from the island of Guadeloupe that have previously been determined to record directional and intensity variations related to the Matuyama-Brunhes reversal process. The mean isochron age of this reversed-transitional-reversed sequence of lavas is 785.2 ± 5.2 ka (2σ analytical uncertainty). If these lavas record snapshots of paleofield behavior that occurred rapidly on a time scale shorter than the precision of the individual $^{40}\text{Ar}/^{39}\text{Ar}$ age determinations, the weighted mean age indicates they record directional variability

between the MB precursor and the final directional reversal. Such behavior has been observed in a sparse number of high sedimentation rate marine paleomagnetic records. The age, duration, and geomagnetic character of the period preceding the final direction reversal must be confirmed by further paleomagnetic work and $^{40}\text{Ar}/^{39}\text{Ar}$ dating on new and previously studied volcanic sections, e.g., Maui [*Coe et al.*, 2004; *Singer et al.*, 2005]. This should be done in conjunction with new paleomagnetic studies on high sedimentation rate cores with coupled oxygen isotope chronologies.

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