Physics of the Earth and Planetary Interiors 237 (2014) 18–24

Contents lists available at ScienceDirect

Physics of the Earth and Planetary Interiors

journal homepage: www.elsevier.com/locate/pepi

Late Permian paleomagnetic results from the Lodève, Le Luc, and Bas-Argens Basins (southern France): Magnetostratigraphy and geomagnetic field morphology

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ARTICLE INFO

Article history:
Received 4 March 2014
Received in revised form 12 September 2014
Accepted 18 September 2014
Available online 30 September 2014

Keywords:
Geocentric axial dipole
GAD
Permo-Carboniferous Superchron
Illawarra
Permian
Paleomagnetism

ABSTRACT

Paleomagnetic results are presented from 271 stratigraphically-ordered horizons at four locations in southern France. Our focus is mainly on the Late Permian (258 horizons), but results from 13 horizons in the Triassic Buntsandstein are also reported. We argue that the Permian results extend magnetostratigraphic coverage up to the upper Capitanian Stage, some 6 million years after the end of the Permo-Carboniferous Reversed Superchron defined by the Illawarra Reversal in the Wordian Stage. When combined with published data, an overall mean paleopole at 49°N, 161°E (A_{95} = 4°, N = 9) is obtained. This is virtually identical to the upper Permian pole obtained by Bazhenov and Shatsillo (2010) using the intersecting great-circle method. Agreement between the two procedures, which are based on entirely independent data, supports the geocentric axial dipole (GAD) model.

1. Introduction

Two characteristics of the geomagnetic field are of particular interest to paleomagnetists: polarity and morphology. In the present case, these are approached using new results from southern France obtained as the first step in a project to investigate as many suitable targets as possible along a paleomeridional belt covering the full extent of the Permian Eurasian Plate—from Iberia to Siberia. Most of the strata investigated were deposited in the Late Permian and span the end of the Permo-Carboniferous Reversed Superchron (PCRS). Several published results from southern France come from lower stratigraphic horizons, so that much of the PCRS is now reasonably-well covered. Having a duration of some 50 million years, the PCRS is the longest interval of constant polarity discovered so far—from ~318 to ~267 Ma, according to the latest global summary (Gradstein et al., 2012). Such a feature is of great interest to the history of the geodynamo, and thus to the geodynamics and thermal evolution of Earth's interior. Paleomagnetic results from this time interval have also played an important role in the long-debated reconstruction of Pangea and the associated problem of the morphology of the geomagnetic field. We therefore scrutinize our new results, in conjunction with the published record, to assess the validity of the geocentric axial dipole (GAD) model in the geological past.

2. Sampling and laboratory measurements

Oriented samples were collected at four localities in southern France: one in the Lodève Basin (~40 km WNW of Montpellier), and three in the Le Luc and Bas-Argens Basins (~40 and ~70 km NE of Toulon, respectively) (Fig. 1). Orientation was by magnetic compass and bubble inclinometer. A total of 416 samples were collected over a combined stratigraphic thickness of 281 m (Table 1A). A single sample was collected at each horizon in order to maximize the density of stratigraphic coverage and thus reduce the chance of missing short polarity events. The entire collection involved seven stratigraphically-ordered sequences, but most of our samples come from the two long sections at La Lieude (La Lieude Formation) and Gonfaron 1 (Pélitique Formation) (Table 1B summarizes the relevant stratigraphic nomenclature). The remaining five sequences were exploratory in nature as we attempted to probe higher stratigraphic levels where outcrops are more restricted. Gonfaron 2b also belongs to the Pélitique Formation, Le Muy 2 samples the La

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http://dx.doi.org/10.1016/j.pepi.2014.09.002
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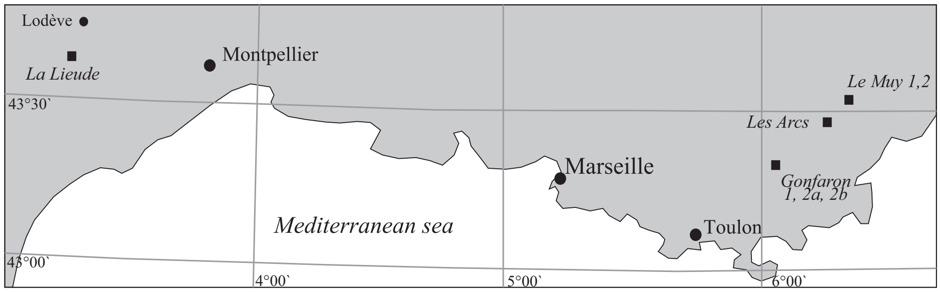

Fig. 1. Squares indicate the sampling locations at La Lieude (Lodève Basin/La Lieude Formation), Gonfaron (Le Luc Basin/Pélitique Formation and Triassic Buntsandstein), Les Arcs (Le Luc Basin/Pélitique and Les Arcs Formations), and Le Muy (Bas-Argens Basin/La Motte Formation and Triassic Buntsandstein). See text and Tables 1A and 1B for further details.

Table 1A
Sampling sites.

Site	Lat (°N)	Long (°E)	Thickness (m)	*N* (*N*)
La Lieude[a]	43.631	3.270	127	74 (127)
Gonfaron 1	43.341	6.294	101	118 (132)
Gonfaron 2a	43.323	6.286	3	8 (16)
Gonfaron 2b	43.323	6.286	16	20 (30)
Les Arcs	43.470	6.488	19	32 (62)
Le Muy 1	43.548	6.571	13	5 (23)
Le Muy 2	43.520	6.563	2	14 (26)

N = number of samples accepted (measured). See text.
[a] The mid-point of the extended section at La Lieude is given.

Table 1B
Summary of stratigraphic nomenclature.

Lodève	Le Luc	Bas-Argens
	Buntsandstein	
	Les Arcs Fm.	Les Arcs Fm.
La Lieude Fm.	**Pélitique Fm.**	**La Motte Fm.**

Formations in bold font are those investigated in this paper.
Durand (2008) equates the Pélitique and La Motte formations.

Motte Formation, and the section at Les Arcs spans the boundary between the La Motte Formation and the overlying Les Arcs Formation. Durand (2008) equates the Pélitique and La Motte Formations. Two sections (Gonfaron 2a and Le Muy 1) fall in the Triassic Buntsandstein.

The La Lieude Formation comprises red, green and gray sandstones and siltstones (with gray colors predominating at higher levels) dipping southwards at 15–20°. The Pélitique Formation is represented by a monotonous alternation of siltstones and claystones of generally red color with occasional green intercalations, all dipping at 5–10°SSE. The lower part of the Les Arcs section (La Motte Formation) consists of red claystones with rare green layers. These are overlain by gray, sometimes reddish, siltstones and sandstones of the Les Arcs Formation. Le Muy 2 consists of red claystones of the La Motte Formation. The strata at Les Arcs and Le Muy are flat-lying.

The Lodève Basin redbeds have been studied by several authors (Kruseman, 1962; Merabet and Guillaume, 1988; Cogné et al., 1990; Maillol and Evans, 1993; Haldan et al., 2009) who all conclude that the entire sequence carries reversed polarity and thus falls within the PCRS. But Evans (2012) found evidence—from a single sample—of a return to normal polarity at the very top of a section that is stratigraphically higher than all previous studies. We therefore spent some time looking for outcrops of even higher levels to extend the stratigraphy as far as possible. The new data reported here essentially represent an upward extension of the section sampled by Evans (2012). The other localities we studied are in the same general area investigated by Merabet and Daly (1986), who reported normal polarity in 20% of their samples. However, they did not collect their samples in any organized stratigraphic way. We therefore sought out appropriate sections that would permit a reliable magnetostratigraphy to be established.

In the laboratory, all samples were subjected to detailed stepwise thermal demagnetization and principal component analysis. Remanence measurements were made on 2G Enterprise cryogenic magnetometers at the Institut de Physique du Globe de Paris and at the University of Alberta. Thermal demagnetization was carried out in a laboratory-built furnace (Paris) and an ASC Model TD-48SC furnace (Edmonton). Some two thirds of the samples (271/416) exhibited straightforward behavior and yielded unambiguous characteristic directions, with most of them having MAD < 10° after the removal of variable amounts of secondary overprints. But the remaining third yielded vector end-point plots that were so noisy as to be uninterpretable. Reliable characteristic directions could not be isolated from such samples. The directional results obtained from interpretable vector end-point plots are summarized in Fig. 2.

3. Discussion

3.1. Magnetostratigraphy

As indicated by Fig. 2, both polarities are found at Les Arcs and Gonfaron but only reversed polarity occurs at La Lieude and Le Muy. The corresponding stratigraphic profiles are shown in Fig. 3. Gonfaron 1 and 2b are entirely reversed, whereas section 2a is entirely normal. At La Lieude, we find no evidence of the normal polarity reported by Evans (2012). But it should be noted that our new section contains a substantial sampling gap (due to lack of outcrop), with only one sampled horizon between 10 and 32 m. At Les Arcs, we see reversed polarity at the base, followed by mostly normal polarity above, but with three possible short reversed zones. Finally, both sections at Le Muy are entirely reversed.

We use the 2012 updated Permian Time Scale of the International Commission on Stratigraphy (www.stratigraphy.org) with the addition of the term Wordian-N for the normal-polarity interval whose lower bound is the Illawarra Reversal (Gradstein et al., 2012). This nomenclature is preferable because it indicates a finite polarity interval (like the terms chron and subchron), rather than just a polarity transition indicated by the term Illawarra Reversal. Given the unsatisfactory state of Permian chronostratigraphy in the sedimentary basins of southern France—poor radiometric coverage, lack of diagnostic fossils, conflicting results (Durand, 2008)—it is worthwhile to enquire if paleomagnetism can provide any chronological control. If we associate the tentative evidence for normal polarity at La Lieude reported by Evans (2012) with the Illawarra Reversal, then a coherent magnetostratigraphic picture

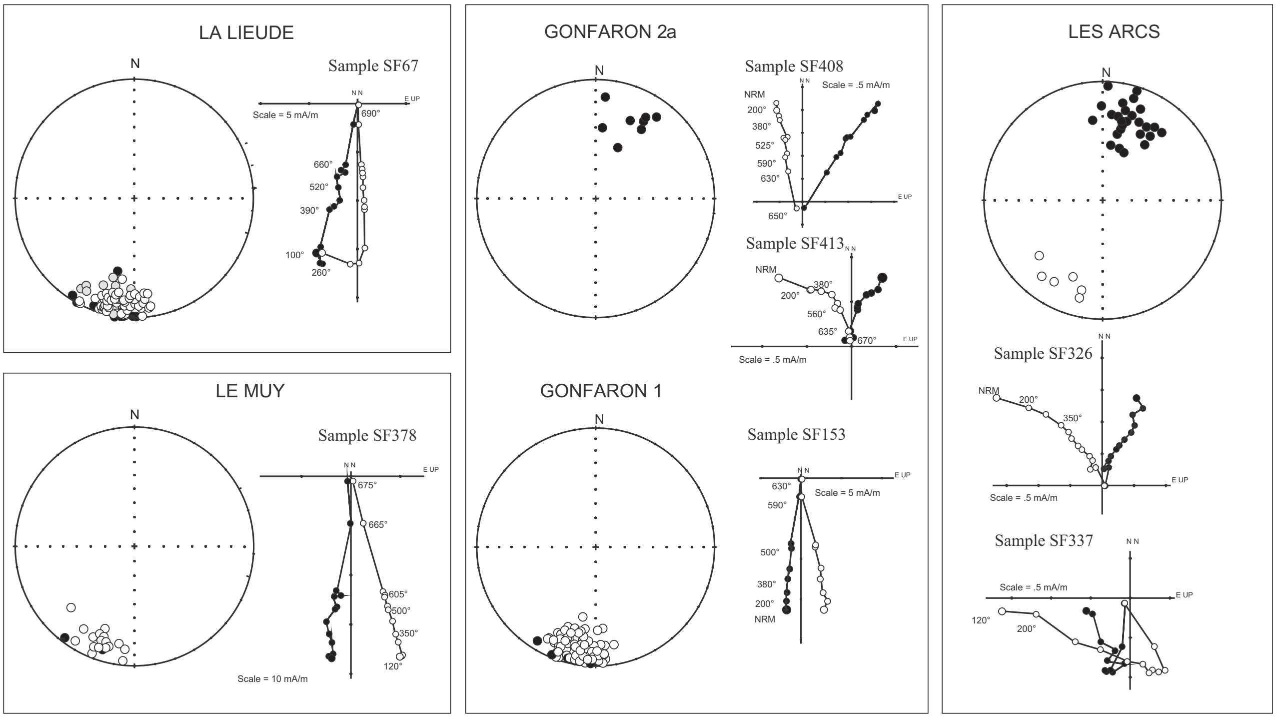

Fig. 2. Characteristic directions for each sampling location (Le Muy 1 and 2 are combined). Open (closed) symbols are on the upper (lower) hemisphere. Representative orthogonal vector end-point plots during stepwise thermal demagnetization are given. Open (closed) symbols are in the vertical (horizontal) plane.

emerges that is compatible with all the geological evidence. Our new data from La Lieude and Gonfaron 1/2b (Fig. 3a) thus fall into the lengthy (~ 5 Myr) reversed interval above the Wordian-N polarity zone, and probably occupy much of the Capitanian Stage. The mixed polarities at Les Arcs can then be correlated with the mixed polarity zone in the uppermost Capitanian. This is consistent with fossil evidence in the La Motte Formation (Bourquin et al., 2007). Le Muy 2 (Fig. 3b) then fits at, or slightly below, the base of the section at Les Arcs — they are both in the La Motte Formation.

Between Les Arcs and our two Triassic sites (Le Muy 1, Gonfaron 2a) there is a significant hiatus spanning the Wuchiapingian and Changhsingian Stages (~ 8 Myr) in the Permian, plus the Induan and Olenekian Stages (~ 5 Myr) in the Triassic (see Table 1 in Bourquin et al., 2007). The samples from Le Muy 1 generally behaved erratically during demagnetization and only 5 samples out of the 23 collected gave interpretable results. They are all reversed. The situation at Gonfaron 2a was a little better, with 8 successful samples out 16. They are all normal. Given the fossil evidence for an Anisian age (Bourquin et al., 2007), it is reasonable to correlate Gonfaron 2a to the mostly normal lower part of the Anisian (centered at ~ 246 Ma), and to associate Le Muy 1 with the mostly reversed zone higher up in the Anisian (centered at ~ 243 Ma) (see Fig. 25.7 in Gradstein et al., 2012).

3.2. Paleomagnetic poles

The mean directions and corresponding paleopoles for each of our sampling locations are summarized in Table 2, and relevant published data from southern France are listed in Table 3. Most entries in Table 3 give the data reported in the original papers, but we also list the IAGA Global Paleomagnetic Database reference number for completeness. In the six cases indicated by asterisks, we quote the IAGA data directly. The results summarized in Table 3 constitute a rather heterogeneous group which requires some scrutiny. Entries in bold font are retained for further analysis as detailed below. The others are regarded—for one reason or another—as being less reliable. Entry1 (Evans and Maillol, 1986) [IAGA number 1207] was obtained from an unoriented mining drill core in an exercise to see if cross-bedding could be used for azimuthal control. It does not provide a reliable paleopole. However, the authors did report data from fifteen fully-oriented surface samples from a nearby 10 m outcrop. For completeness, we list this result (2), but since it represents a single site we do not regard it as a robust paleopole. Entries 3 [2361] and 4 [2454] involve rather restricted sampling (one and three sites, respectively—the latter with a large uncertainty). The early work of Kruseman (1962) (5 and 6, both [168]) is superseded by that of Merabet and Guillaume (1988) (7 and 8, both [1813]).

A detailed paleomagnetic study of the Lodève Basin (1200 m, 108 sites, 201 samples) was reported by Maillol and Evans (1993). Results from a further 88 samples (cut from six large blocks collected from different layers in the lower part of the section studied by Maillol and Evans) were added by Haldan et al. (2009). These latter authors make the important observation that the directional results from the entire 1200 m section fall into two groups, a lower one (9), which they assign to the Sakmarian–Artinskian Stages, and an upper one (10), which they assign to the Kungurian–Wordian Stages. We note that Maillol (1992) made a very similar analysis in his unpublished doctoral thesis. Giving unit weight to sites, he obtained poles of 46°N, 154°E, A_{95} = 2° and 42°N, 154°E, A_{95} = 3°, for the lower and upper halves of the section, respectively—virtually identical to the Haldan et al. (2009) results. Entry 11 gives the pole corresponding to the directional results reported by Evans (2012) from a 100 m section at La Lieude in the Lodève Basin.

Poles 12 to 19 are from different areas in southern France. We place the Estérel results (15 and 16, both [165]) in the “less reliable” category for two reasons. First, the result obtained from sediments (15) is based on only three sites. Second, the pole obtained from igneous rocks (16) is compromised by ambiguous conglomerate tests (Vlag et al., 1997). Pole 17 is from the Dôme de Barrot compilation of Haldan et al. (2009) who add new data to the earlier work of van den Ende (1970) and Kruiver et al. (2000). We include

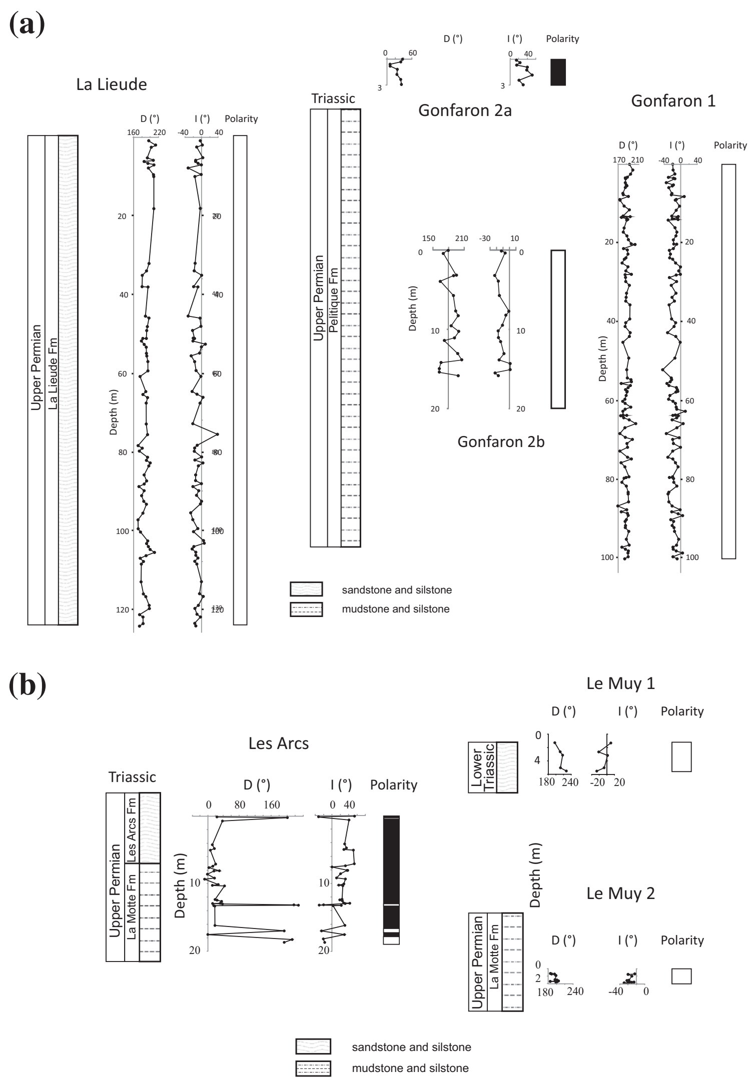

Fig. 3. Lithology, declination, inclination, and interpreted polarity (black = normal, white = reversed). (a) La Lieude and Gonfaron. (b) Les Arcs and Le Muy.

the Rodez Basin results (18 and 19), but defer comment until the discussion of tectonic rotations. Entries 20 and 21 represent the poles obtained from our two long stratigraphic sections (La Lieude and Gonfaron 1, respectively), except that number 20 combines (at the site level) all the data from the La Lieude Formation in the Lodève Basin, i.e., the result in Table 2 plus the data of Evans (2012).

Having described the broad picture, we can now more effectively discuss the five "exploratory" results (Table 2: Gonfaron 2a and 2b, Les Arcs, and Le Muy 1 and 2). The two Triassic sections, Gonfaron 2a (8 samples spanning 3 m) and Le Muy 1 (5 samples spanning 13 m), yield paleopoles lying to the west of the other results listed in Table 3, as would be expected from the European apparent polar wander path (Domeier et al., 2012). But their large uncertainties (10.1° and 12.8°, respectively) preclude any firm conclusions regarding apparent polar wander. Gonfaron 2b (20 samples, 16 m) is laterally equivalent to part of Gonfaron 1 and the two results do not differ significantly; the VGP for Gonfaron 1 falls inside the 95% confidence circle of 2b. This is certainly encouraging, but counting 2b as an independent VGP would give undue weight to this time interval. The VGP for Le Muy 2 is in good agreement with the cluster of reliable results in Table 3, but we choose not to include it in the calculation of an overall mean paleopole because the 14 samples involved span only 2 m stratigraphically. Finally, the results from Les Arcs are important because they yield evidence of both polarities that pass the reversal test. However, the observed inclination is steeper than the other results in Table 2 and this leads to a VGP some 10° to the northwest of the main VGP cluster. This discrepancy is puzzling. Inadequate averaging of secular variation seems unlikely in a collection of 32 samples spanning 19 m that include a polarity reversal. Allowing for possible flattening and/or local tectonic rotations only makes matters worse. In view of these difficulties we omit this VGP from further discussion. In short, the five "exploratory" results do provide some useful information—particularly regarding polarities—but none of them are adequate for deriving completely reliable paleopoles.

The twelve paleopoles regarded as reliable are illustrated in Fig. 4. First, we note that poles 20 and 21 are in agreement and thus support our magnetostratigraphic correlation which places them both in the Capitanian Stage. All twelve poles form a reasonably tight cluster with a mean of 48°N, 162°E, A_{95} = 3°. But the question of how much time is represented must be addressed. Geological ages deduced by the various authors involved indicate that a time span of ~30 million years may not be unreasonable, during which time appreciable apparent wander may have occurred. To assess this potential difficulty, we re-calculate the mean VGP after removal of what can be regarded as older poles (entries 7, 9, and 14, and the 3 older sites from entry 13). Very little change occurs,

Table 2
Paleomagnetic directions and poles.

Section	*N*	In situ				Tilt corrected				
		D	I	k	α95	D	I	k	α95	
La Lieude	74	189.8	14.2	27.5	3.2	189.5	−9.7	30.3	3.0	Ft+
Plat = 50.4; Plong = 168.4; dp/dm = 1.5/3.0										
Plat = 50.5; Plong = 168.4; A_{95} = 2.4; *K* = 48.6										
Gonfaron 1	118	190.3	−6.5	37.2	2.2	190.2	−13.3	44.4	2.0	Ft+
Plat = 50.4; Plong = 169.6; dp/dm = 1.0/2.0										
Plat = 52.5; Plong = 169.5; A_{95} = 1.5; *K* = 79.7										
Gonfaron 2a	8	24.2	22.2	28.6	10.5	24.4	28.8	23.8	11.6	
Plat = 55.2; Plong = 142.1; dp/dm = 7.0/12.8										
Plat = 55.9; Plong = 141.8; *N* = 8; A_{95} = 10.1; *K* = 30.8										
Gonfaron 2b	20	186.2	−9.0	23.7	6.8	185.7	−11.5	24.3	6.8	
Plat = 52.2; Plong = 177.0; dp/dm = 3.5/6.9										
Plat = 52.3; Plong = 177.0; A_{95} = 6.0; *K* = 30.4										
Les Arcs										
Normal	26	18.0	30.2	22.9	6.1	18.0	30.2	22.9	6.1	Rt+, γ/γc = 10.3/13.5
Reversed	6	207.7	−24.5	32.3	12.0	207.7	−24.5	32.3	12.0	
Total	32	19.9	29.2	23.4	5.4	19.9	29.2	23.4	5.4	
Plat = 57.4; Plong = 149.1; dp/dm = 3.3/6.0										
Plat = 58.1; Plong = 148.3; A_{95} = 4.7; *K* = 30.1										
Le Muy 1	5	212.6	−7.7	20.3	17.4	213.0	−8.6	19.1	18.0	
Plat = 43.9; Plong = 140.7; dp/dm = 9.2/18.2										
Plat = 41.0; Plong = 140.3; A_{95} = 12.8; *K* = 36.9										
Le Muy 2	14	196.8	−15.2	78.3	4.5	196.8	−15.2	78.3	4.5	
Plat = 51.3; Plong = 159.3; dp/dm = 2.4/4.6										
Plat = 51.4; Plong = 159.3; A_{95} = 3.5; *K* = 128.2										

Bold (regular) font indicates mean pole calculated from VGPs (directions).
Ft+ – fold test positive. Rt+ – reversal test positive.

the new mean lying at 49°N, 161°E (A_{95} = 4°, *N* = 9). At face value, it appears that intra-Permian apparent polar wander relative to southern France was minimal. Alternatively, the time span involved may be significantly reduced because of inaccurate age assignments made by the various authors. At the present time, there seems to be no way of deciding. But the choice does not significantly affect the conclusions discussed below.

3.3. Tectonic rotations

Possible rotations of small crustal blocks in southern Europe are intimately connected to the larger tectonic framework during the evolution of Pangea. This topic has received a great deal of study and has generated an enormous literature. We restrict attention to the Permian of southern France. Cogné et al. (1990) and Diego-Orozco and Henry (1993) report paleomagnetic results from the Saint-Affrique Basin which lies about 40 km north-west of Lodève. Both papers conclude that the Lodève Basin has not rotated, whereas the Saint-Affrique Basin has had a complex history involving rotations of up to 20°. These observations are important for the study of local tectonics, but they cannot be used to help define the European Apparent Polar Wander Path (APWP). Diego-Orozco et al. (2002) report a very detailed study of the Rodez Basin, about 100 km north–west of Lodève. They conclude that their results from the FIII and Grès Rouges Formations (18 and 23 sites, respectively) imply an average counter-clockwise rotation of 4.3°, but the evidence is by no means compelling. Referring to Fig. 4, we see that the Rodez poles (18 and 19) are entirely consistent with the other data for southern France. Small rotations on the order of a few degrees are very difficult, if not impossible, to demonstrate on paleomagnetic data alone. It is prudent, therefore, to always keep them in mind. In this context, we note that the Dôme de Barrot pole (17) appears to be something of an outlier. Without it the east–west spread of VGPs is reduced from 23° to 15°, but its removal hardly changes the overall mean VGP (49°N, 163°E, A_{95} = 4°, *N* = 8, compared to 49°N, 161°E, A_{95} = 4°, *N* = 9). Lacking independent geological evidence for local rotation, we have opted to retain it.

Aubele et al. (2012) studied Permian and Triassic sediments and volcanic rocks from the Toulon-Cuers Basin which is located immediately west of the sections we sampled: Les Arcs, Gonfaron, Le Muy. They find evidence for significant rotations at their Permian sites, but not at their Triassic ones. Putting their results into a regional context derived largely from Edel (2000), they develop a scenario involving small crustal blocks subjected to wrench faulting. Briefly, they argue that a number of brittle upper crustal blocks riding—like ice floes—on a deeper zone undergoing ductile deformation can undergo relative rotations in both senses (clockwise and counter-clockwise). This whole topic is crucial to working out the evolution of Pangea, but is beyond the scope of the present paper. Here, we are concerned mainly with identifying which data should be used for calculating a robust Permian paleopole for southern France. With the possible exception of site BRO (see Table 1 in Aubele et al., 2012; VGP at 51.5°N, 154.7°E), the results from the Toulon-Cuers Basin provide no such data. However, it is worth noting that site BRO is located close to sites 1–6 of Merabet and Daly (1986), which—like all their sites—gave no indication of rotations.

3.4. Inclination shallowing

It is well known that sediments may acquire a remanent magnetization that is shallower than the ambient field in which they formed. King (1955) found by experiment that the observed inclination, I_{obs}, is related to the inclination of the ambient field, I_{amb}, by $\tan I_{obs} = f \tan I_{amb}$, where f is a coefficient (usually called the flattening factor) lying between 0 and 1. Bilardello and Kodama (2010) find mean values of 0.65 and 0.59 for magnetite-dominated and hematite-dominated sediments, respectively. In their thorough synthesis, Domeier et al. (2012) assume f = 0.6, unless the original authors provided specific values. Using the E/I method of Tauxe and Kent (2004), Haldan et al. (2009) obtain f values of

Table 3
Permian paleomagnetic poles for southern France.

#	Lat	Lon	A_{95}	IAGA	Location/Reference
1	53	151	2	1207	Lodève, mining drill core/Evans and Maillol (1986)
2	47	148	3		Lodève, surface samples/Evans and Maillol (1986)
3*	50.9	144.2	2.9	2361	Lodève, baked contact study/Smith et al. (1991)
4*	49.3	161.6	12.2	2454	Lodève/Cogné et al. (1990)
5*	41.9	170.3	4.0	168	Lodève, Lower/Kruseman (1962)
6*	46.3	156.8	5.1	168	Lodève, Upper/Kruseman (1962)
7	**42.2**	**169.4**	**2.2**	1813	Lodève, Lower/Merabet and Guillaume (1988)
8	**48.6**	**153.3**	**1.2**	1813	Lodève, Upper/Merabet and Guillaume (1988)
9	**46.4**	**154.4**	**1.4**		Lodève, Sakmarian–Artinskian/Haldan et al. (2009)
10	**41.9**	**156.7**	**1.9**		Lodève, Kungurian–Wordian/Haldan et al. (2009)
11	46.1	172.6	4.0		Lodève, La Lieude/Evans (2012)
12	**51.1**	**160.7**	**3.5**	1408	Massif des Maures/Merabet and Daly (1986)
13	**48.8**	**162.5**	**2.6**	3144	Brive Basin/Chen et al. (1997)
14	**45.4**	**164.9**	**4.1**	3292	Largentière Basin, Autunian/Henry et al. (1999)
15*	47.0	150.5	4.5	165	Estérel sediments/Zijderveld (1975)
16*	51.5	142.0	4.8	165	Estérel igneous/Zijderveld (1975)
17	**47.2**	**145.5**	**1.0**		Dôme de Barrot, Roadian/Haldan et al. (2009)
18	**47.0**	**168.1**	**2.2**		Rodez Basin, FIII/Diego-Orozco et al. (2002)
19	**51.5**	**165.8**	**3.5**		Rodez Basin, Grès Rouges/Diego-Orozco et al. (2002)
20	**49.6**	**169.4**	**2.1**		La Lieude combined (see text)
21	**52.5**	**169.5**	**1.5**		Gonfaron 1 (Table 2)

Bold font indicates results accepted for further analysis, as described in the text. Lat(itude), °N; Lon(gitude), °E, A_{95} = 95% confidence limits (degrees). Data were obtained from original sources, or from the IAGA Global Paleomagnetic Database (indicated by asterisks). Confidence limits reported as ellipses (dp,dm) have been converted to circles with $A_{95} = \sqrt{(dp.dm)}$.

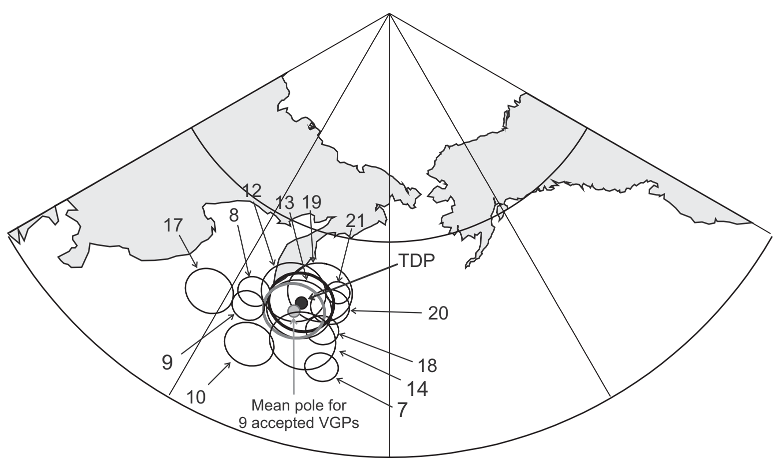

Fig. 4. Virtual Geomagnetic Poles for southern France and their mean (N = 9). Numbers correspond to Table 3. The True Dipole Pole (TDP) obtained by Bazhenov and Shatsillo (2010) using the intersecting great circle method is also shown. 95% confidence circles throughout.

0.82 for the Sakmarian–Artinskian, 0.77 for the Kungurian–Wordian (both in the Lodève Basin), and 0.90 for the Roadian of the Dôme de Barrot. A Monte-Carlo approach (Tauxe et al., 2008) implies that data sets larger than 100 are required to successfully apply the E/I method. Of the new data reported in the present paper, only Gonfaron 1 is large enough. It yields f = 0.81.

Given the low inclination values observed in southern France, the implied paleolatitude adjustments are all less than 1.3°. It is not known to what extent the other results in Tables 2 and 3 might be affected by flattening, and they are based on insufficient numbers of samples to permit the application of the E/I method.

4. Conclusions

Paleomagnetic results from the Permian of southern France indicate that most sediments in this region are reversely magnetized and fall in the PCRS. The new data reported here extend coverage above the Wordian-N interval (whose base is the well-known Illawarra Reversal that defines the end of the PCRS). Evidence from one locality reveals normal polarity that we correlate to the uppermost Capitanian Stage (~ 260 Ma). Some authors have reported paleomagnetic evidence for local tectonic rotations in southern France, connected with the paleogeographic evolution of Pangea. But this is by no means universal. We argue that there are nine results that can be used to establish a robust Late Permian paleopole that falls in the northwest Pacific Ocean (49°N, 161°E, A_{95} = 4°). This is in excellent agreement with the so-called True Dipole Pole (50°N, 163°E, A_{95} = 4°) obtained by the intersecting great-circle method (Bazhenov and Shatsillo, 2010) using entirely independent data. Agreement between the two procedures supports the Geocentric axial dipole (GAD) model, although statistical uncertainty could permit small (< 10%) higher-order terms.

Acknowledgements

Financial support was provided by Grants RFBR #12-05-00403 and 13-05-12030, Ministry of Education and Science of the Russian Federation Grant # 14.Z50.31.0017 and by the Natural Sciences and Engineering Council of Canada. We thank Marc Durand for advice on regional stratigraphy.

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