Trabajos de Geología, Universidad de Oviedo, 30 : 28-36 (2010)

Oviedo (Spain) 1-3 July 2008 International Meeting of Young Researchers in Structural Geology and Tectonics
ORSGET

A synchronous Alpine and Corsica-Sardinia rotation: new paleomagnetic evidences from the Tertiary Piedmont Basin (NW Italy)

M. Maffione[1*], F. Speranza[2], C. Faccena[3], A. Cascella[2], G. Vignaroli[3] and L. Sagnotti[2]

[1]*Now at: University of Plymouth, Plymouth, UK.*

[2]*Istituto Nazionale di Geofisica e Vulcanologia, Laboratorio di Paleomagnetismo. Via di Vigna Murata, 605, 00143 Rome, Italy.*

[3]*Università Roma Tre, Largo San Leonardo Murialdo, 1 – 00146, Rome, Italy.*

[*]*e-mail: marco.maffione@plymouth.ac.uk*

Abstract: We report on the paleomagnetism of 34 sites from Lower Oligocene-Middle Miocene sediments exposed in the Tertiary Piedmont Basin (TPB, NW Italy). Paleomagnetic directions from 23 sites show that the TPB rotated ca. 50° counterclockwise with respect to Africa in Aquitanian-Serravallian times. The rotation, likely driven by underneath nappe stacking, was synchronous with (further) bending of the Alpine chain. Both the rotation magnitude and its timing are similar to those documented for the Corsica-Sardinia microplate, therefore the formation of the western Alpine arc (or part of its present-day curvature) occurred during the rollback of the Apenninic slab and related back-arc spreading of the Liguro-Provençal Basin, and drift of the Corsica-Sardinia block. This suggests a common dynamics driving both the Alpine and the Apennine slab motions. Paleomagnetic data also document that the Adriatic plate has undergone no paleomagnetic rotation since Middle-Late Miocene times.

Keywords: Tertiary Piedmont Basin, paleomagnetism, Alps, Corsica-Sardinia, western Alpine arc.

The boundary between the Africa-Adria plate and the Eurasia plate in the western Mediterranean region is represented by a diffuse, "S-shaped", orogenic belt (Fig. 1). Complexities arise from the fact that boudins of the older inner "Alpine" chain are fragmented, stretched and drifted apart during the Neogene opening of the backarc extensional basins (Alvarez *et al.*, 1974). Because of this intensive late reworking, the 3D restoration of the style and geometry of the ancient Alpine chain is complex and disputed. The western Alpine arc, in particular, is remarkably tight (almost isoclinal) in shape compared to the Apennines-Calabria-Maghrebide arc (Fig. 1). The timing of the formation of the horseshoe-shaped alpine arcuate belt is poorly constrained at present, and hence the mechanism of its formation is still a matter of debate. The rocks exposed in the Tertiary Piedmont Basin (TPB) (Fig. 1) offer the unique opportunity to detail the timing of the CCW rotation affecting the western Alpine arc, and hence to investigate the geodynamics that favoured its bending.

In this paper, we report on a paleomagnetic investigation of the whole sedimentary succession exposed in the TPB. Our data, together with previous paleomagnetic evidence, reveal the rotation recorded by TPB strata while they were passively carried on top of Alpine nappes overthrusting the Adriatic foreland. The detailed reconstruction of the timing and magnitude of the TPB rotation, besides being a definitive

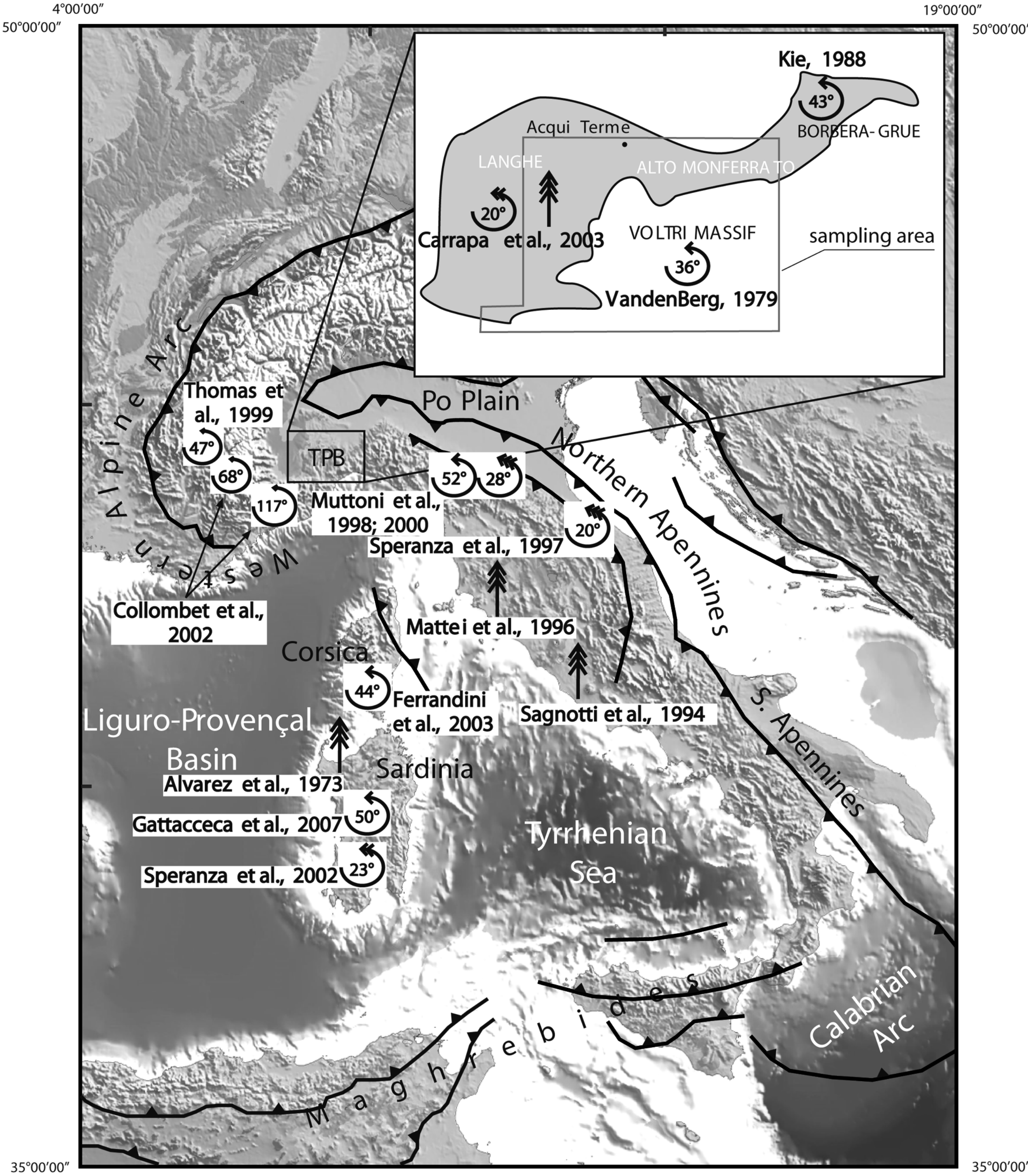

Figure 1. Digital elevation model of the central Mediterranean domain, and mean paleomagnetic rotation values (within circular arrows) with respect to nearby African/European plates for the internal western Alps, the northern Apennines, and the Corsica-Sardinia block (see text for details). Circular arrows with simple, double, and triple tips indicate post-Oligocene, post-Burdigalian, and post-Pliocene rotations, respectively. Vertical arrows indicate non-rotated areas after Late Miocene-Pliocene times.

proof for a null paleomagnetic rotation of Adria, documents that bending of the western Alpine chain is synchronous (and probably genetically related) with a previously unconsidered fourth geodynamic engine: the back-arc spreading of the Liguro-Provençal Basin and drift-rotation of the Corsica-Sardinia microplate.

***Table 1**. Paleomagnetic directions from the Tertiary Piedmont Basin*

Site	Formation	Geographic coordinates Latitude N	Longitude E	Nannofossil Zone	Age	Age (Ma)	Bedding (°)	Chrons	Cleaning Strategy	Tilt corrected D (°)	Tilt corrected I (°)	In situ D (°)	In situ I (°)	k	α95 (°)	n/N	Rotation (°)	Flattening (°)
BTP01	Molare	44° 18' 35.0"	8° 03' 12.2"	-	Rupelian	30.5-33.5	252-14	C12n-C13n	AF ; TH	317.4	39.7	308.4	32.8	332.1	4.2	5/12	-38.2 (6.6)	13.6 (5.4)
BTP06	Rocchetta	44° 32' 17.4"	8° 18' 59.3"	NP24	Rupelian	28.7-29.7	284-11	C10r-C11n1n	AF	124.2	-51.0	130.9	-61.3	94.0	5.3	9/11	-51.3 (0.4)	2.5 (6)
BTP07	Rocchetta	44° 32' 26.8"	8° 18' 19.6"	NP24	Rupelian-Chattian	28.0-29.4	327-6	C9r-C10r	AF	131.7	-55.7	128.7	-61.8	19.5	12.0	9/10	-43.9 (17.7)	-2.2 (10)
BTP09	Rocchetta	44° 36' 31.4"	8° 21' 26.7"	NP24	Rupelian-Chattian	28.0-29.7	18-9	C9r-C11n1r	AF	140.5	-54.6	128.7	-58.5	12.7	14.1	10/11	-35.1 (20.1)	-1 (11.8)
BTP11	Rocchetta	44° 35' 34.8"	8° 33' 01.5"	NP23	Rupelian	30.0-30.5	319-16	C11r	AF	106.2	-48.7	91.4	-59.2	96.9	8.4	6/9	-74.2 (11)	5.7 (7.8)
BTP12†	Rocchetta	44° 36' 38.0"	8° 32' 11.6"	-	Rupelian-Chattian	21.6-32.0	23-21	-	AF ; TH	-	-	-	-	-	-	-	-	-
BTP13	Rocchetta	44° 38' 30.8"	8° 29' 52.8"	NP23	Rupelian	29.9-30.9	236-35	C11n2n-C12n	AF	269.2	32.5	296.5	57.8	56.7	6.5	10/12	-86.4 (7.9)	21.1 (6.6)
BTP15	Cremolino	44° 39' 47.5"	8° 30' 39.1"	MNN4a	Burdigalian	16.5-17.6	359-9	C5Dn-C5Cn3n	AF ; TH	0.5	26.4	0.9	38.9	62.1	9.8	5/10	-1.8 (9.1)	32 (8)
BTP18	Rocchetta	44° 37' 45.0"	8° 40' 08.0"	NP23	Rupelian	30.1-32.3	325-23	C11r-C12r	AF	134.1	-45.1	124.8	-67.5	43.0	9.3	7/8	-51.6 (11.5)	8.5 (8.4)
BTP19*	Rocchetta	44° 36' 20.0"	8° 34' 0.8"	NP23	Rupelian	29.9-30.9	356-23	C11n2n-C12n	AF ; TH	4.4	26.2	7.5	48.9	499.2	2.5	8/8	8.7 (5.5)	27.4 (4.7)
BTP25†	Rocchetta	44° 36' 21.4"	8° 27' 49.1"	NP23	Rupelian	29.9-30.9	325-23	-	AF ; TH	-	-	-	-	-	-	-	-	-
BTP29*	Cremolino	44° 38' 54.8"	8° 27' 22.0"	MNN5a	Langhian	15.0-15.2	29-12	C5Bn2n	AF	5.5	42.7	359.7	53.2	165.0	3.5	12/13	3.3 (4.9)	15.7 (3.5)
BTP30*	Serravalle	44° 43' 44.2"	8° 28' 58.6"	MNN4a	Burdigalian-Langhian	16.0-17.6	21-12	C5Cn	AF ; TH	10.1	40.9	7.4	52.2	202.0	4.3	7/8	7.8 (5.5)	17.5 (4)
BTP31*	Cessole	44° 41' 20.0"	8° 47' 38.0"	MNN5b	Langhian	14.2-14.6	336-22	C5ADn	AF	350.5	34.3	357.3	55.2	46.2	6.8	11/11	-11.8 (7.2)	24 (5.7)
BTP38	Cessole	44° 41' 20.0"	8° 48' 38.0"	MNN5a/b	Langhian	14.8-15.2	310-49	C5Bn1n-C5Bn2n	AF	337.3	36.1	35.6	68.4	96.4	4.7	11/11	-25 (5.5)	22.4 (4.3)
BTP39	Rocchetta	44° 38' 10.0"	8° 45' 53.0"	NP23	Rupelian	30.1-32.3	356-25	C11r-C12r	AF	155.1	-18.5	161.4	-38.7	50.4	7.3	9/9	-20.6 (7.9)	35 (7)
BTP41	Rocchetta	44° 22' 35.0"	8° 13' 50.0"	NP23	Rupelian	29.9-30.9	38-3	C11n2n-C12n	AF	302.4	41.8	299.5	41.4	79.4	4.9	12/12	-53.2 (7.2)	11.6 (5.8)
BTP43	Rocchetta	44° 22' 50.0"	8° 12' 28.0"	NP24	Rupelian-Chattian	28.3-29.9	197-7	C10n-C11n1n/2n	AF	309.4	65.4	321.4	59.6	38.4	9.4	8/10	-44 (17.2)	-9.6 (8.5)
BTP47	Rocchetta	44° 38' 08.0"	8° 41' 42.4"	NP23	Rupelian	29.9-30.9	325-18	C11n2n-C12n	AF ; TH	312.9	42.1	307.8	58.5	62.1	11.7	4/10	-42.8 (13.4)	11.5 (10)
BTP53	Rocchetta	44° 35' 21.9"	8° 32' 47.1"	NP23	Rupelian	29.9-30.9	280-12	C11n2n-C12n	AF	311.7	19.4	314.8	29.7	128.9	3.7	13/13	-44 (5.9)	34.2 (5.2)
BTP57	Rocchetta	44° 34' 22.8"	8°19' 57.0"	NP23	Rupelian	29.9-30.9	253-17	C11n2n-C12n	AF	287.3	43.5	300.1	56.4	101.2	4.8	10/12	-68.3 (7.3)	10 (5.7)
BTP60	Rocchetta	44° 34' 26.7"	8° 19' 54.6"	NP23	Rupelian	29.9-30.9	11-9	C11n2n-C12n	AF	343.9	48.6	338.1	56.2	51.3	8.5	7/9	-11.7 (11.3)	4.9 (7.9)
BTP61	Rocchetta	44° 34' 28.1"	8° 19' 53.6"	NP23	Rupelian	29.9-30.9	245-27	C11n2n-C12n	AF	302.6	52.4	343.2	58.9	86.6	5.6	9/11	-53 (8.8)	1.1 (6.2)
BTP62	Rocchetta	44° 34' 33.1"	8° 19' 51.2"	NP23	Rupelian	29.9-30.9	276-9	C11n2n-C12n	AF	316.6	44.7	323.6	51.2	119.0	4.2	11/11	-39 (6.9)	8.8 (5.4)
BTP64	Rocchetta	44° 34' 43.5"	8° 19' 40.6"	NP23	Rupelian	29.9-30.9	257-2	C11n2n-C12n	AF	306.1	55.1	308.6	56.5	64.9	6.9	8/12	-49.5 (10.7)	-1.6 (6.9)
BTP65*	Monesiglio	44° 35' 08.7"	8° 19' 29.5"	MNN2a	Aquitanian	20.5-20.7	329-10	C6An1n	AF	357.0	49.3	3.7	57.4	72.9	5.1	12/13	-7 (7.5)	7 (5.2)
BTP66	Cremolino	44° 35' 25.0"	8° 18' 41.2"	MNN2b	Burdigalian	19.2-20.2	308-4	C6n	AF ; TH	9.8	36.7	12.3	38.4	226.0	4.5	6/13	5.8 (6.2)	19.6 (4.9)
BTP69*	Cremolino	44° 35' 34.6"	8° 15' 37.9"	MNN4a	Burdigalian-Langhian	16.0-17.6	247-4	C5Cn-C5Dn	AF	0.6	59.2	5.7	57.7	398.2	3.5	5/11	-1.6 (6.2)	-0.9 (3.6)
BTP72*	Cassinasco	44° 38' 17.7"	8° 14' 15.9"	MNN5a	Langhian	14.8-15.2	352-9	C5Bn	AF	359.0	43.3	0.4	52.2	111.3	4.6	10/10	-3.2 (5.9)	15.1 (4.2)
BTP73*	Cassinasco	44° 38' 15.8"	8° 14' 13.8"	MNN5a	Langhian	14.8-15.2	27-4	C5Bn	AF	5.2	49.5	3.2	53.4	97.3	6.8	6/11	3 (8.8)	8.9 (5.8)
BTP75*	Cassinasco	44° 34' 46.4"	8° 08' 11.4"	MNN5a	Langhian	14.8-15.2	296-10	C5Bn	AF	350.3	48.5	1.0	53.6	139.3	3.7	12/13	-11.9 (5.4)	9.9 (3.7)
BTP80	Monesiglio	44° 26' 07.3"	8° 14' 0.8"	MNN1c	Aquitanian	22.9-23.8	322-7	C6An2n/C6Cn	AF	320.8	39.2	320.6	45.9	51.9	8.5	7/11	-39.8 (10.1)	18 (7.7)
BTP84	Rocchetta	44° 28' 36.2"	8° 24' 56.1"	NP23	Rupelian	29.9-30.9	295-9	C11n2n-C12n	AF	334.2	20.0	336.8	27.1	42.6	6.7	12/12	-29.6 (7.5)	33.3 (6.8)
BTP85	Molare	44° 29' 54.3"	8° 25' 09.2"	-	Rupelian	30.9-33.1	263-5	C12r	AF	110.4	-51.4	113.7	-55.9	280.0	3.6	7/13	-65.2 (6.8)	2.1 (5.1)

Table 1. Paleomagnetic directions from the Tertiary Piedmont Basin. The geographical coordinates are referred to ED50 datum. Nannofossil zones are from Martini, (1971) and Fornaciari and Rio, (1996). Age in Ma is from the geological timescale of Gradstein *et al.* (2004), and is inferred considering both the magnetic polarity (chron boundary ages) and our new biostratigraphic data. Bedding is expressed in dip azimuth and dip values. Cleaning strategy is alternating field (AF) and/or thermal (TH). D and I are site mean declination and inclination calculated before and after tectonic correction. k and α_{95} are statistical parameters after Fisher, (1953). n/N is number of samples giving reliable results/number of studied samples at a site. Site mean rotation and flattening values, according to Demarest, (1983), are relative to coeval D and I African values expected at Tertiary Piedmont Basin (errors are in parentheses). The reference African paleopoles are from Besse and Courtillot, (2002). † Sites yielding scattered demagnetization diagrams. *Remagnetized sites (see text).

Methods

We collected 378 cylindrical cores from 34 sites (8-14 cores at each site) located within the Alto Monferrato and the Langhe regions using a petrol-powered portable drill (Table 1). All laboratory analyses were performed in the paleomagnetic laboratory at the Istituto Nazionale di Geofisica e Vulcanologia (INGV, Rome, Italy). The sampled sediment ages were defined according to new *ad hoc* analyses of the calcareous nannoplancton content of specimens from each sampling site. The cores were cut into standard cylindrical specimens of 22 mm height, and then stepwise AF demagnetized in 14-15 steps from 5 to 100 mT, their natural remanent magnetization (NRM) being measured with a DC-SQUID cryogenic magnetometer (2G Enterprises, USA) at the same time. For 8 sites, where the AF cleaning proved to be ineffective, twin specimens from the same cores were subjected to thermal demagnetization in 12 steps up to 600 °C. Furthermore, we measured the hysteresis properties and the acquisition of an isothermal remanent magnetization (IRM) and its subsequent back-field demagnetization of at last one specimen per site, using a Micromag Alternating Gradient Magnetometer (AGM, model 2900). Finally, one specimen per site was also selected in order to investigate the thermal change of the magnetic susceptibility during a heating-cooling cycle from room temperature to 700 °C, using an AGICO CS-3 apparatus coupled to the KLY-3 bridge.

Results

The analyses of the hysteresis properties, the low-field magnetic susceptibility thermal variation and the demagnetization properties during the removal of the NRM indicate that in most of the Oligocene sites the magnetic mineralogy is composed of prevailing pseudo-single domain magnetite and a subordinate fraction of hematite, while the magnetic properties of the younger sediments from the Miocene sites are mainly controlled by the paramagnetic clayey matrix with only a minor fraction of ferromagnetic (*sensu lato*) minerals.

Most of the sites (26) were efficiently AF cleaned at 70-100 mT, while six additional sites needed a thermal treatment up to 450 °C (though several specimens were completely demagnetized at 330 °C). A viscous component, subparallel to the GAD field direction for the study area, was removed for all specimens at 10-20 mT or at 120-180 °C, while a characteristic remanent magnetization (ChRM) direction was isolated in the 20-100 mT or 180-330 °C AF/temperature intervals.

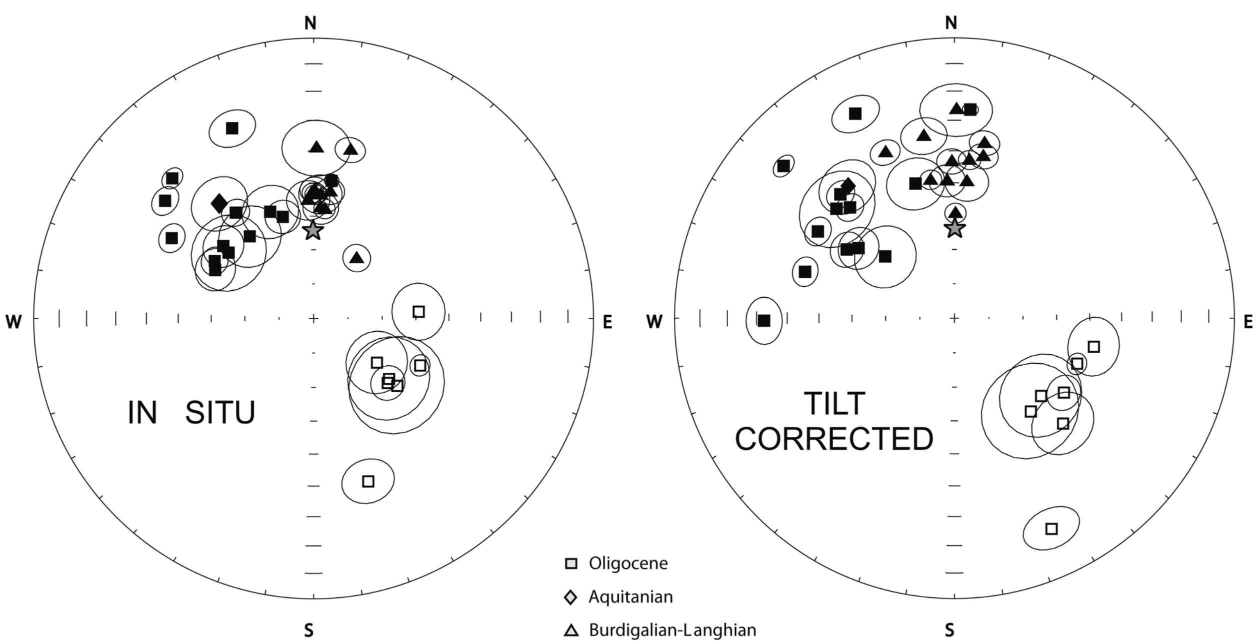

Figure 2. Equal-area projections of the site mean paleomagnetic directions from the TPB. Solid symbols represent projection onto the lower hemisphere (normal polarity magnetization components), while open symbols is the projection onto the upper hemisphere (reverse polarity magnetization components). Open ellipses are the projections of the α_{95} cones about the mean directions. The star represents the normal polarity geocentric axial dipole (GAD) field direction (D = 0°, I = 63.0°) for the study area.

The site-mean directions, evaluated with the help of Fisher's statistics (Fisher, 1953), are generally well defined, the α_{95} values being lower than 10° in all but three sites (Table 1). The tilt-corrected declinations are noticeable scattered, with a spread from a westward to a northward direction (Fig. 2).

Field tests evidenced that all Oligocene-Aquitanian sites (except site BTP19) host a primary magnetization, and their rotation values are reliable for reconstructing the tectonics of the TPB, whereas 8 out of 11 Miocene sites are remagnetized. *In situ* paleomagnetic directions for the remaining 3 Miocene sites lie far from the GAD field direction, suggesting that they retain a primary magnetization (Table 1).

Discussion

The rotation vs. time evolution of the TPB is shown in figure 3. Our data define a 47 ± 17° post-Oligocene CCW rotation of the TPB with respect to Africa/Adria, which is consistent with the 43 ± 8.5° post-Oligocene CCW rotation reevaluated from the data by Kie (1988) and with data by Carrapa *et al.* (2003). The results from Carrapa *et al.* (2003) clearly show that the TPB rotation occurred before Tortonian times and robustly constrain it to the Early-Middle Miocene. The nine Lower-Mid Miocene paleomagnetic directions (five from Carrapa *et al.* (2003), four from this study) do indeed show intermediate rotation values, but do not allow a precise determination of the rotation timing. To sum up, our data, integrated with previous results from Kie (1988) and Carrapa *et al.* (2003), consistently reveal that the TPB rotated ca. 50° CCW with respect to Africa between Aquitanian and Serravallian (roughly between 23 and 12 Ma).

A wealth of paleomagnetic data gathered from Corsican sediments (Ferrandini *et al.*, 2003) and

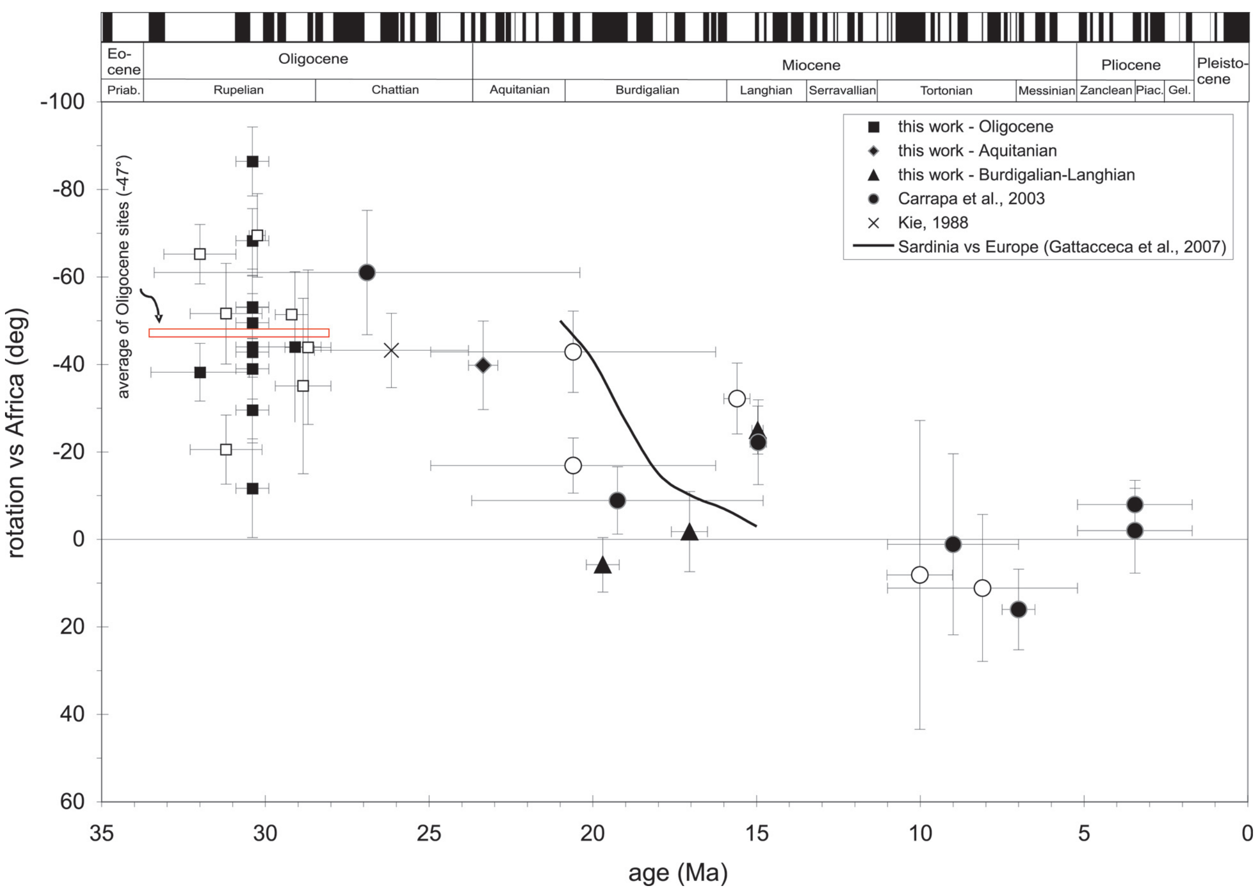

Figure 3. Site-mean paleomagnetic rotation with respect to Africa vs. age, for sites from the TPB. Solid symbols indicate sites yielding normal magnetic polarity, while open symbols indicate sites yielding reverse magnetic polarity. Geological and geomagnetic polarity time scales are from Gradstein *et al.* (2004). Error bars for declination site mean values are the α_{95}/cos (I) values. Error bars for rotations were computed according to Demarest (1983). Error bars for ages were drawn considering both biostratigraphic information and paleomagnetic polarity (see text and Table 1).

Sardinian volcanics (e.g. Gattacceca *et al.*, 2007) and sediments (Speranza *et al.*, 2002) have proven that the Corsica-Sardinia microplate drift was accompanied by a CCW rotation with respect to Europe of ca. 50° in Early-Middle Miocene, between 20-21 and 15-16 Ma. If the Corsica-Sardinia rotation through time, proposed by Gattacceca *et al.* (2007), is superimposed onto the rotation vs. age plot of the TPB (Fig. 3), both the rotation magnitude and its timing from the two data sets appear similar.

The TPB rotation magnitude is also similar to the 52 ± 8° CCW rotation with respect to Africa documented by Muttoni *et al.* (1998) for the Epiligurian units unconformably resting upon Liguride nappes from the northern Apennines (Fig. 1), yet its timing is different. In fact, Muttoni *et al.* (2000) proved that ca. 24° rotation occurred in Oligocene-Miocene times (thus possibly being related with the Corsica-Sardinia rotation), while the remaining 28° occurred during the Pliocene Apennine shortening episodes, in agreement with previous results from Speranza *et al.* (1997).

When considered altogether, the paleomagnetic data from the western Alps, Corsica-Sardinia, the northern Apennines, and TPB may support the following tectonic-rotational scenario (Fig. 4): in the Late Oligocene (Fig. 4a), both the Alpine and the Apennine orogenic fronts roughly struck NE-SW; in the western Alps, E-directed subduction lead to the closure of the oceanic domain and concomitant exhumation of HP-units. At that time, the W-directed Apennines-Calabria subduction process started migrating backward toward ESE as attested by the initiation of the Liguro-Provençal-Balearic and Sardinia rift system (Faccenna *et al.*, 1997). In Early-Middle Miocene times (between 20-21 and 15-16 Ma), the Corsica-Sardinia microplate drifted eastward (from the Provençal-Catalan margin) and contemporaneously rotated CCW by ca. 50°, according to Gattacceca *et al.* (2007) (Fig. 4b). The TPB, located north of the (spreading) Liguro-Provençal Basin, also rotated ca. 50° CCW, together with the underneath Alpine wedge, producing a further tightening of the western Alpine arc. Conversely, the Alpine nappes (including the Liguride units) located NE of Corsica-Sardinia underwent an intermediate (ca. 25°) CCW rotation, implying that they accommodated the excess Corsica-Sardinia rotation (and drift) by internal deformation (through nappe stacking). Most likely, both the TPB and the Epiligurian units were passively carried (and rotated) by underneath rotational thrust sheet emplacement inducing belt bending. Finally, thrust sheet emplacement caused a further 20-30° CCW rotation during the Pliocene, but solely for the northern Apennines (Fig. 4c).

The data set presented in this paper gives a first order constraint on the timing and magnitude of the formation of the western Alpine arc. Its genesis is in fact inextricably linked with the formation of the Apennine-Calabrian Arc, as it develops during the fast rotation of the Sardinia-Corsica block related with the rollback of the Apennine slab. From a geodynamic point of view, this intimate relationship is not unimportant. In fact, if the formation of the Apennine-Calabrian Arc is commonly related with the pre-existing paleogeographic scenario (landlocked oceanic domain) controlling the width of the retreating panel (Faccenna *et al.*, 2006), the formation of the western Alpine arc is commonly related with an opposite process related with the indentation of the Adria microplate (Schmid and Kissling, 2000). The other option is related with the possibility that the western Alpine slab also retreated backwards (westwards) during orogenic accretion in a similar, though slower manner to what observed for the Apennine slab. If this is the case, then we are left to imagine that both the western Alpine and the Apennine slabs start to migrate backwards in opposite directions just after the onset of continental collision (Jolivet and Faccenna, 2000). The mechanism of a concomitant process of two adjacent, but separate, slabs is quite complex. One possible explanation could be related with the displacement of mantle material during subduction. For the case of the Apennine-Calabrian slab, the idea put forward until now is that its backward retreat could have been driven by the consumption of the Liguro-Piedmont and Ionian oceanic crust. In this case it is possible that the backward retreat of the western Alpine arc was driven by the push of the mantle material displaced by the retreating Apenninic slab. Recent 3D experiments of the behavior of retreating slabs show that near the lateral edge of the slab the asthenospheric material located below it escapes laterally, inducing a toroidal component in the mantle flow (Funiciello *et al.*, 2006; Piromallo *et al.*, 2006). Asthenospheric material expelled from below the Apennine slab would then push the Alpine slab westward and force the subduction of continental material. The arcuate shape of the Alpine arc and the helicoidal shape of the Alps-Apennines belt would then essentially result from the geometry of the asthenospheric flow below Liguria and the Ligurian Sea.

We can make a final especulation: with the TPB lying on Alpine nappes stacked onto the Adriatic litho-

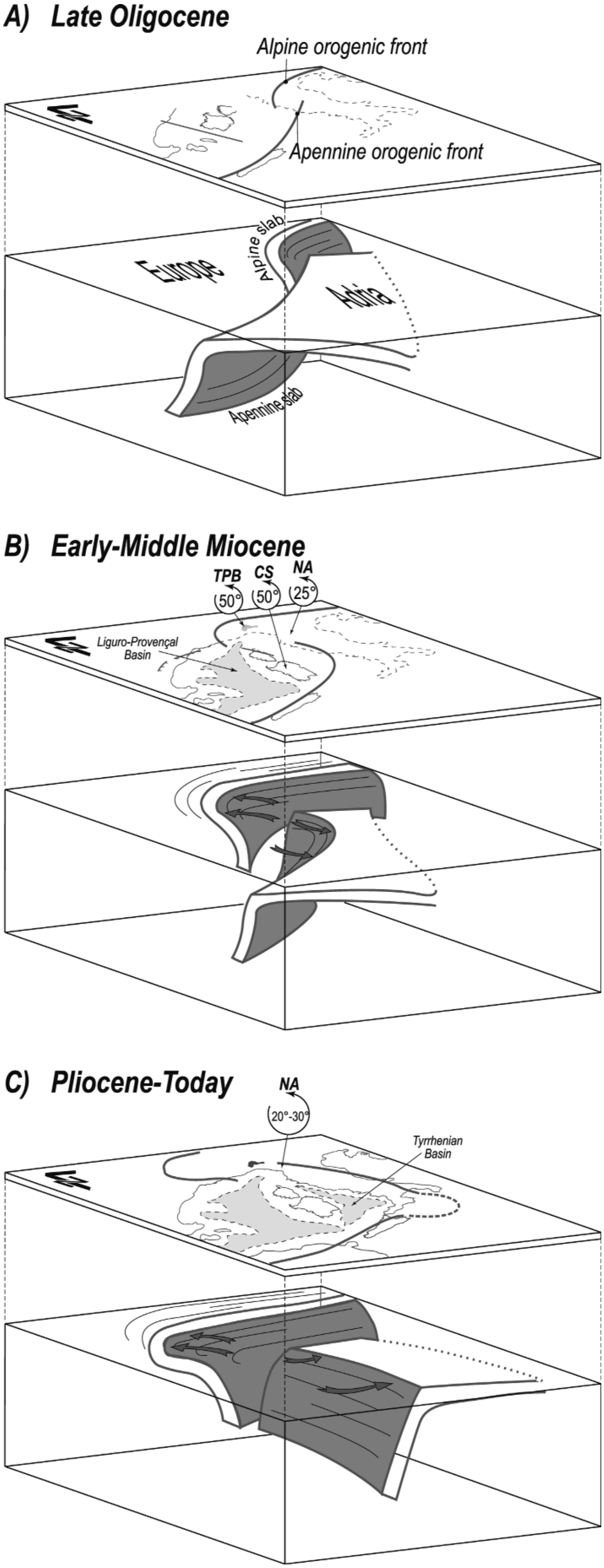

Figure 4. Schematic 3D-block diagram suggesting a possible kinematic reconstruction of the Alps-Apennines belt system since the Late Oligocene. The evolution in time and space of both the Alpine and the Apennine orogenic fronts are correlated together with the deep subduction geometry. The mean paleomagnetic rotation values for each stage are also reported. (TPB) Tertiary Piedmont Basin, (CS) Corsica-Sardinia block, (NA) Northern Apennines.

sphere along the Po Plain, our paleomagnetic data, along with previous results from Carrapa *et al.* (2003), definitely prove that Adria has undergone no paleomagnetic rotation since Middle Miocene times.

Conclusion

Our paleomagnetic data, integrated with previous results from Kie (1988) and Carrapa *et al.* (2003) show that the TPB, unconformably resting upon Alpine nappes, rotated ca. 50° CCW with respect to major nearby plates during Aquitanian-Serravallian times. A very similar rotation magnitude and timing have been previously constrained for the Corsica-Sardinia block, which drifted away from Europe during the spreading of the Liguro-Provençal Basin. This suggests that the Alpine wedge underlying the TPB rotated along with Corsica-Sardinia, inducing the tightening of the western Alpine arc.

The synchronicity between the rotation-drift of the Corsica-Sardinia block (induced by the eastward retreat of the Apenninic slab) and (further) bending of the western Alpine arc, strongly suggests a dynamic link. We speculate that the asthenosphere laterally escaping from the retreating Apenninic slab pushed the western Alpine slab, leading to its further retreat and bending.

Finally, we find no paleomagnetic support for Adria rotation since at least Late Miocene times, which suggests an Adria-Africa coupling during Mesozoic-Tertiary drift.

Acknowledgements

We are grateful to R. Polino and R. Lanza for both the fruitful discussions on the TPB and the help given for the sampling campaign, as well as to M. Mattei who kindly provided sampling facilities. N. D'Agostino and E. Boschi are thanked for providing information on Adria Plate motion and encouragement, respectively.

References

ALVAREZ, W., COCOZZA, T. and WEZEL, F. C. (1974): Fragmentation of the Alpine orogenic belt by microplate dispersal. *Nature*, 248: 309-314.

ALVAREZ, W., FRANKS, F. G. and NAIRN, A. E. M. (1973): Paleomagnetism of Plio-Pleistocene basalts from NW Sardinia. *Nature*, 243: 10-11.

BESSE, J. and COURTILLOT, V. (2002): Apparent and true polar wander and the geometry of the geomagnetic field over the last 200 Myr. *J. Geophys. Res.*, 107, B11.

CARRAPA, B., BERTOTTI, G. and KRIJGSMAN, W. (2003): Subsidence, stress regime and rotation(s) of a sedimentary basin within the western Alps: the Tertiary Piedmont Basin (Alpine domain, Northwest Italy). In: MCCANN and T., SAINTOT, A. (eds): *Tracing tectonic deformation using the sedimentary record. Geol. Soc. London, Spec. Publ.*, 208: 205-227.

COLLOMBET, M., THOMAS J. C., CHAUVIN, A, TRICART, P, BOUILLIN, J. P. and GRATIER, J. P. (2002): Counterclockwise rotation of the western Alps since the Oligocene: New insights from paleomagnetic data. *Tectonics,* 21, 4.

DEMAREST, H. H. (1983): Error analysis of the determination of tectonic rotation from paleomagnetic data. *J. Geophys. Res.*, 88: 4321-4328.

FACCENNA, C., BELLIER, O., MARTINO, J., PIROMALLO, C. and REGARD, V. (2006): Slab detachment beneath eastern Anatolia: A possible cause for the formation of the North Anatolian fault. *Earth Planet. Sc. Lett.*, 242: 85-97.

FACCENNA, C., MATTEI, M., FUNICIELLO, R. and JOLIVET, L. (1997): Styles of back-arc extension in the Central Mediterranean. *Terra Nova*, 9: 126-130.

FERRANDINI, J., GATTACCECA, J., FERRANDINI, M., DEINO, A and FISHER, R. A. (1953): Dispersion on a sphere. *P. Roy. Soc. Lond. A Mat.*, 217: 295-305.

FORNACIARI, E., and RIO, D. (1996): Latest Oligocene to Early Miocene quantitative calcareous nannofossil biostratigraphy in the Mediterranean region. *Micropaleontology*, 42: 1-36.

FUNICIELLO, F., MORONI, M., PIROMALLO, C., FACCENNA, C., CENEDESE, A. and BUI, H. A. (2006): Mapping mantle flow during retreating subduction: Laboratory models analyzed by feature tracking. *J. Geophys. Res.*, 111, B3, B03402.

GATTACCECA, J., DEINO, A., RIZZO, R., JONES, D. S., HENRY, B., BEAUDOIN, B. and VADEBOIN, F. (2007): Miocene rotation of Sardinia: New paleomagnetic and geochronological constraints and geodynamic implications. *Earth Planet. Sc. Lett.*, 258, 3-4: 359-377.

GRADSTEIN, F. M., OGG, J. G. and SMITH, A. G. (2004): *A geologic time scale*, Cambridge University Press, 589 pp.

JANIN, M. C. (2003): Chronostratigraphie et paléomagnétisme des dépôts oligo-miocènes de Corse: implications géodynamiques pour l'ouverture du bassin liguro-provençal. *B. Soc. Géol. Fr.*, 174, 4: 357-371.

JOLIVET, L., and FACCENNA, C. (2000): Mediterranean extension and the Africa-Eurasia collision, *Tectonics*, 19, 6: 1095-1106.

KIE, H. T. (1988): Magnetotectonics in the Piemont Tertiary Basin. *Phys. Earth Planet. Inter.*, 52: 308-319.

MARTINI, E. (1971): Standard Tertiary and Quaternary calcareous nannoplankton zonation. In: FARINACCI, A. (ed): *Proceedings – Planktonic Conference 2. Planktonic Microfossils Roma*. 2: 739-777.

MATTEI, M., KISSEL, C. and FUNICIELLO, F. (1996): No tectonic rotation of the Tuscan Tyrrhenian margin (Italy) since late Messinian. *J. Geophys. Res.,* 101: 2835-2845.

MUTTONI, G., ARGNANI, A., KENT, D. V., ABRAHAMSEN, N. and CIBIN, U. (1998): Paleomagnetic evidence for Neogene tectonic rotations in the northern Appennines, Italy. *Earth Planet. Sc. Lett.*, 154: 25-40.

MUTTONI, G., LANCI, L., ARGNANI, A., HIRT, A. M., CIBIN, U., ABRAHAMSEN, N. and LOWRIE, W. (2000): Paleomagnetic evidence for a Neogene two-phase counterclockwise tectonic rotation in the Northern Apennines (Italy). *Tectonophysics*, 326: 241-253.

PIROMALLO C., BECKER, T. W., FUNICIELLO, F. and FACCENNA, C. (2006): Three-dimensional instantaneous mantle flow induced by subduction. *Geophys. Res. Lett.*, 33, L08304.

SAGNOTTI, L., MATTEI, M., FACCENNA, C. and FUNICIELLO, R. (1994): Paleomagnetic evidence for no tectonic rotation of the central Italy Tyrrhenian margin since upper Pliocene. *Geophys. Res. Lett.*, 21: 481-484.

SCHMID, S. M. and KISSLING, E. (2000): The arc of the western Alps in the light of geophysical data on deep crustal structure. *Tectonics*, 19, 1: 62-85.

SPERANZA, F., SAGNOTTI, L. and MATTEI, M. (1997): Tectonics of the Umbria-Marche-Romagna Arc (central northern Apennines, Italy): new paleomagnetic constraints. *J. Geophys. Res.*, 102, B2: 3153-3166.

SPERANZA, F., VILLA, I., SAGNOTTI, L., FLORINDO, F., COSENTINO, D., CIPOLLARI, P. And MATTEI, M. (2002): Age of the Corsica-Sardinia rotation and Liguro-Provençal Basin spreading: new paleomagnetic and $^{40}Ar/^{39}Ar$ evidence. *Tectonophysics*, 347, 4: 231-251.

THOMAS, J. C., CLAUDEL, M. E., COLLOMBET, M., TRICART, P., CHAUVIN, A. and DUMONT, T. (1999): First paleomagnetic data from the sedimentary cover of the French penninic Alps: evidence for Tertiary counterclockwise rotations in the western Alps. *Earth Planet. Sc. Lett.*, 171: 561-574.

VANDENBERG, J. (1979): Preliminary results of a paleomagnetic research on Eocene to Miocene rocks of the Piemonte basin (NW Apennines, Italy). *Geol. Ultraiectina*, 20: 147-153.