

Probable Middle Holocene geomagnetic excursion at the Red Rock archaeological site, California

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RESUMEN

Se reporta información paleomagnética de tres secciones sedimentarias de la misma localidad en el oeste de California (EE.UU.). Las direcciones del magnetismo remanente natural (MRN) obtenidas en 61 especímenes orientados de tres muestreos detallados, mostraron que algunos registraron componentes magnéticas diferentes a las del campo geomagnético normal actual. La magnetización remanente característica (MRC) fue determinada por desmagnetización progresiva térmica y por campos alternos. El análisis de las muestras indicó que éstas registraron MRC de polaridad oblicua normal, oblicua reversa y reversa durante el Holoceno Medio. Los VGP transicionales muestran algunas coincidencias con los registrados durante el Holoceno Temprano y Medio en México central y los de la posible excursión observada en otras áreas de los Hemisferios norte y sur.

PALABRAS CLAVE: Paleomagnetismo, arqueología, excursión, Holoceno.

ABSTRACT

Paleomagnetic data from three sedimentary sections at a locality in western California (U.S.A.) is reported. Natural remanent magnetization directions obtained from 61 oriented cores showed a magnetic component different from the present geomagnetic field. The characteristic remanent magnetizations (ChRM) show oblique normal, oblique reverse and reverse polarities during the Middle Holocene. The transitional VGP resembles those registered during Early and Middle Holocene in central Mexico and other areas of the Northern and Southern Hemispheres.

KEY WORDS: Paleomagnetism, archaeology, excursion, Holocene.

INTRODUCTION

San Luis Obispo county in Central California has an extraordinary abundance of archaeological remains from late Pleistocene to historical times. The Red Rock quarry site is unusual because there is evidence of native pigment quarrying. The site was excavated by C. Singer and R. Gibson during the 1980's (Gibson *et al.* 1990, Singer 1991).

The Red Rock quarry (RRS, 35°41'N, 121°17'W), is situated on the west side of highway 101, about 3000 m south of Oso Creek on the Pacific shoreline (Figure 1). This quarry is a large chunk of red volcanic rock broken into three pieces, within the high tide splash zone. It was eroded at the end of the eighties. Two rocks have been moved on the beach and the other one, which was sampled, is in its original place. Currently, it is being eroded and removed by the ocean and one piece is already gone.

The rock was hollowed out in one place due to mineral extraction by natives. Sediments covered the rock afterwards until its recent discovery (Figure 2a).

The site has not been dated. Our initial goal was to document a relative chronology of the archaeological level using palaeosecular variation. The southeast face exposed by wind and wave erosion was sampled in 1992. In 1997, two additional samplings (RR1 and RR2) were made in the same strata, with a 7 m interval, in a cliff located 20 m to the east of the RRS (Figure 2b-c).

Two different soil strata, called here level I and II, cover the top of RRS to a depth of 1 to 1.5 meters. The upper stratum is dark gray to black clayey silt and the lower is sandy clay with gray-mottled yellow tonalities (Figure 3a). In the RR1 and RR2 sections, under an artificial landfill, both strata are located above a gravel deposit (Figure 3b). In RRS the upper level apparently contains no cultural materials. Level II yielded most of the archaeological remains. A large collection of hammerstones used for mining activities and other stone artifacts were found in the lower level (Gibson *et al.* 1990, Singer, written comm. 1998).

A small piece of charcoal from the archaeological level was dated by AMS ¹⁴C at 5710 ± 60 yr. B.P. (Beta-79333). A

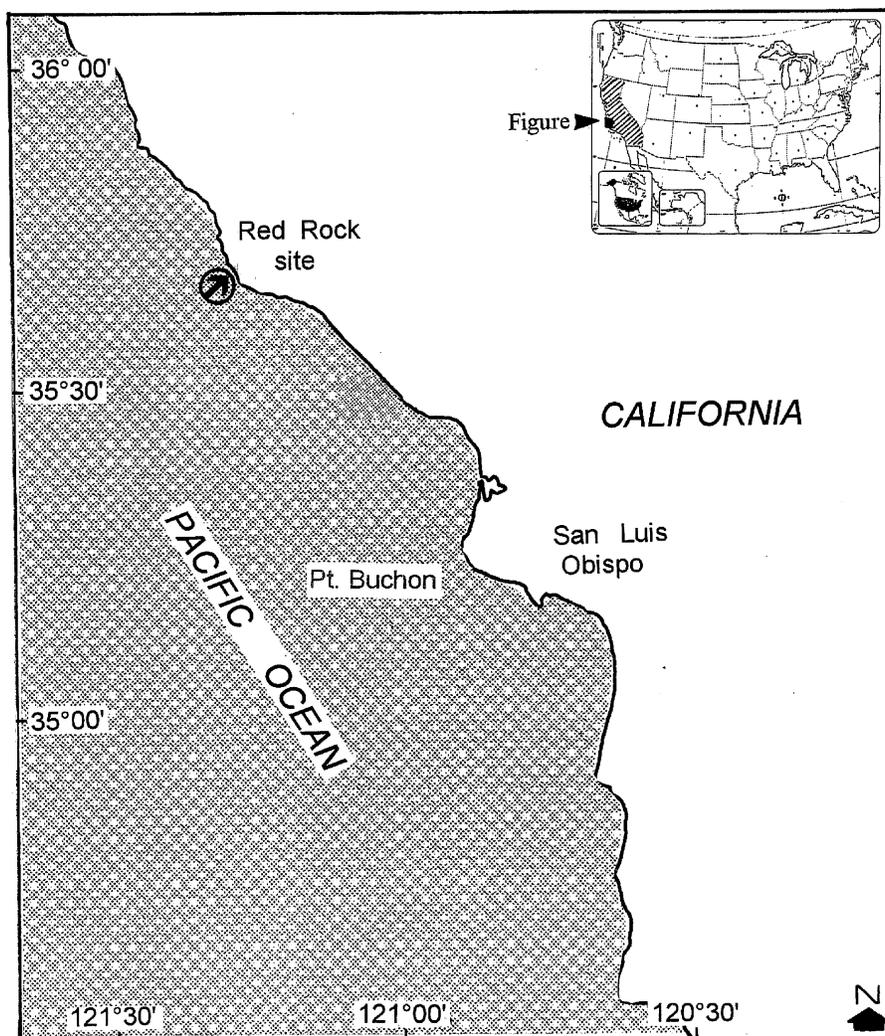


Fig. 1. Location of the Red Rock site in Western California.

very small sample of organic sediment from between samples RR2 17 and 22 was analyzed by conversion of sample carbon to graphite and determining ^{14}C age in an AMS. The date for this sample was 4070 ± 50 yr. B. P. (Beta-108166). This date can be considered as a minimum age because the apparent mean residence time of organic components is a significant factor in soil dating (Scharpenseel 1971, Stein 1992). Therefore, the possible age of the whole sequence might be attributed to the middle and late Holocene.

Samples were collected in cylindrical hydrobronze containers 2.5 cm long by 2.5 cm in diameter for RRS ($n = 18$), and in plastic cylinders 2 cm in diameter for RR1 ($n = 22$) and RR2 ($n = 27$).

Samples RRS 1 to 12, RR1 1 to 3 and RR2 1 to 7 were located in level I and RRS 14 to 18, RR1 4 to 24 and RR2 8 to 27 were obtained from the lower level. Sediment near the surface was not sampled because it was highly disrupted by plant roots.

The cylinders were carefully pushed with a hammerstone into the sediment. Each sample overlapped the next one by about 50% each. They were consolidated with sodium silicate and their strike and dip was measured using a Brunton compass and inclinometer. Finally, the samples were numbered from top to bottom (Figure 2b-c).

LABORATORY RESULTS

In 1992, an 8 Hz spinner magnetometer (Vilas 1979) was used to measure the natural remanent magnetization (NRM) of all hydrobronze contained samples. They were subjected to thermal demagnetization using a Schonstedt demagnetizer (TSD-1) in 50° steps until 350°C , and in additionally 25°C steps until 450°C . RR1 and RR2 samples were measured with a 2G cryogenic magnetometer (755R) and progressive AF demagnetization with 3, 6, 9, 12, 15, 20, 25, 30, 40 and 60 mT in a static 3 axis degausser attached to the cryogenic magnetometer. Additional 80 and 100 mT steps were made in some samples. This procedure was more efficient than thermal cleaning.



a



b



c

Fig. 2. a) The Red Rock site in 1992 with the arrow showing the SE sampled profile. The photograph also shows the three pieces of the red rock broken chunk (photo by Terry Frederick). b) and c) RR1 and RR2 sections showing the location of the samples (photo by the author). The numbers indicate the first and the last samples of each section respectively.

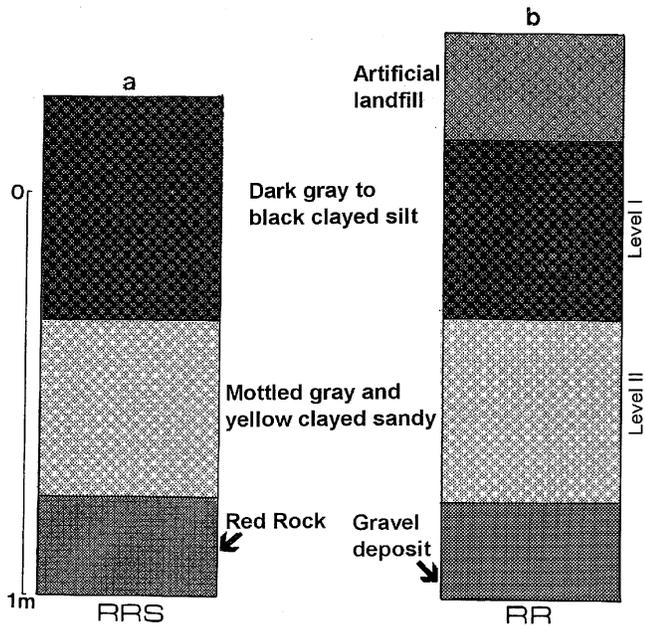


Fig. 3. Schematic stratigraphic profiles showing the sampled sections. RRS = Red Rock quarry site, RR = RR1 and RR2 sections.

Typical demagnetization curves for AF and thermal procedures are illustrated in Figure 4. Thermal cleaning showed an almost regular decay of the NRM up to 350° to 450°C, except for sample RRS18, characterized by a sudden drop of the remanence at 400°C (Figure 4c). In most RR1 and RR2 cores less than 20% of the NRM remained at fields of 60mT (Figure 4 d-f). This behavior suggests titanomagnetite as the dominant carrier of the NRM (Tarling 1983, Butler 1992).

Samples from all three sections showed a common pattern with similar magnetic behavior. Some samples, thermally cleaned, were highly unstable and were rejected (n= 7). Most samples presented linear demagnetization plots (Figure 5) with one or two magnetic components. In most cases, a characteristic remanent magnetization (ChRM) could be defined trending in the Zijderweld (1967) diagrams towards the origin.

Most secondary components were a soft viscous magnetism that was easily removed between 3 and 12 mT. Unexpected reversed (samples RR1 3, RR1 6, Figure 5f and g) or anomalous southward directions (samples RR1 1, RR2 14, Figure 5d and l) were found in several samples.

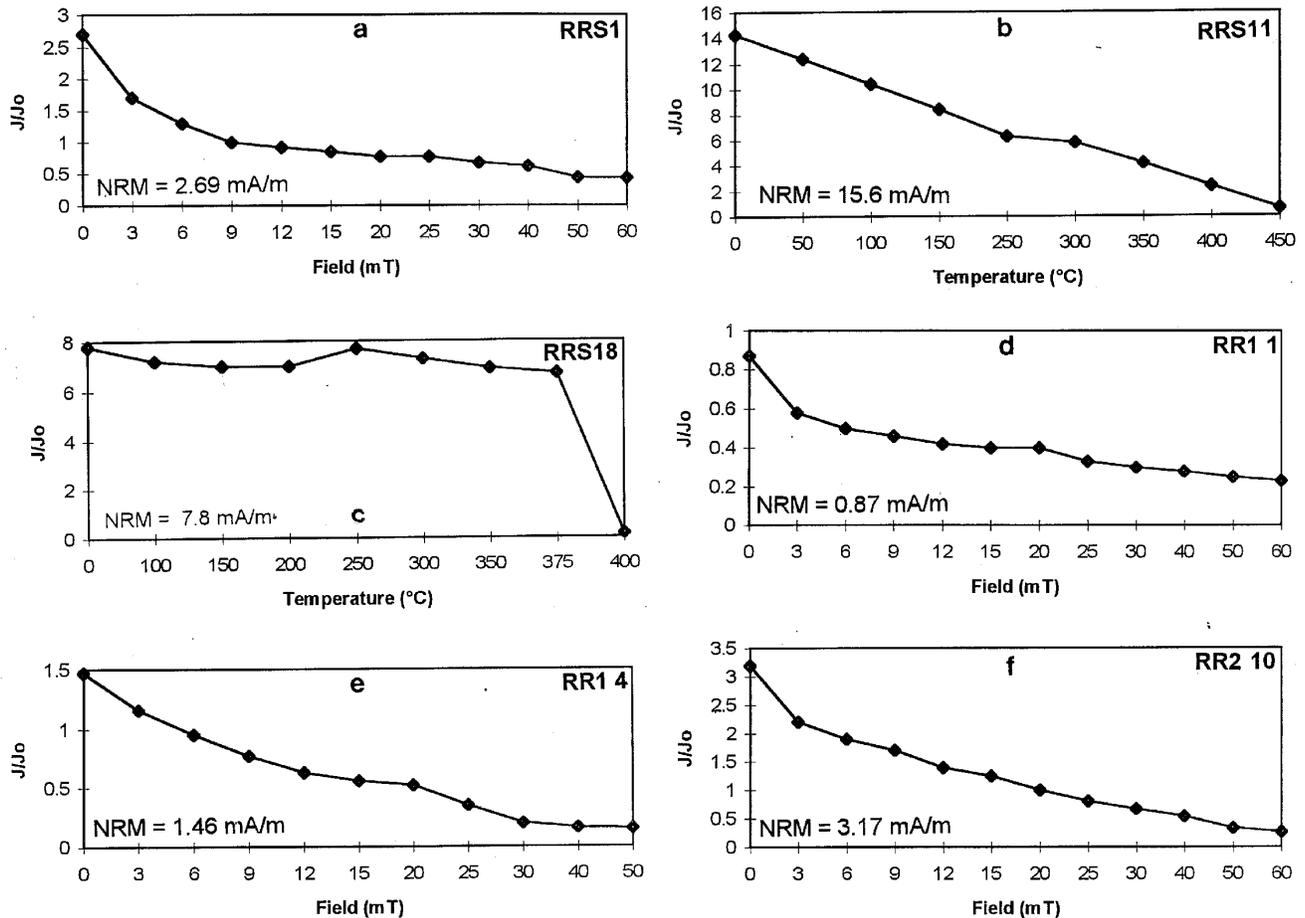


Fig. 4. Typical demagnetization curves for different samples from RRS, RR1 and RR2.

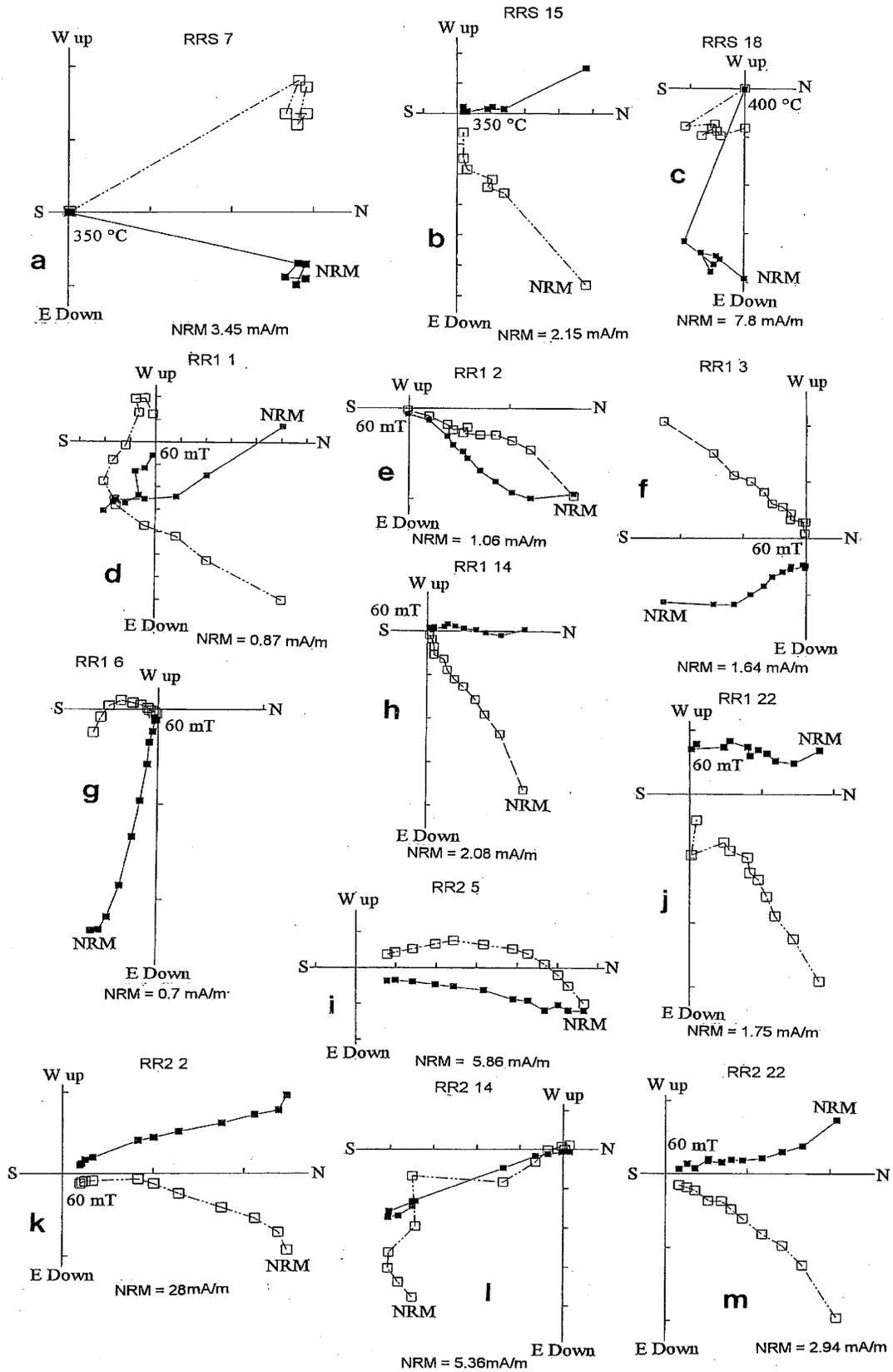


Fig. 5. Typical Zijdeveld diagrams from the sections reported in this paper. Most of the samples were AF demagnetized. Solid symbols correspond to the projection onto the horizontal plane, while open symbols are projection onto the vertical plane.

ChRM directions were defined using principal component analysis (Kirschvink 1980). In general, maximum angular deviation values were low, ranging between 0° to 5° (n = 11, 18.1 %), 5.1° to 10° (n = 41, 67.2 %) and 10.1° to 15° (n = 9, 14.7 %).

The number and intervals of demagnetization steps used to isolate the ChRM are shown in Table 1. Declination and inclination values are shown in Figure 6.

The three sections show normal, intermediate and reversed polarity with wide amplitude pulses between normal declination and transitional positive to negative inclination (Figure 6).

Figure 7 illustrates the overlapped stratigraphic presentation of each section showing the probable excursion of the magnetic field between dashed lines.

Figure 8 and 9 illustrates the stereographic projection of ChRM and VGP calculated from the directions of Figure 6. When plotted on a present world map, most VGP's are located along the Americas, Europe and Africa (Figure 10).

DISCUSSION AND CONCLUSION

Records of paleomagnetic secular variation obtained from lavas and lake sediments across North America are generally consistent in declination and inclination (*e.g.* Cham-

Table 1

Values of characteristic remanent magnetization, virtual geomagnetic pole positions and intervals of selected ChRM for each sample. Negatives values show negative inclination or VGP located in the southern Hemisphere. Intervals of selected ChRM are given in mT or °C with decimal and centesimal numbers respectively. References: D: Declination, I: Inclination, Long.: Longitude, Lat.: Latitude, IChRM: Intervals of selected ChRM, Or.: Origin in the Zijderveld diagram

RRS						Sample	D°	I°	Lat.°	Long.°	IChRM
Sample	D°	I°	Lat.°	Long.°	IChRM	19	52	71	282	50	0-12
1	77	20	328	16	0-25	20	21	61	303	73	3-Or.
2	358	32	63	72	50-250	21	6	50	11	83	3-25
3	13	20	31	62	100-300	22	9	59	296	82	0-30
7	16	-27	39	38	0-350	RR2					
9	35	15	2	48	250-Or.	1	98	49	300	11	1-60
10	22	29	8	62	0-Or.	2	346	21	89	62	3-25
11	352	2	73	55	250-Or.	3	86	29	318	12	12-60
12	14	22	28	63	100-300	4	2	43	51	80	3-15
14	21	25	13	61	100-250	5	6	-13	46	61	25-60
15	7	49	11	82	50-400	6	101	-3	56	53	6-50
16	68	-26	356	5	250-Or.	7	5	27	44	70	0-25
18	98	9	320	-4	350-Or.	8	356	35	73	74	3-20
RR1						9	360	60	237	85	3-40
1	132	62	271	0	20-50	10	8	17	42	62	6-25
2	41	14	356	43	3-50	11	55	64	298	48	3-15
3	146	-35	309	-56	3-50	12	324	69	194	60	3-12
4	52	46	324	45	6-Or.	13	355	39	77	76	3-25
5	9	37	27	73	6-60	14	161	13	266	-44	15-60
6	298	76	205	43	12-Or.	15	10	57	312	82	3-30
7	9	56	321	83	12-30	16	357	83	238	50	0-25
8	16	58	308	77	0-Or.	17	11	52	344	80	0-Or.
9	345	59	174	77	9-60	18	64	45	318	36	3-30
10	5	64	259	81	0-60	19	73	63	295	35	0-60
11	23	58	312	72	0-30	20	358	65	232	79	0-Or.
12	339	50	138	71	0-15	21	356	33	71	72	3-30
13	49	23	344	41	40-Or.	22	349	35	92	71	3-Or.
14	2	59	261	85	0-Or.	23	82	4	229	22	20-60
15	4	-27	54	40	0-60	24	12	68	267	73	3-25
16	8	37	31	73	0-15	25	325	61	173	62	0-25
17	21	59	308	73	0-Or.	26	8	59	293	82	0-60
18	42	83	253	46	0-25	27	317	41	143	51	0-20

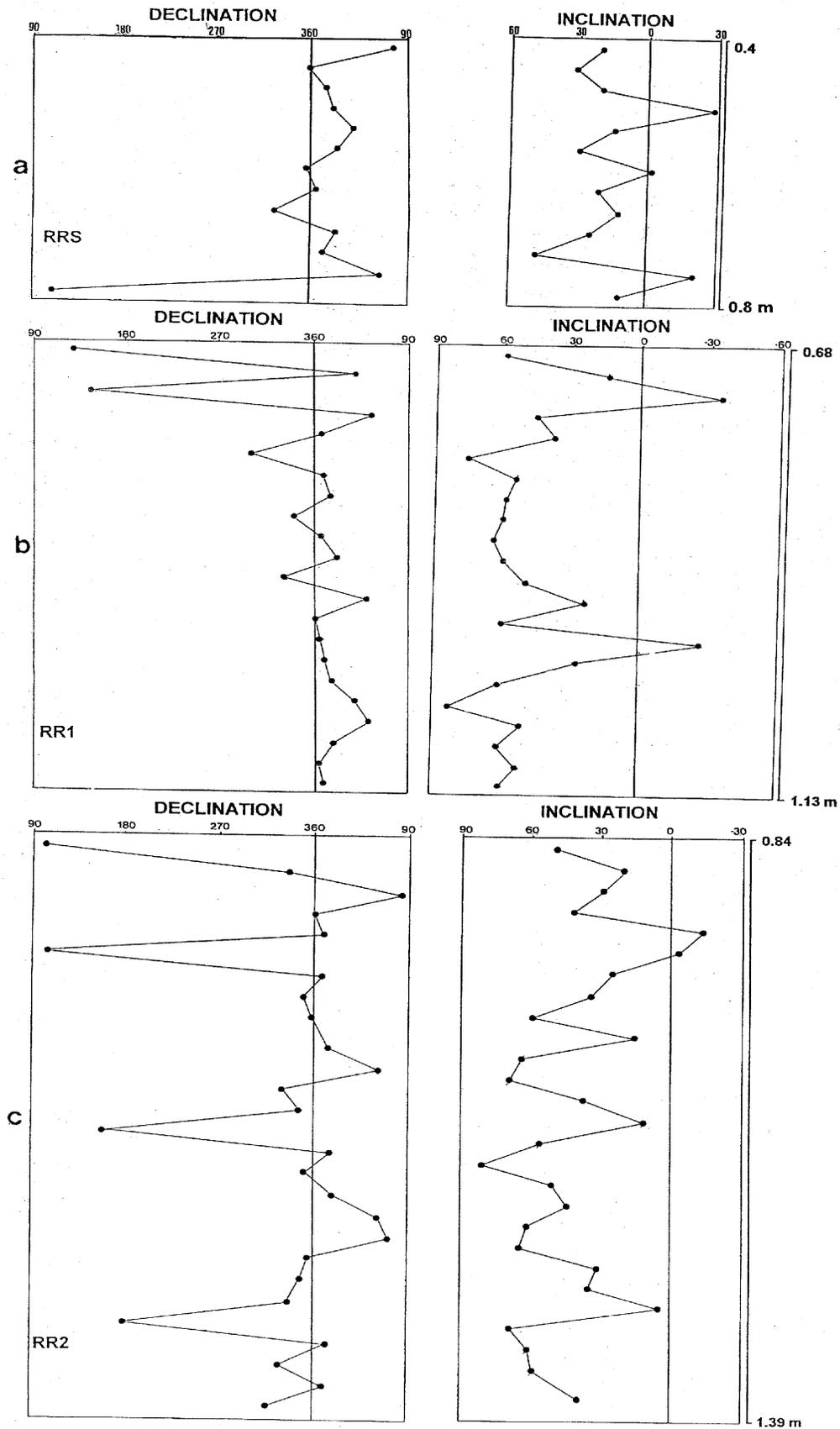


Fig. 6. Stratigraphic presentation of the declination and inclination profiles from RRS (a), RR1 (b), RR2 (c).

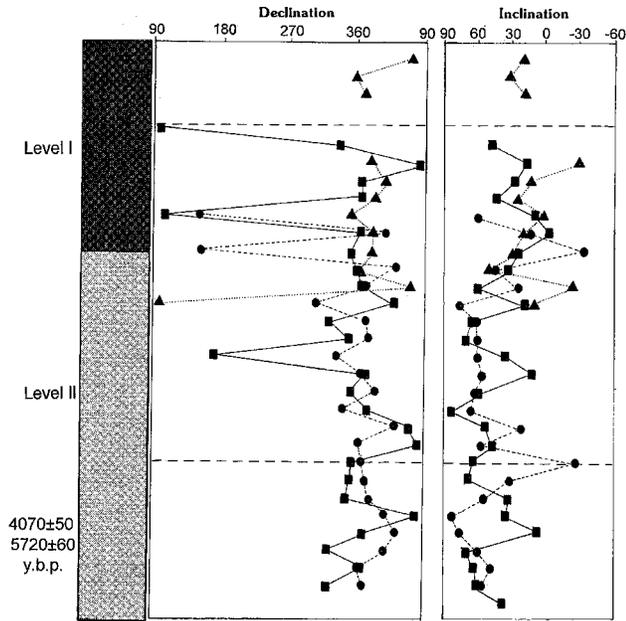


Fig. 7. Overlapped stratigraphic presentation of the three declination and inclination profiles shown in Figure 6 related with the direct absolute dates by ¹⁴C. Triangular and pointed line represents RRS, solid circles and dashed lines is RR1 profile and the squares and continuous line illustrates RR2. The more conspicuous long declination and inclination departures are depicted between dashed lines. The gap existing in the upper part of the RRS represents rejected samples.

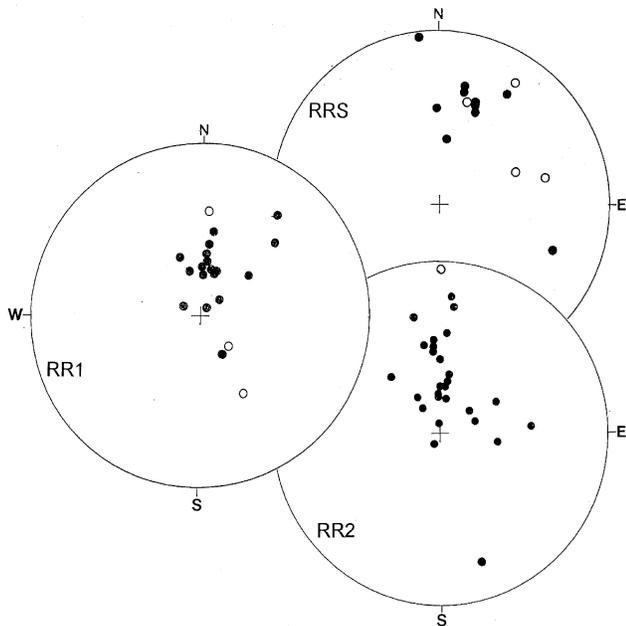


Fig. 8. Directions of characteristic remanent magnetizations for the sections reported in this paper. Negative inclination (open circle) and positive inclination (solid circle).

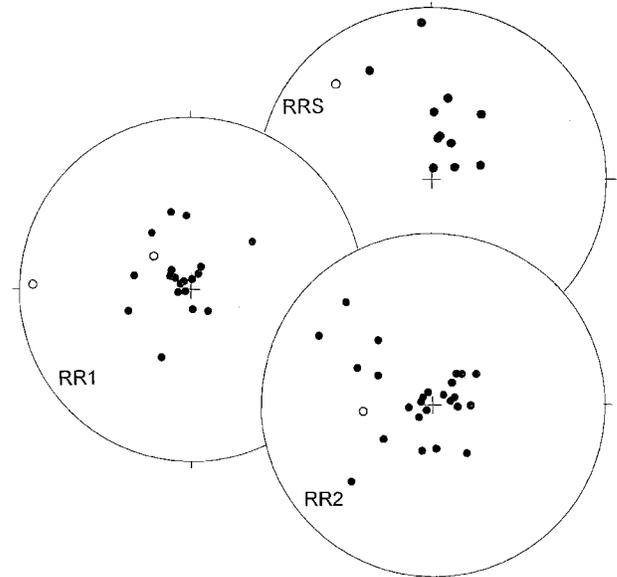


Fig. 9. Stereographic projection of VGP calculated from directions of ChRM isolated in the sites mentioned in the text. Solid circles show those located in the Northern hemisphere and open circles represented VGP located in the southern hemisphere. The center of the projection is the geographic northern Pole.

pion 1980, Creer and Tucholka 1982, Lund and Banerjee 1983, Verosub *et al.* 1986, Brandsma *et al.* 1989, Hagstrum and Champion 1995, Lund 1996). Specifically in western North America and the East Pacific, they show a gentle eastward shift in the declination between ~5-1 ka bp (Hagstrum and Champion 1995). The inclination for the same span of time (~60-30°) shows the lower values (~20-30°) during ~3-2 ka bp for Hawaiian lava flows and ~10-30° in lacustrine sediments (*cf.* Hagstrum and Champion 1995, Peng and King 1992). The normal directions observed in the Red Rock site are generally agreeable with this paleomagnetic data; however, intermediate and reversed directions were also observed. Similar anomalous directions have been documented in other places in the world in Late Pleistocene/Holocene paleomagnetic records. In fact, some studies have reported geomagnetic anomalies in the last 10 ka (Ransom 1973, Noël 1975, Noël and Tarling 1975, Vitorello and Van der Voo 1977, Burakow and Nahasova 1990, Petrova and Pospelova 1990, Pospelova 1990, Wiegank *et al.* 1990, Kochegura and Pisarewsky 1994, Gonzalez *et al.* 1997, Urrutia Fucugauchi *et al.* 1995, Ortega Guerrero and Urrutia Fucugauchi 1997, Nami 1995, 1999). In the Northern Hemisphere and near the Red Rock quarry, reliable records obtained in lava flows from central Mexico show a strong eastward swing in declination (González *et al.* 1997). One VGP obtained in El Metate volcano (Michoacan-Guanajuato Volcanic Field) yielded a VGP at the latitude of 14° N. Two VGPs from Tres Cruces and El Metate volcanos are plotted in Figure 10 and, they coincide remarkably well with those from Red Rock sections. Both

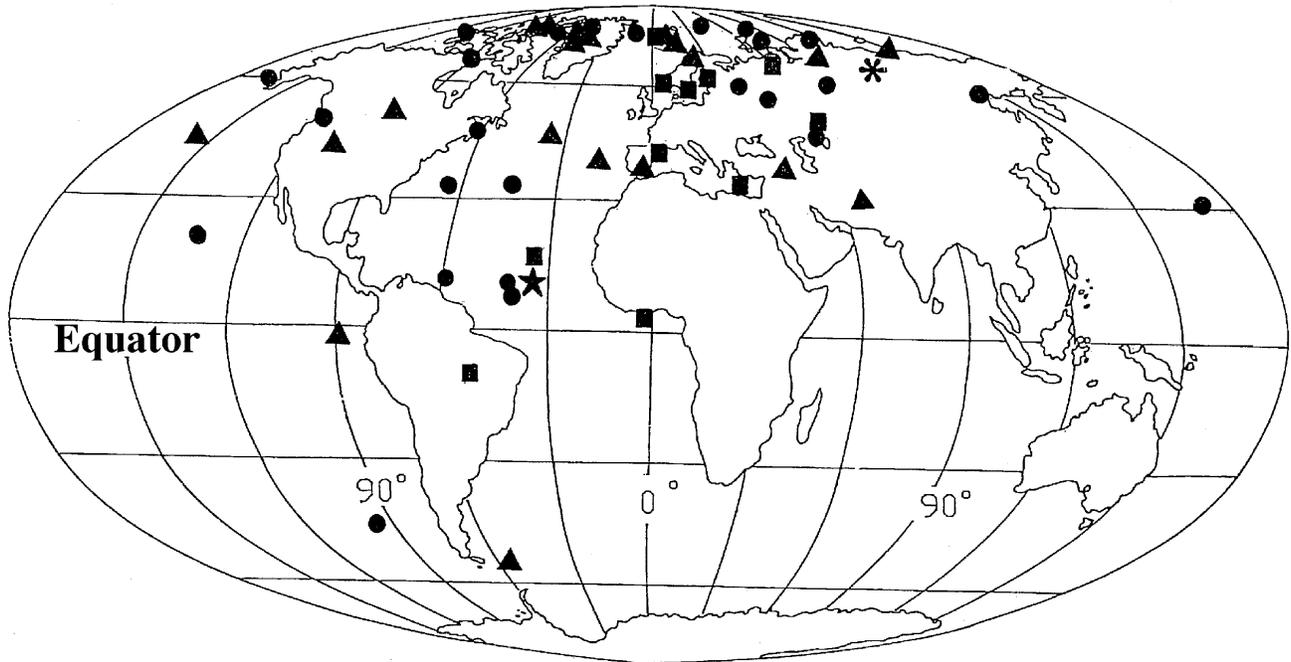


Fig. 10. Virtual geomagnetic pole (VGP) paths plotted in the world map for the sections mentioned in the text. (■) RRS, (▲) RR1, (●) RR2. The star and the asterisk show the VGP's given by González and colleagues (1997) for the San Juan and Metate volcanoes respectively.

volcanos were dated by ^{14}C at 4070 ± 150 and 4700 ± 200 years B.P., respectively (González *et al.* 1997).

Similar swings with wide amplitude variations in declination and inclination were observed in lake sediments of the Valley of Mexico during the same time span (Urrutia Fucugauchi *et al.* 1995, Ortega Guerrero and Urrutia Fucugauchi 1997). Chalco lake lacustrine declination record shows a pronounced swing of $\sim 45^\circ$ at ~ 5 ka bp. Actually, results from the volcanic rocks and a lake sediments were compared, and a similar paleomagnetic behavior with the Red Rock declination swing is noted. This suggests that the excursion observed in Central Mexico might have a regional extent.

During the 1970's, several investigators reported paleomagnetic data for cores with likely excursions during the Early/Middle Holocene. In eastern North America, Vittorelo and Van der Voo (1977) reported an excursion in cores from the Great Lakes. Clark and Kennett (1973; Figure 2) illustrated paleomagnetic results obtained in cores K4, K38 and K44 from the Gulf of Mexico, with negative inclinations during the Holocene.

Wollin and colleagues (1971) described reversed inclinations at ~ 7 ka for two deep-sea cores from the North Pacific (V20-108) and the Mediterranean (RC9-181). In the Mediterranean region, early observations on clay fired in kilns

by the Etruscans and Greeks in the eighth century BC suggest that the geomagnetic field was reversed in Italy and Greece (Ransom 1973). Data from pottery and sediments for several archaeological sites in Georgia (Caucasus) yielded evidence of the so-called "Etrussia excursion", dated about 2.7 ka (Burakov and Nachasova 1990, Petrova and Pospelova 1981, 1991, Pospelova 1990). This excursion was also registered in sedimentary rocks of the Predurals and in bottom sediments of the White Sea (Wiegank, Petrova and Pospelova 1990). Recently, Kochevura and Pisarevsky (1994) reported results for twelve cores from bottom sediments and varved clays of the Finnish Gulf, Ladoga Lake, Pre-Ladoga area, White Sea and Batentz Sea. In the upper part (dated ~ 2.5 -4 ka) there are also anomalous directions attributed to the "Etrussia excursion".

In Sweden and contemporary with the Etrussia excursion, Noël (1975) and Noël and Tarling (1975) reported evidence for a "Stärno event".

Recently, eleven sections from Argentina and Chile yielded evidence about a probable geomagnetic "Myllodon excursion" occurred between $\sim 11 \leq 2$ ka (Nami 1995, 1999). The VGP's located in the Northern Hemisphere from this excursion coincide remarkably well with those from the Red Rock sections. Several VGPs are located along the Americas, as observed in different reversals and excursions during the last 200 Ma (Vizán *et al.* 1994).

In conclusion, paleomagnetic studies carried out at a site in California yielded normal, intermediate and reversed directions. This suggests that the Earth's magnetic field probably underwent an excursion in southwestern North America during the Middle Holocene. Similar excursions were found in different sections and materials from North and Central Europe, Eastern Asia, South America and North America. This may suggest that some anomalous geomagnetic phenomenon might have occurred globally, although perhaps not simultaneously. A global reverse excursion (Merrill and McFadden 1994) might have occurred sometime between late Pleistocene and late Holocene.

According to Nowazick and colleagues (1994) during the last 170 ka and particularly between 50 ka and late Pleistocene, the normal polarity of the Earth's magnetic field has been interrupted by several short-lived reversed polarity events. The observed Holocene excursion might be another short-term manifestation of this process.

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