MAGNETIC STRATIGRAPHY OF THE LATE PLIOCENE MAMMAL-BEARING DEPOSITS FROM GYPSUM RIDGE, SAN BERNARDINO COUNTY, CALIFORNIA

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ABSTRACT

Paleontological collecting between 1997 and 1999 at Gypsum Ridge on the Marine Corps Air Ground Combat Center (MCAGCC), Twentynine Palms, San Bernardino County has yielded a significant vertebrate assemblage of early Irvingtonian age. The fauna is diverse containing invertebrates such as the slug *Deroceras* sp., an unidentified cyprinid fish, amphibians such as salamanders, frogs and toads, reptiles including the giant tortoise *Hesperotestudo*, snakes, shore birds and rails, and mammals including edentates, insectivores, rodents, lagomorphs, carnivores, perissodacyls and artiodactyls. The grade of evolution of the *Paraneotoma* sp. coincident with the joint occurrences of *Erethizon* sp., *Paramylodon harlani, Nothrotheriops texanus, Ondatra idahoensis*, and *Sigmodon minor medius* in deposits of reversed polarity support an age of 2.1 to 1.9 Ma for the Gypsum Ridge local fauna. The composition of the Gypsum Ridge assemblage resembles faunas of late Blancan-early Irvingtonian age in the Fish Creek-Vallecito Creek sequence.

INTRODUCTION

Between 1997 and 1999 three visits to the Gypsum Ridge Training Area of the Marine Corps Air Ground Combat Center (MCAGCC), Twentynine Palms, San Bernardino County, California (Figs. 1, 2) yielded a diverse assemblage of late Pliocene-early Pleistocene terrestrial vertebrates of Irvingtonian Age. This is the first report of a vertebrate fauna of early Irvingtonian age from this region of San Bernardino County where approximately 24 localities were discovered and collected from a thick alluvial fan sequence within an interval of 55 feet of strata. This fauna is here recognized as the Gypsum Ridge local fauna. The fourteen mammalian taxa identified from this collection suggest a late Blancan-early Irvingtonian age for the assemblage. The paleomagnetics for the section support an early Irvingtonian age as suggested by Cassiliano (1999). The rock unit has not been formally named but is well mapped by Dibblee (1967).

METHODS

In the winter of 1998, 6 paleomagnetic sites (3 samples per site) sites were taken from the fossiliferous portion of the alluvial fan sequence over a stratigraphic interval of 55 feet and one other 40 feet higher in the unfossiliferous portion of the section. (Fig. 3). Oriented block samples were taken, then hardened with dilute sodium silicate solution in the field to prevent them from crumbling. In the laboratory, the block samples were subsampled into cylindrical cores with an air-cooled drill press, or cast into a cylinder using Zircar aluminum ceramic. Each sample was then measured in a 2G cryogenic magnetometer with an automatic sample changer at the California Institute of Technology paleomagnetics laboratory. After measurement of NRM (natural remanent magnetization), each sample was demagnetized in alternating fields (AF) of 25, 50, and 100 Gauss. This removes any remanence held in multidomain grains, and also allows determination of the coercivity behavior of each sample. After AF demagnetization, each sample was then thermally demagnetized in a shielded furnace in multiple temperature steps ranging from 300-600°C. This removes any chemical remanent overprinting due to iron hydroxides such as goethite, and also allows the blocking temperatures of the magnetic minerals to be determined.

About 0.1 g of powdered rock from several samples was subjected to increasing isothermal remanent magnetization (IRM) to determine their IRM acquisition behavior. They were also AF demagnetized twice, once after having acquired an IRM produced

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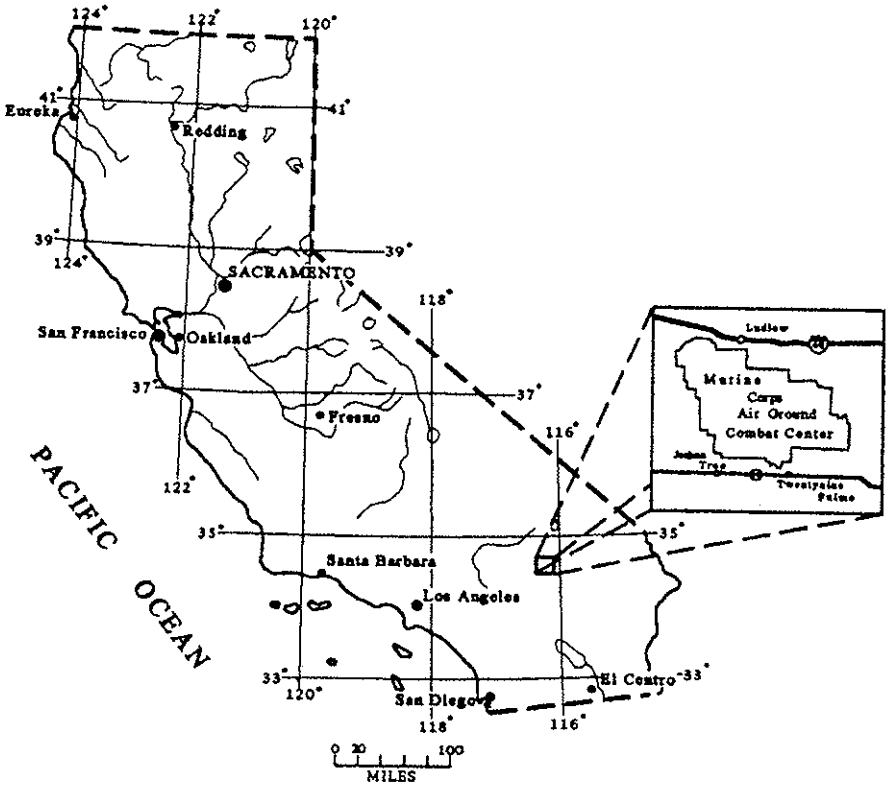


Figure 1. Location map of the Marine Corps Air Ground Combat Center, Twentynine Palms, San Bernardino County, California.

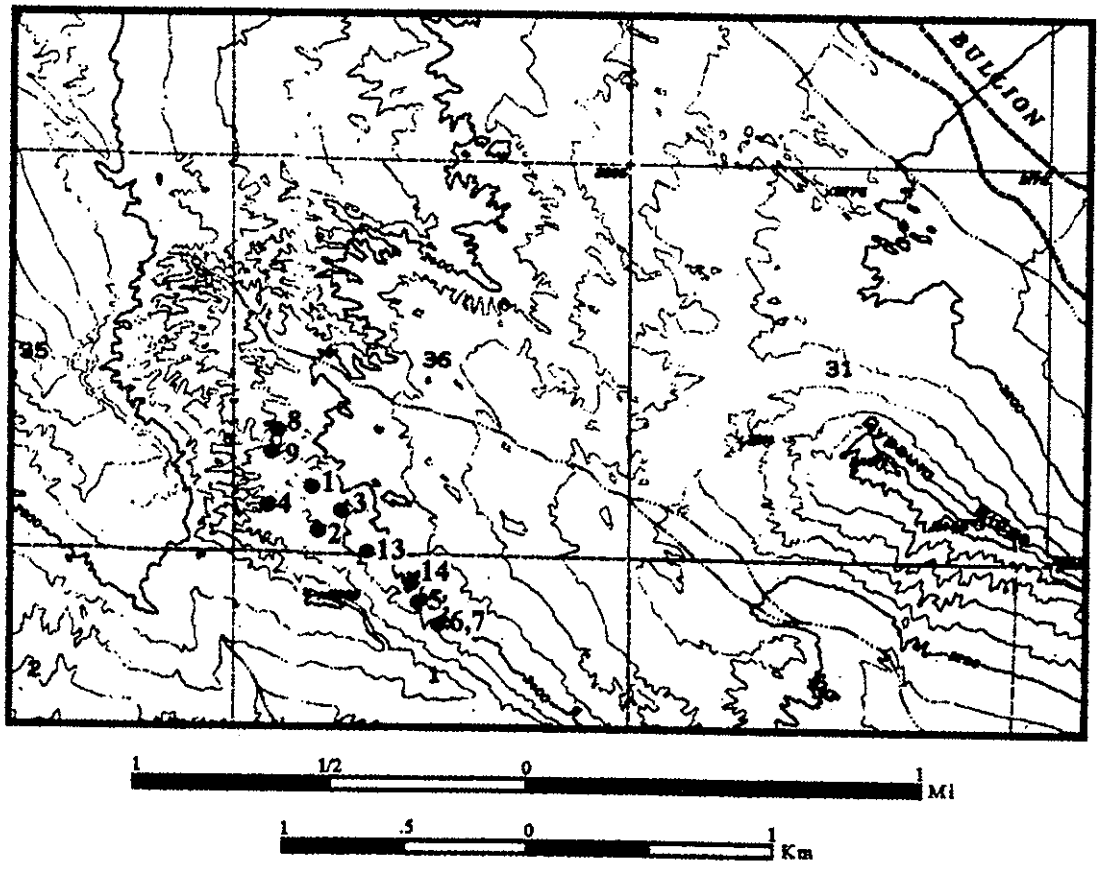


Figure 2. The most productive fossil localities collected at Gypsum Ridge.

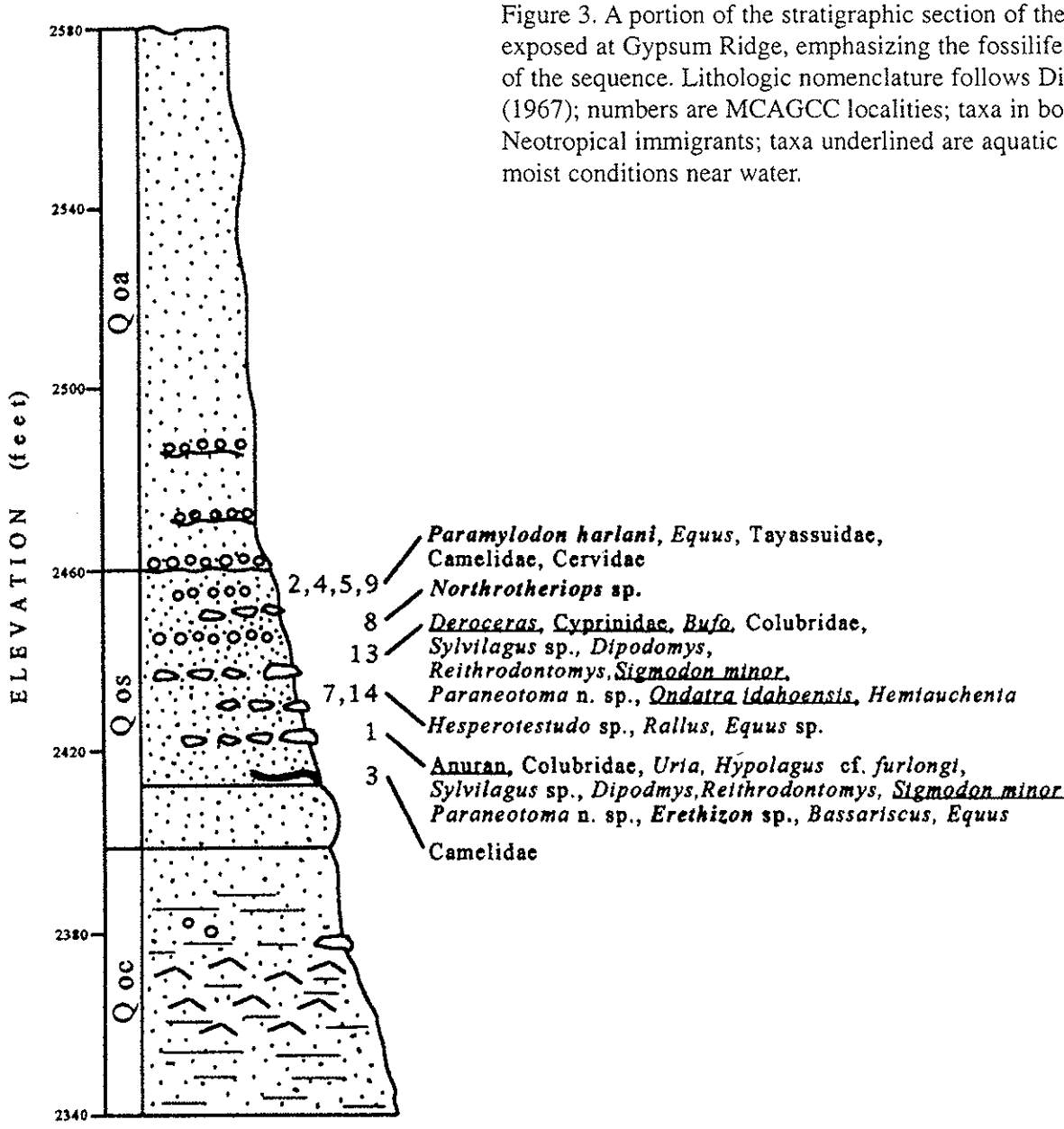


Figure 3. A portion of the stratigraphic section of the deposits exposed at Gypsum Ridge, emphasizing the fossiliferous portion of the sequence. Lithologic nomenclature follows Dibblee (1967); numbers are MCAGCC localities; taxa in bold are Neotropical immigrants; taxa underlined are aquatic or prefer moist conditions near water.

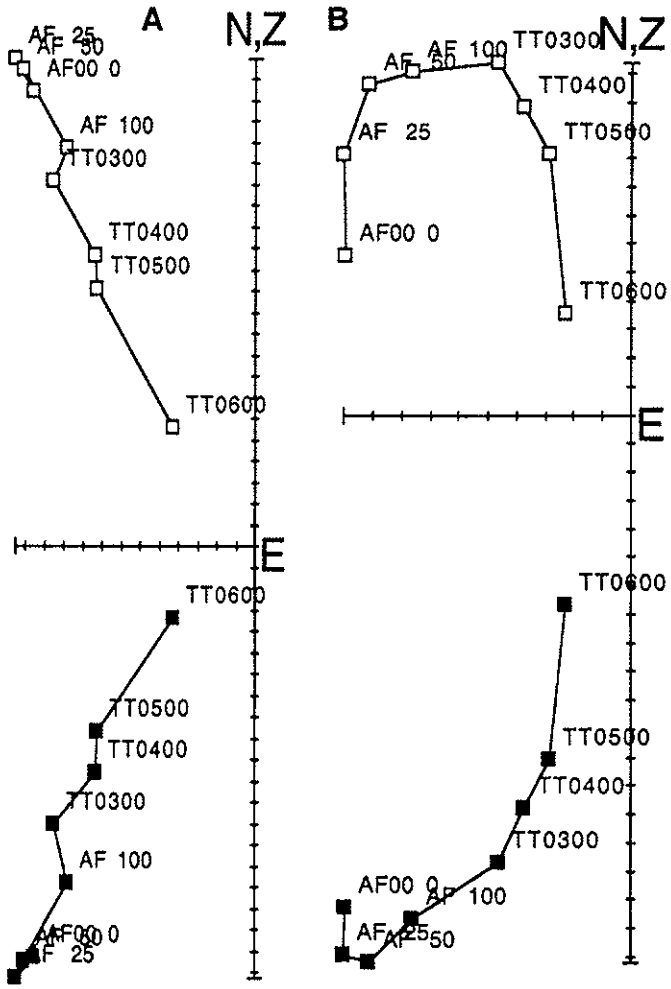
in a 100 mT peak field and once after having acquired an anhysteretic remanent magnetization (ARM) in a 100 mT oscillating field. Such data are useful in conducting a modified Lowrie-Fuller test (Pluhar et al., 1991).

RESULTS

Orthogonal demagnetization plots ("Zijderveld plots") of representative samples are shown in Figure 4. In all samples, there is a significant decrease in intensity during AF demagnetization, suggesting that much of the remanence is carried by a low-coercivity mineral such as magnetite. However, all of the samples still had significant remanence at temperatures above the Curie point of magnetite (580°C), showing that hematite carries much of the remanence. Most samples (Fig. 2A) had a single stable component of reversed polarity apparent even at NRM. Other samples (Fig. 2B) showed a slight overprint which was removed by 300°C, but these samples still pointed south and up from NRM until the final demagnetization step.

IRM acquisition studies (Fig. 5) showed no sign of IRM saturation, confirming that hematite carries most of the remanence. In most samples, the ARM was more resistant to AF demagnetization than the IRM, suggesting that the remanence his held in multi-domain grains.

The stable vectorial components for each sample were summarized using the least squares method of



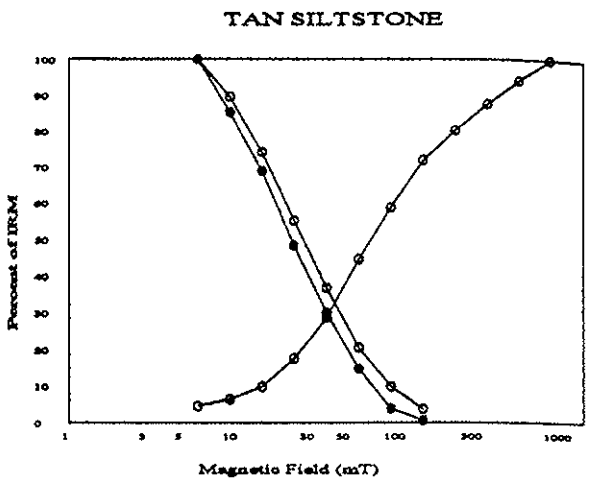


Figure 4. (left two figures). Orthogonal demagnetization ("Zijderveld") plots of representative samples. Solid squares indicate horizontal component; open squares indicate vertical component. AF = alternating field step (in Gauss); TT = thermal step (°C). Each division = 10^{-6} emu.

Figure 5. (above) IRM acquisition (ascending curve on right) and Lowrie-Fuller test (two descending curves on left) of a representative powdered sample from the Gypsum Ridge. Open squares = IRM; solid squares = ARM.

Kirschvink (1981), and averaged using Fisher (1953) statistics. Results are shown in Table 1. All six sites were of reversed polarity, and were significantly separated from random at the 95% confidence level (Class I sites of Opdyke et al., 1977). Averaging the vectors gives a formational normal mean of D = 196.5, I = -48.0, k = 26.9, α_{95} = 13.2. Although there were no normal directions to obtain a reversal test, the fact that all the cleaned directions are reversed in polarity shows that potential normal overprinting has been removed, and a primary or characteristic direction has been obtained.

DISCUSSION

The Gypsum Ridge local fauna has been recovered from a sequence of locally calcareous concretionary, brown, micaceous silty sandstones and pebbly conglomerates fifty-five feet thick. The fossiliferous deposits are sandwiched between underlying barren gray mudstones with abundant gypsum and

TABLE 1—Paleomagnetic data from the Gypsum Ridge section. N: number of samples per site; D, I: declination, inclination; k, α_{95}, precision parameters.

Site	N	D	I	k	α_{95}
2	3	224.6	-49.4	81.9	13.7
3	3	176.9	-55.4	22.7	26.5
4	3	211.4	-42.4	24.4	25.5
5	3	194.5	-55.1	26.7	24.3
6	3	184.3	-50.0	5.6	57.9
7	3	186.0	-28.7	25.0	25.2

overlying massive, light brown, coarse-grained, arkosic sandstones that develop prominent palisades. The fauna is diverse containing invertebrates such as the slug *Deroceras* sp., an unidentified cyprinid fish, amphibians such as salamanders, frogs and toads, reptiles including the giant tortoise *Hesperotestudo*, snakes, shore birds and rails, and mammals including edentates, insectivores, rodents, lagomorphs, carnivores, perissodacyls and artiodactyls. The grade of evolution of the *Paraneotoma* sp. coincident with the joint occurrences of *Erethizon* sp., *Paramylodon harlani, Nothrotheriops texanus, Ondatra* sp., and *Sigmodon minor medius*, support an age of 2.1 to 1.9 Ma for the Gypsum Ridge local fauna. The composition of the Gypsum Ridge assemblage resembles faunas of late Blancan-?early Irvingtonian age in the Fish Creek-Vallecito Creek sequence (Anza-Borrego, San Diego County; Cassiliano, 1999; personal observation, 1999). *Erethizon* first appears in the Fish Creek-Vallecito Creek section approximately 2.58 Ma and *Paramylodon* sp. (*Glossotherium*) at approximately 2.2 Ma and *Nothrotheriops* sp. at 2.1 Ma (Cassiliano, 1999; personal communication G. McDonald, G. Jefferson, 2000, 2001). *Paramylodon* sp. also appears approximately 2 Ma in the Elsinore trough (McDonald *in* Pajak et al, 1996). The Gypsum Ridge mammalian assemblage has a definite Neotropical component characteristic of the Great American Interchange (Webb, 1976; Marshall and others, 1976, 1990) that began approximately 2.7 Ma (Woodburne and Swisher, 1995) and includes *Paramylodon harlani, Nothrotheriops texanus, Erethizon* sp., and *Sigmodon minor medius*.

The vertebrate fossils from Gypsum Ridge were recovered from a very limited stratigraphic interval within the rocks exposed. Right lateral movement on the West Calico Fault has generated drag folds on the margin of the eastern block that expose a Plio-Pleistocene sequence of sedimentary deposits that have been subdivided into three lithologies (Dibblee, 1967). Careful collecting and mapping has resulted in a better understanding of the depositional sequence. The overall sedimentary sequence exposed at Gypsum Ridge supports the progradation of an alluvial fan onto a shallow, possibly, alkaline lake, recorded in the barren lower gray, gypsiferous, mudstones that are overlain by what appears to be a distal, fine-grained fan sequence represented by the fossiliferous micaceous silty sandstones, in turn overlain by the nonfossiliferous, massive, thick, coarse pebbly arkosic sandstones of the alluvial fan. The presence of the slug tests, in conjunction with semi-aquatic mammals, and rare cyprinid fish remains, suggest that deposition occurred during a moist, equitable interval of time that enhanced paleosol development. The overlying barren sandstones possibly represent a change in climatic conditions that was not conducive to the preservation of bone. The Neotropical component, coincident with its apparent age, suggests that this fauna may record the early onset of climatic change documented by Repenning and Brouwers (1992) for the North American glacial episodes of the Pleistocene Epoch. The following taxa have been recovered and identified from the Gypsum Ridge sequence: *Deroceras* sp., Cyprinidae, urodele, *Bufo* sp., *Hesperotestudo* cf. *H. campester*, Colubridae indeterminate, *Rallus* sp., *Uria* sp., Charadriiformes indeterminate, Aves small indeterminate, *Paramylodon harlani, Nothrotheriops texanus, Hypolagus* cf. *H. furlongi, Sylvilagus* sp. *Perognathus* sp., cf. *Dipodomys* sp., *Reithrodontomys* sp., *Sigmodon minor medius, Paraneotoma* sp., *Ondatra idahoensis, Erethizon* sp., *Bassaricus* sp., *Equus* sp., Tayassuidae, cf. *Hemiauchenia* sp., Camelidae, Cervidae.

Prior to the results of the paleomagnetics, the age of the fauna was unresolved, as being either late Blancan or early Irvingtonian. The results of the paleomagnetics indicate the section is all reversed. The Olduvai is a normal event of approximately 200,000 years duration (Fig. 6) in the middle of the reversed Matuyama Chron in the Magnetic Polarity Time Scale (MPTS). The reversed interval below the Olduvai is 190,000 years. The reversed interval above it spans 700,000 years. Ninety feet of coarse alluvial fan sediments of reversed magnetism seems inordinately thick, requiring an extremely rapid rate of deposition to occur within 190,000 years. However, a comparison of the thickness of the stratigraphic sequence deposited during this interval of time in the Vallecito Creek section of the Anza Borrego Desert 80 miles to the south supports rapid depositional rates in this region of southern California. According to Opdyke and others (1975) approximately 750 feet of section accumulated during this interval of time in the Anza Borrego section. Cassiliano (1999) indicates a thickness of approximately 400 meters of section deposited in the Vallecito Creek section during this interval of time. Assuming the possibility of rapid depositional rates in southeastern California during this interval of time the reversed interval represented at Gypsum Ridge is

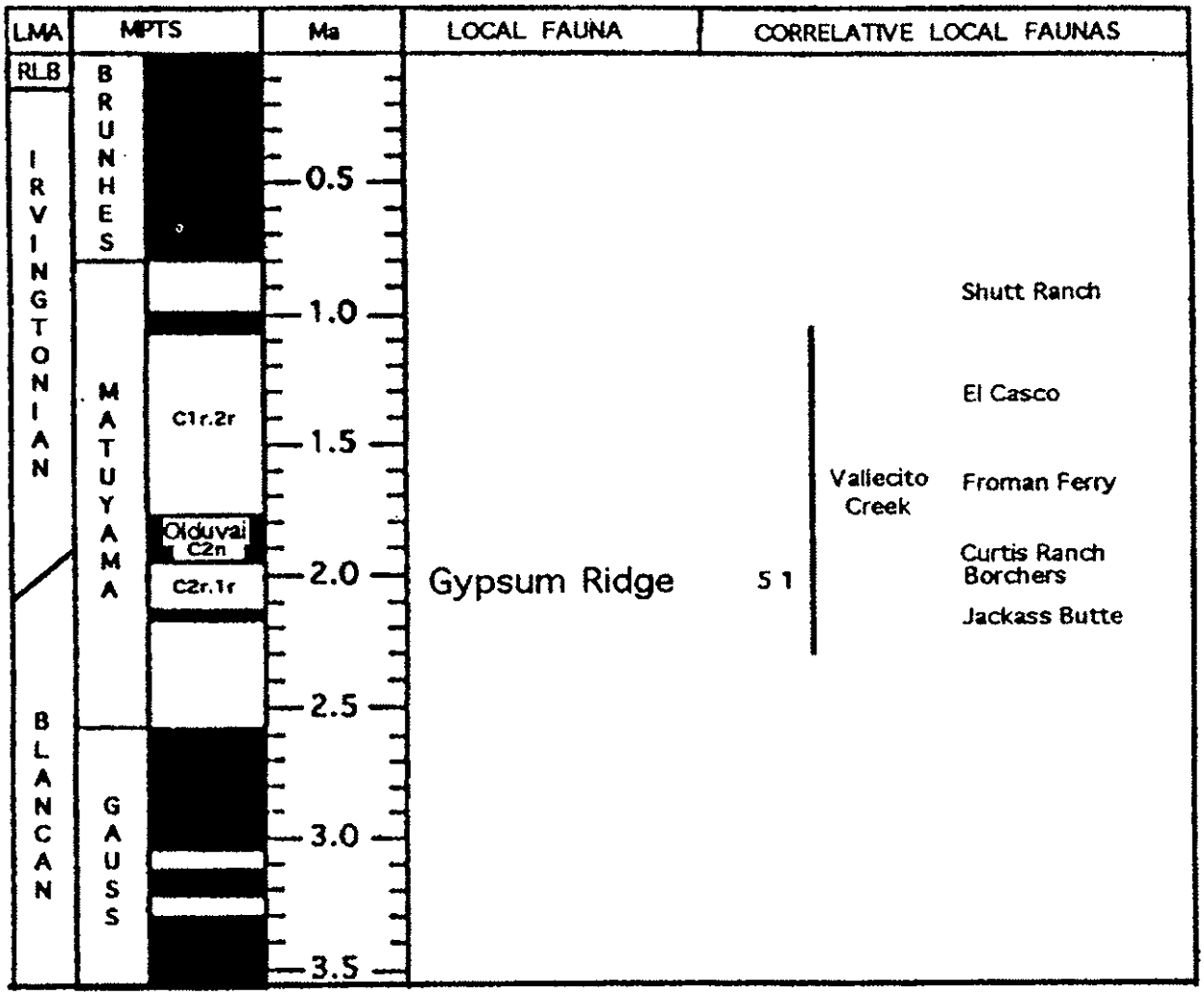


Figure 6. Magnetostratigraphic correlation of the Gypsum Ridge section.

here assigned to the C2r.1r reversed event of the Matayama Chron. Unfortunately the absence of microtine rodents prevents tying this assemblage into the microtine biochronology of Repenning (1987). A careful review of the literature indicates that *Nothrotheriops* (the small ground sloth found in the Gypsum Ridge assemblage) has only two reported occurrences in "Blancan" age deposits. The one occurrence in the Temecula Arkose by Golz and others (1974) was determined to be a tooth of *Megalonyx* (Akersten and McDonald, 1991). The other reported occurrences are in the Vallecito Creek local fauna of the Palm Spring Formation (Cassiliano, 1999). The other mammals identified from the Gypsum Ridge local fauna occur in deposits of early Irvingtonian to Rancholabrean age.

The stage of evolution represented by a limited amount material of *Paraneotoma* represented in the Gypsum Ridge assemblage compares best with the specimens examined in the collections of the Anza Borrego State Park from collecting unit 52.7 (personal observation, 1999). As a brief review, the collections at the Anza Borrego State Park from the Fish Creek-Vallecito Creek section of the Palm Spring Formation have been divided into collecting sites 1 though 62. Cassiliano (1997) indicates that this was set up by Downs prior to 1990. These collecting sites have been carefully calibrated to the paleomagnetic timescale and have several well-dated tuffs correlated into the section. The use of these collecting units and their calibration was first observed in publications by the authors in Downs and Miller (1994) and subsequently applied by Cassiliano (1999). Collecting unit 52 occurs in the reversed interval between the Olduvai and Reunion (Chron C2r.1r) of the Matayama Chron, between 1.95 and 2.14 Ma. Cassiliano (1999) indicates the occurrence of *Nothrotheriops* at four collecting units

between 51 and 55 in the Palm Spring Formation. He also indicates two occurrences of the larger ground sloth *Paramylodon harlani* (*Glossotherium* sp. of Cassiliano) and 4 occurrences of *Erethizon* during this interval of time. The occurrence of a small species of *Hypolagus* at Gypsum Ridge does differ significantly from the range of the taxon in the Fish Creek-Vallecito Creek sequence of the Palm Spring Formation according to Cassiliano (1999). The species of *Paraneotoma* from Gypsum Ridge is more primitive tha the form from the middle Irvingtonian age El Casco local fauna of Riverside County (Albright, 1999). Due to increasing crown height and subsequent change in morphology of the m3 in *Paraneotoma* in Pliocene-early Pleistocene populations, the Gypsum Ridge form may represent an undescribed form that warrants further examination.

The overall taxonomic composition of the mammalian assemblage collected from Gypsum Ridge is Irvingtonian rather than Blancan in character. That is one of the reasons that the fauna is referred to as early Irvingtonian in age. Characteristic Irvingtonian taxa such as *Mammuthus, Lepus*, and *Euceratherium* are not represented (Opdyke and others, 1977), but the presence of *Nothrotheriops*, normally an Irvingtonian and Rancholabrean form (Akersten and McDonald, 1991; MacDonald, 1995) in conjunction with *Ondatra idahoensis, Dipodomys* sp. and the stage of evolution of the *Paraneotoma* sp. give the assemblage an Irvingtonian complexion. This extends the Blancan/Irvingtonian boundary to below the Olduvai event (between 1.95 and 2.1 Ma) in the eastern Mojave Desert and supports the conclusions of Opdyke and others (1977) and Cassiliano (1999).

The Gypsum Ridge local fauna most closely resembles the assemblage recovered from collecting units 51-55 of the Vallecito Creek section of the Palm Spring Formation of the Anza Borrego Desert (Cassiliano, 1999). In the San Pedro Valley of Arizona, the Curtis Ranch local fauna is considered to be temporally equivalent to the Gypsum Ridge assemblage. In the central United States, the Borchers local fauna is probably temporally correlative with Gypsum Ridge. Faunas of the Unnamed Sandstone in the Elsinore Trough of Riverside County may be correlative, though the grade of evolution of the *Paraneotoma* observed at Gypsum Ridge was not present in the material examined from the San Bernardino County Museum. The El Casco fauna of Riverside County appears significantly younger.

CONCLUSIONS

As a result of a paleontological resource assessment of the Marine Corps Air Ground Combat Center, Twentynine Palms, San Bernardino County, California, a new terrestrial vertebrate fauna of early Irvingtonian age was discovered and collected between 1997 and 1999. The Gypsum Ridge local fauna, north of Deadman Lake, was recovered from the base of an alluvial fan sequence that had prograded out onto an alkali lake bed. The fauna, recovered from approximately 24 localities within a thickness of 55 vertical feet of section, yielded invertebrates including the slug *Deroceras* sp. a minnow, amphibians, reptiles including the large tortoise *Hesperotestudo*, birds, and seventeen mammalian taxa. Six paleomagnetic sites were taken through 85 feet of section and all were reversed. Based upon the mammalian fauna, which includes *Paramylodon harlani, Nothrotheriops texanus, Dipodomys* sp., *Erethizon* sp., *Sigmodon minor, Paraneotoma* sp., *Ondatra idahoensis,* and *Bassaricus* sp., we correlate the fossiliferous beds with the reversed interval below the Olduvai event of the Matayama Chron, C2r.1r. This indicates an age of between 1.95 to 2.1 Ma for the Gypsum Ridge local fauna. The Gypsum Ridge local fauna appears to temporally correlative with the collection units between 51 and 55 of the Vallecito Creek section of the Anza Borrego Desert, the Curtis Ranch fauna of Arizona, and the Borchers fauna of Kansas.

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