new Sr^{90} to total Sr^{90} between 18 October 1964 and 31 March 1965 is shown in Table 2, together with the deposition per unit area for total Sr^{90}; contribution (from new to total) for the period 18–31 October 1964 amounted to 11 percent, while a similar contribution of 4.3 percent was derived in the same way from analysis (*7*) of a sample of rain collected at Fayetteville, Arkansas, on 26 October 1964, 10 days after the Chinese explosion. The latter value was less than half the average at Niigata between 18 and 31 October 1964 and was comparable with an average of 4.4 percent at Niigata during November of the same year. The contribution from new Sr^{90} of Chinese origin to total Sr^{90} was estimated at 3.9 percent between 18 October 1964 and 15 January 1965; from new Russian, 7.5 percent between 21 January and 31 March 1965; and from new Chinese and new Russian, 5.8 percent between 18 October 1964 and 31 March 1965.

The Sr^{90} deposition per unit area per unit explosive power of the Russian bomb was 0.30 to 0.15 mc km^{-2} $Mton^{-1}$ between 21 January and 31 March 1965. On the other hand, as the total explosive power of the 1957–58 test series was assessed at 36.3 Mton equivalents (*8*), the Sr^{90} deposition per unit area per unit explosive power for the series was estimated at 0.73 mc km^{-2} $Mton^{-1}$.

This finding suggests that the Russian blast caused heavy deposition of Sr^{90} per unit area per unit explosive power, deposition of the same order as that from the 1957–58 atmospheric series, in Niigata, more than 5000 km from Semipalatinsk. Table 2 further shows that the contribution decreased with time and became constant at 0.7 percent; this fact may imply that atmospheric mixing of new Sr^{90} from the Chinese and the Russian tests with old Sr^{90} from the 1961–62 test series was almost complete by early January and early March 1965, respectively.

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Geomagnetic Polarity Epochs: A New Polarity Event and the Age of the Brunhes-Matuyama Boundary

Abstract. *Recent paleomagnetic-radiometric data from six rhyolite domes in the Valles Caldera, New Mexico, indicate that the last change in polarity of the earth's magnetic field from reversed to normal (the Brunhes-Matuyama boundary) occurred at about 0.7 million years ago. A previously undiscovered geomagnetic polarity event, herein named the "Jaramillo normal event," occurred about 0.9 million years ago.*

Earlier quantitative investigations of the geomagnetic polarity epoch time scale have placed the last change in the polarity of the earth's magnetic field (from the Matuyama reversed epoch to the Brunhes normal epoch) at 1.0 million years ago (*1*, *2*). In a recent publication (*3*) we pointed out that the revision of the age of the normally magnetized Bishop Tuff (Pleistocene), of California, from 1.0 to 0.7 million years made the age of the Brunhes-Matuyama boundary less certain. Over 15 reversely magnetized volcanic rocks with potassium-argon ages in the range between 1.5 and 1.0 million years clearly define the boundary as being younger than 1.0 million years. Between 1.0 and 0.7 million years, however, the only datum was that from the Bishop Tuff, and thus the revision of its age raised the possibility that the boundary might be as young as 0.7 million years.

We have now completed paleomagnetic measurements and potassium-argon age determinations of 19 Pleistocene volcanic units from the Valles Caldera, Sandoval County, New Mexico. Six of these units, all rhyolite domes that were emplaced in the caldera after the extrusion of the Bandelier Tuff (*4*), have potassium-argon ages between 0.7 and 1.0 million years (Table 1), and are therefore important for defining the age of the Brunhes-Matuyama boundary. The ages are based on replicate potassium and argon determinations, and the paleomagnetic data were obtained from multiple samples. Sampling and measurement techniques are essentially the same as those described previously (*2*, *5*). Ages were measured on sanidine, except for unit 3X194, for which obsidian was used, and were calculated with $\lambda_\epsilon = 0.585 \times 10^{-10}$ yr^{-1}, $\lambda_\beta = 4.72 \times 10^{-10}$ yr^{-1}, $K^{40}/K = 1.19 \times 10^{-4}$ mole/mole. The atmospheric corrections ranged from 20 to 58 percent for the five younger units and from 76 to 77 percent for 3X194. The standard deviation of the calculated ages is 6 percent for 3X194 and 4 percent for the other units. This calculated standard deviation is based on the results of replication studies (*6*) and on the effect on precision of the atmospheric argon correction as calculated from the formula given by Lipson (*7*).

The discovery of both normal and reverse remanent magnetizations (as well as an intermediate direction) in these rocks is not surprising because they were formed near the time of the last polarity transition. Finding the normal and intermediate directions bracketed between reversed directions was, however, not anticipated and suggests three possibilities: (i) The precision of the potassium-argon age measurements is not sufficiently high to distinguish between the ages of the units, that is, 4D057 and 3X187 are really younger than the other domes; (ii) One or more of the domes may have self-reversed remanent magnetization (*8*); or (iii) There may be a short polarity event near the Brunhes-Matuyama boundary.

There is no stratigraphic evidence concerning the relative ages of the first five domes listed in the table, although all are known to be younger than 3X194. Four other domes in the Valles Caldera that are normally magnetized and are stratigraphically younger than any of the domes discussed here give ages between 0.43 and 0.54 million years. Thus, the ages in Table 1 are not inconsistent with the known stratigraphy. These relations, and the fact that at least two of the calculated ages would have to be in error by more than four times their standard deviations, lead us to reject the first hypothesis.

To investigate the possibility of self-

Table 1. Potassium-argon ages and polarities of six volcanic units from the Valles Caldera, New Mexico.

Unit No.	K-Ar age (millions of years)	Polarity
4D049	0.71	Reversed
3X122	.72	Reversed
4D074	.73	Reversed
4D057	.88	Intermediate
3X187	.89	Normal
3X194	1.04	Reversed

reversal, several petrographic, thermomagnetic, and other paleomagnetic "reliability" investigations were made on these rocks. We have not found any evidence that might be construed as indicating self-reversal, and, in fact, these rocks all have quite similar intrinsic magnetic properties. Finally, we note that a self-reversal hypothesis for these data cannot explain the intermediate direction of magnetization for 4D057.

Because polarity intervals of short duration are known in other parts of the polarity epoch time scale—the Olduvai normal event at 1.9 million years and the Mammoth reversed event at about 3.0 million years, during the Matuyama reversed and Gauss normal epochs, respectively (*5*)—the third of the three hypotheses appears most likely. Thus, these data and those previously published suggest the sequence for the more recent polarity changes shown in Fig. 1.

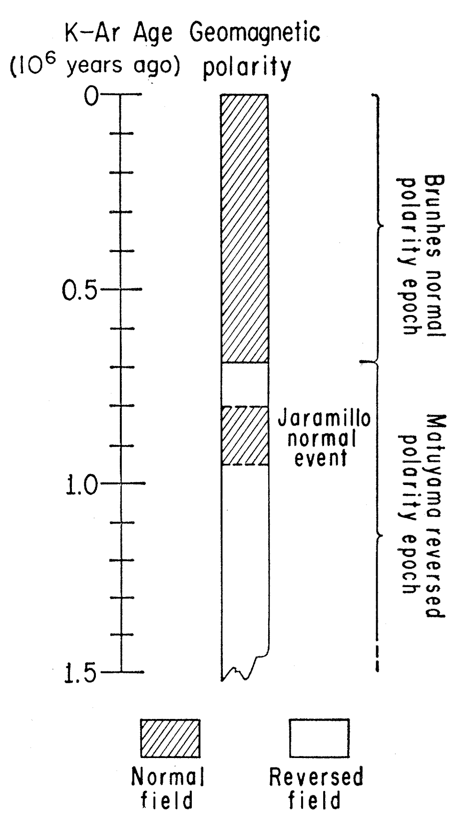

Fig. 1. Suggested sequence of the most recent changes in polarity of the earth's magnetic field.

The placement of the Brunhes-Matuyama boundary is more or less arbitrary in view of the present data. It could be placed between 0.9 and 1.0 million years ago, in which case the three reversely magnetized domes with ages between 0.71 and 0.73 million years would represent a reversed polarity event in the Brunhes normal epoch; or the boundary could be placed at 0.7 million years ago with 4D057 and 3X187 representing a normal event in the Matuyama reversed epoch at about 0.9 million years. For purposes of stratigraphic correlation, the last transition of polarity will undoubtedly be the most useful, and we therefore prefer to assign the epoch boundary at 0.7 million years. Accordingly we here name the normal event near 0.9 million years the "Jaramillo normal event," after Jaramillo Creek, which is approximately 3 km south of the locality of unit 3X187. From the present data it is not possible to tell whether the intermediate direction represents the transition to or from the Jaramillo normal event, nor, therefore, whether the event occurred just before or just after 0.9 million years ago.

Details of these studies as well as those on the other 13 units investigated in this region will be published shortly. Meanwhile, stratigraphers and other scientists making use of the geomagnetic polarity epoch time scale for geological correlation or other purposes may find these recent data valuable and timely.

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Color Center in Amethyst Quartz

Abstract. *Treatment with x-rays increased the intensity of color of natural amethyst up to fivefold, and an electron paramagnetic resonance spectrum was detected. The intensity of the spectrum was proportional to the intensity of the optical absorption near 545 mμ. The EPR spectrum of the color center corresponded to a positive hole trapped on a substitutional Fe^{3+} ion in the quartz structure. We ascribe the color to a charge-transfer transition, $Fe^{4+} + O^{2-} \rightarrow Fe^{3+} + O^{1-}$.*

Studies of electron paramagnetic resonance (EPR) and optical spectra of amethyst have revealed several different Fe^{3+} centers: a substitutional center, S_1, charge-compensated by an interstitial alkali ion (*1*); substitutional centers, S_2, charge-compensated by a proton (*2*); and an interstitial center, I_1 (*3*). Of these, center S_1 appears to be the precursor of the actual color center, which could be formed from it by x- or γ-irradiation. However, the EPR spectrum of the color center itself has not hitherto been identified.

Prolonged irradiation of a natural amethyst with x-rays caused a five-fold increase in the intensity of its color (measured in the 545-mμ band) (*4*). At the same time the intensity of the EPR spectrum of the S_1 center decreased to about one-third of its initial value. An increase in intensity of the S_2 spectrum accounted for about half the decrease in S_1. The residual decrease in intensity of precursor was assumed to be due to conversion to the color center.

Examination of the EPR spectrum at 93°K revealed an intense resonance line, without hyperfine structure, having a minimum width of 7.5 gauss. This line is shown in Fig. 1 for a rotation around the *c*-axis. Its intensity is proportional (within ± 15 percent) to that of the optical absorption at 545 mμ.

A comparison of its maximum intensity with a 1 percent pitch standard (both at 93°K) gave a value for free spins per unit volume of $N = 1.7 \times 10^{18}$ cm^{-3}. This figure is equal to almost one-third of the number of iron atoms present in the sample, as determined by spectrographic analysis. This value of N can be used in the Smakula formula (*5*), together with the intensity of the optical absorption band near