6-1985

Magnetic Polarity Stratigraphy and Stratigraphic Completeness

Steven R. May

Robert F. Butler
University of Portland, butler@up.edu

Frances A. Roth

GEOPHYSICAL RESEARCH LETTERS, VOL. 12, NO. 6, PAGES 341-344, JUNE 1985

MAGNETIC POLARITY STRATIGRAPHY AND STRATIGRAPHIC COMPLETENESS

Steven R. May, Robert F. Butler, and Frances A. Roth

Department of Geosciences, University of Arizona

Abstract. A fundamental limiting factor in the precision of magnetostratigraphic correlation is stratigraphic completeness. Sadler [1981] has suggested a method by which the expected completeness of any given stratigraphic section can be calculated given the thickness, duration, and depositional environment. The technique is probabilistic and requires the investigator to specify a meaningful short-term time scale at which completeness is to be estimated. For magnetostratigraphy, the short-term time scale is defined by the duration of the polarity chron or other polarity feature of interest. Sadler's method allows the probability of observing such features to be quantified. It is a useful tool for evaluating the reliability of magnetostratigraphic correlations and for judging between alternative correlations.

Introduction

A fundamental limiting factor in the precision of magnetostratigraphic correlation is the completeness of stratigraphic sections. Net sediment accumulation is an unsteady process involving sedimentation, non-deposition, and erosion. Stratigraphic sections are commonly incomplete at geologically important time scales and as such are discontinuous records of geologic time and of the "absolute" history of geomagnetic polarity. Thus the chronometry of sediment accumulation can be a sequence of brief, sporadic events (much like the Chink's clockworks in Siwash cave, Robbins, 1976 p.210), a reality to be appreciated by the magnetostratigrapher. The purpose of this paper is to discuss a technique which allows the completeness of stratigraphic sections to be estimated and to demonstrate the significance and usefulness of this technique for magnetostratigraphy.

Sadler [1981] has suggested a method by which the expected completeness of any given stratigraphic section can be calculated given the thickness, duration, and depositional environment. The technique is probabilistic and requires the investigator to specify a meaningful short-term time scale at which completeness is to be estimated. A necessary philosophy for the application of Sadler's method is to consider a 100% complete section as one which contains at least some sediment for each specified increment of time. A complete section is not one without gaps but one in which the duration of any gap is less than the duration of the specified short-term time scale.

The basic observation made by Reineck [1960], Sadler [1981] and others is that the mean rate of sediment accumulation for any given depositional environment decreases significantly as the time span of observation increases. Sadler [1981] proposed that stratigraphic completeness can be estimated by: "long-term rate/short-term rate" expressed as a percentage. The long-term rate is the total thickness of a section divided by the total time represented. The short-term rate may be read from Sadler's compilation of nearly 25,000 rates of sediment accumulation for different depositional environments at varying time spans. This philosophy of stratigraphic completeness considers the time that is likely represented by increments of net sediment accumulation in relation to the total time spanned by a section. An inherent imprecision derives from the need to use "global" average short-term rates as the expected values for a given section. In Sadler's compilation, sediment accumulation rates for any given time span may vary by as much as three orders of magnitude but clearly possess a log normal frequency distribution. This imprecision should be carefully acknowledged especially when the long-term rate for a given section is significantly faster or slower than the "global" average for the appropriate time span.

Magnetostratigraphers enjoy the ability to define the length of the appropriate short-term

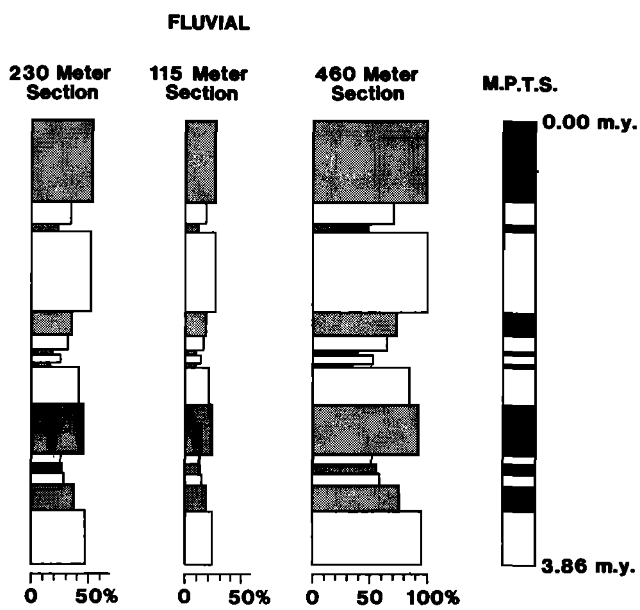

Fig. 1. Probability histograms for three hypothetical stratigraphic sections ranging from 0 to 3.86 m.y. in age. Section on far left yields approximate average fluvial long-term rate of sediment accumulation. % values across base of each histogram scale the probability of the section having accumulated some sediment during the corresponding polarity interval on the right.

Paper number 4L6390.
0094-8276/85/004L-6390$03.00

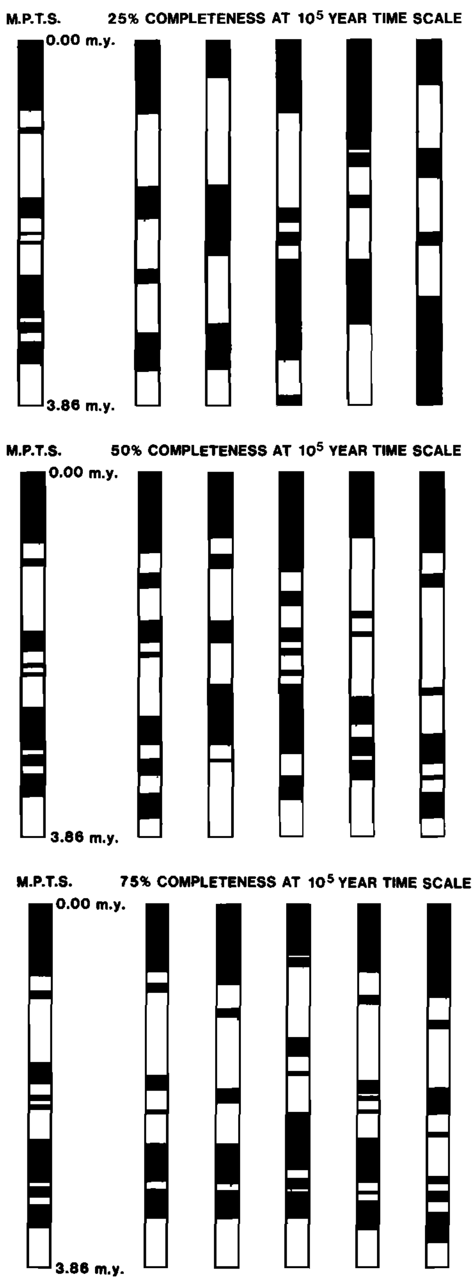

Fig. 2. Synthetic magnetic polarity stratigraphies for 100,000 year time scale at 25, 50, and 75% completeness for the interval 0-3.86 m.y.

time scale because we know (with varying degrees of precision) the durations of our magnetic polarity intervals. The temporal length of any given polarity interval can be found in a Magnetic Polarity Time Scale (M.P.T.S.). Therefore, magnetostratigraphers can stipulate precisely at what time resolution stratigraphic completeness need be considered for exercises in magnetostratigraphic correlation.

It is not uncommon to observe a polarity stratigraphy which when "best correlated" with the M.P.T.S. does not contain all of the "short duration" subchrons. Sadler's method allows the probability of observing such events to be estimated. Contrary to the opinion of Hall and Butler [1983], polarity intervals of short duration generally do not "provide a basis upon which sections can be correlated" because their probability of being recorded in a stratigraphic section is less than intervals of long duration. Stratigraphic completeness calculations can be very useful for assessing the reliability of potential magnetostratigraphic correlations and for judging between alternative correlations. It is also instructive to consider the effect of varying completeness on our ability to recognize patterns of normal and reverse polarity. It will become evident that sampling parameters are of secondary importance and that claimed average temporal spans between paleomagnetic sites based on assumed constancy of sedimentation are misleading.

Completeness and Magnetostratigraphic Correlation

The probability that each polarity interval expected in a particular time span was recorded by net sediment accumulation can be portrayed in histogram fashion as shown in Figure 1. We have generated probability histograms for fluvial sections of different thickness but of the same duration (3.86 m.y.). The histogram on the left represents a section whose long-term rate of net sediment accumulation (0.06 meters/1000 years) is about average in Sadler's compilation of fluvial rates. The two histograms to the right represent stratigraphic sections with 1/2 and twice the long-term rate of the average section. In the average section we see that even for the long duration polarity intervals such as the Brunhes Chron or the Matuyama Chron between Jaramillo and Olduvai Subchrons, the expected completeness is between 50 and 60%. At twice the mean long-term rate (far right histogram) the probability of our section having recorded these same intervals is 100%. The intuitive and widely appreciated message in Figure 1 is that the probability of any section having recorded a long duration polarity interval is greater than for a short duration interval. The revelation in Figure 1 is that using Sadler's method for estimating stratigraphic completeness, we can begin to quantify these probabilities.

Synthetic Magnetic Polarity Stratigraphies

Johnson and McGee [1983] and Hall and Butler [1983] have used synthetic polarity stratigraphies to illustrate the potential effects of sampling method and various stratigraphic/sedimentologic parameters on recognition of magnetic polarity patterns. Similarly, we have generated synthetic polarity stratigraphies by modeling sedimentary sampling of the M.P.T.S. to yield sections of desired stratigraphic completeness. We simply divide a portion of the M.P.T.S. into increments of specified duration and then randomly select an appropriate number of these increments to produce the desired stratigraphic completeness. The polarity corresponding to each of these increments was then composited in appropriate chronologic order to yield a synthetic stratigraphy. Multiple trials were produced for

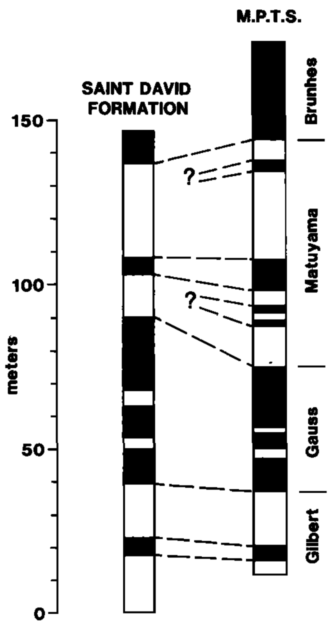

Fig. 3. Magnetic polarity stratigraphy of the St. David Formation modified from Johnson et al. [1975].

various completeness-time scale parameters as shown in Figure 2. The synthetic polarity stratigraphies illustrate that relatively complete stratigraphic sections are necessary to allow confident pattern recognition without the aid of abundant external chronologic data.

Since stratigraphic completeness requires only that some sediment be present for any selected interval, not that all of the represented intervals preserve the same thickness of sediment, the synthetic polarity stratigraphies in Figure 2 have a time axis and not a thickness axis. If we further select appropriate, random thickness increments, polarity intervals are not lost but their relative prominence changes. Nevertheless, the optimistic synthetic polarity stratigraphies we offer clearly illustrate the fundamental control of completeness on polarity pattern recognition.

The variability of patterns in Figure 2 emphasizes both the need for external age control and the dangers of correlation by simple pattern recognition for stratigraphic sections that are only moderately complete at time scales pertinent to magnetic polarity history. Clearly, the appropriate short-term time scale will vary as a function of the time interval within the M.P.T.S. The length of the shortest polarity event during the last 3.86 m.y. is 20,000 years. In order to observe the fine detail of polarity history in this time range, we must require appreciable completeness at the 20,000 year scale. If, on the other hand, we are working with sediments of early Paleocene age then the shortest polarity interval one hopes to observe is chron 28R of approximately 400,000 years duration. 50% completeness at a 100,000 year time scale may be adequate to record the pattern of polarity reversals in early Paleocene sediments but certainly not in those of late Neogene age.

Case Examples

Consider an example from the late Neogene of Arizona. Johnson et al. [1975] published a magnetic polarity stratigraphy for the Saint David Formation exposed in the San Pedro Valley, southeastern Arizona. The observed polarity zonation was correlated with the M.P.T.S. between the upper Gilbert and lower Brunhes Chrons but Johnson et al. [1975] did not observe normal polarity zones representing the Jaramillo or Reunion Subchrons (Figure 3). By calculating the completeness of the Saint David Formation section at time scales equivalent to the duration of the Jaramillo and Reunion Subchrons, we can quantitatively assess whether one should expect to observe these events.

The approximate time interval from the base of the Gauss Chron to the base of the Brunhes Chron would be 2.7 m.y. The thickness of this 2.7 m.y. interval is 94 meters yielding a long term rate of 0.035 meters/1000 years. Taking the lengths of the Jaramillo (60,000 years) and the Reunion Subchrons (30,000 and 20,000 years, Ness et al. 1980) to be appropriate short-term time spans, we calculate only a 14% probability for the Saint David section having recorded the Jaramillo Subchron and 11% and 10% probabilities for the Reunion Subchrons. The completeness estimates suggest that one should never have expected to observe these relatively short duration events within the polarity stratigraphy of the Saint David Formation. This conclusion should be viewed as evidence in support of the correlation made by Johnson et al. [1975].

Another case example illustrates how stratigraphic completeness can be used to help evaluate the reliability of magnetostratigraphic data. Payne et al. [1983] published a magnetic polarity stratigraphy for a 33 meter long core from the Raton Basin in northeastern New Mexico. This core is purported to contain the Cretaceous-Tertiary boundary and the interpreted polarity pattern was correlated with Chrons 28N through 30R of the M.P.T.S. Using this correlation from the base of Chron 30N to the base of Chron 28N, the long-term rate of sediment accumulation for the Raton core is 0.0059 m/1000 years. When compared to Sadler's compilation of sediment accumulation rates for fluvial environments, the calculated rate of sediment accumulation for the Raton core is extremely low. In fact, 90% of all compiled rates at the 4,000,000 year time span are higher. Accordingly, the completeness estimates calculated for short-term time scales equivalent to the durations of the supposed polarity chrons represented in the Raton core are nearly zero (4.6% for the shortest and 7.8% for the longest). There are two possible conclusions which can be drawn from these completeness estimates. (1) The interpretation of the Raton Basin core magnetostratigraphic data by Payne et al. [1983] is correct and the Raton Basin section is extremely unusual in being quite complete at the 100,000 year time scale despite the very low long-term sediment accumulation rate. (2) A problem exists with the paleomagnetic data from the Raton Basin core and/or with the interpretation thereof. Given the acknowledged problem of a strong down-core magnetic overprint and the low completeness estimates, we favor the conclusion that the interpretation by Payne et al. [1983] is in error.

Summary

Sediment accumulation can be modeled as a random process producing a discontinuous record of geomagnetic polarity history. Sadler's method for calculating stratigraphic completeness can be very useful for interpreting the reliability of magnetostratigraphic correlations and for judging a most likely correlation given certain reasonable alternatives. The technique should not be viewed as an added degree of freedom manufactured to make magnetostratigraphic correlation easier nor should it be viewed as a proclamation that stratigraphic sections are too incomplete to be amenable to detailed magnetostratigraphic studies. It allows estimates of the likelihood of preservation of a polarity pattern in a particular section when compared with an "average" section of the same general environment.

Acknowledgments. This work was supported in part by NSF grant EAR8115430.

References

Hall, S.A., and J.C. Butler, Potential problems in the magnetostratigraphic studies of shallow water sequences, J. Geology, 91, 693-705, 1983.

Johnson, N.M., and V.E. McGee, Magnetic polarity stratigraphy: stochastic properties of data, sampling problems, and the evaluation of interpretations, J. Geophys. Res., 88, 1213-1221, 1983.

Johnson, N.M., Opdyke, N.D., and E.H. Lindsay, Magnetic polarity stratigraphy of Pliocene-Pleistocene terrestrial deposits and vertebrate faunas, San Pedro Valley, Arizona, Geol. Soc. Am. Bull., 86, 5-12, 1975.

Ness, G., Levi, S., and R. Couch, Marine magnetic anomaly timescales for the Cenozoic and late Cretaceous: a precis, critique, and synthesis, Rev. Geophys. Space Phys., 18, 753-770, 1980.

Payne, M.E., Wolberg, D.L., and A. Hunt, Magnetostratigraphy of a core from the Raton Basin, New Mexico - implications for synchroneity of Cretaceous /Tertiary boundary events, New Mexico Geol., 5, 41-44, 1983.

Reineck, H.E., Über Zeitlucken in rezenten Flaschee-Sedimenten, Geol. Rundschau, 49, 149-161, 1960.

Robbins, T, Even Cowgirls Get The Blues, Houghton Mifflin Co., Boston, 365 pp., 1976.

Sadler, P.M., Sediment accumulation rates and the completeness of stratigraphic sections, J. Geology, 89, 569-584, 1981.

S. May, R. Butler, and F. Roth, Department of Geosciences, University of Arizona, Tucson, AZ 85721

(Received October 29,1984;
revised March 15, 1985;
accepted March 19, 1985.)