

Magnetostratigraphy Adds a Temporal Dimension to Basin Analysis*

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General Statement

Knowledge of basin evolution rates provides insight into the timing of hydrocarbon generation, facies migration, and structural trap formation. In marine environments, fossils often furnish excellent geochronometry from which relatively precise rate calculations are possible, but the near lack of well-constrained fossils in most continental environments confounds our ability to establish the temporal dimension of basin-filling (overburden) strata in which basin history is recorded (Figure 1).

Magnetostratigraphy can provide a relatively precise chronology in strata independent of fossil content. The technique correlates magnetic reversals found in a stratigraphic column with reversal ages derived from sea-floor magnetic stripes. Magnetostratigraphic geochronometry works best in fine-grained, Neogene, siliciclastic strata, but it can be used effectively in rocks as old as Middle Jurassic. In rocks that predate the oldest

modern sea-floor, magnetic reversal patterns can still be used as correlative tools.

Siliciclastic rocks are desirable because they are more likely to possess sufficient magnetic mineral contents, but successful studies exist from chemical and biochemical sedimentary environments. Fine grain sizes are necessary because only single-domain magnetic minerals consistently align with the ambient magnetic field during deposition. Siltstones and mudstones are most effective, but poorly sorted fine- to medium-grained sandstones can yield a consistent signal. Young rocks are most favorable because the Global Magnetic Polarity Time Scale (GMPTS) is more precisely constrained and because there is less likelihood that these strata were overprinted by remagnetization events that mask the original Natural Remanent Magnetization (NRM).

Field Techniques

Oriented samples are collected throughout a stratigraphic section. A minimum of three samples is collected from each site for statistical purposes. Sampling is usually accomplished using a coring drill. Hand-sampling techniques also work but are more labor-intensive. Because precise rock ages and deposition rates are intangible at the outset, initial sampling intervals are judged largely on regional experience and intuition. A general rule in continental environments is that sections proximal to their source sustain larger intervals than distal sections.

In Argentine Andean foreland basins, stratigraphic sample spacings of 15-40 meters are common, whereas in the Himalayan foreland of Pakistan intervals of 5-10 meters are more typical. Spacings between adjacent sites usually express

considerable variation determined by the availability of fine-grained strata.

Laboratory Analysis

Samples are first analyzed to determine their outcrop NRM. A cryogenic magnetometer is usually the instrument of choice, but spinner magnetometers still play important roles in many laboratories. The NRM consists of two components: a "stable" Detrital Remanent Magnetization (DRM) and a variable Viscous Remanent Magnetization (VRM).

The VRM may change polarity during magnetic reversals; the DRM does not. The VRM may or may not be stronger than the DRM, so it is essential that it be removed to determine the true orientation of the DRM. VRM removal is usually accomplished by either Thermal Demagnetization or Alternating Field Demagnetization. Both techniques effectively randomize the VRM component allowing the stable DRM to dominate.

Confident magnetic cleaning is the greatest obstacle to downhole magnetostratigraphic analysis. Demagnetized sample orientations from each site are averaged and tested for statistical significance. Sites that pass are designated Class I. Class II sites have only two surviving samples, but both exhibit the same polarity. These are used only to support adjacent sites of the same polarity.

Data Interpretation

Upon completion of laboratory analysis, the latitude of the Virtual Geomagnetic Pole (VGP) is calculated for each site. This parameter places the North Magnetic Pole in either the northern (normal) or southern (reversed) hemisphere. VGP latitudes are plotted vs. sample stratigraphic levels. This

information is abstracted to the standard black and white column in which black designates normal and white signifies reversed polarity. Reversal boundaries are placed halfway between adjacent sites of unlike polarity (Figure 2).

The local paleomagnetic column is correlated with the GMPTS (Figure 2). Because of the binary nature of polarity zones (normal or reversed), it is essential that the local column be independently calibrated with either an isotopic age or a well-constrained fossil to avoid correlation errors due to variable sediment accumulation rates.

Sediment accumulation (basin subsidence) history (rate) is derived by plotting reversal ages vs. their stratigraphic levels (Figure 3). Variation in accumulation rate is often due to tectonism in mountain belts, but climate and eustacy may also be important contributors. Relatively precise dating of internal and cross-cutting features of the sedimentary pile also arise from the magnetostratigraphy. These can include constraining sediment source area changes, depositional hiatus, facies changes, and ages of faulting and folding. Where strong seismic reflectors crop out, they can be dated and carried into the subsurface to provide an intrinsic chronometry for seismic sections.

Case Study

Perhaps the most interesting application of these data is an estimate of ages of hydrocarbon maturation/migration. Subsidence of source strata through the generation window can be modeled using the ages of the overburden beds.

Paleomagnetic results from the 4,650 meter-thick Neogene Quebrada la Porcelana

section in the Sierra de Ramos of northwestern Argentina illustrate this application. The base of the paleomagnetic section is situated ~ 1,700 meters above the base of the 300 meter-thick Los Monos source horizon. Magnetostratigraphic chronology suggests that growth strata derived from rising anticlinal structures accumulated between 5.2 Ma and the top of the section (< 1 Ma). Assuming a generation depth of four kilometers and using outcrop thicknesses, the base of the Los Monos Formation probably attained generating depths ~ 8 Ma. A backstripped sedimentary column would suggest that generation depth may actually have been reached at about the same time the growth strata began to accumulate. Using either data set suggests that local trapping structures were available during initial generation and migration.

Similar analysis in the 7.5 km-thick Rio Iruya section, ~35 km to the west, revealed that generation depths were attained two-three million years before local trapping structures formed. Ongoing magnetostratigraphic research continues to reveal the chronology of basin evolution in other parts of the Argentine Andean foreland. In conjunction with existing geological and geophysical information, these data are unveiling an impressive diachronism in structural development and hydrocarbon generation across the region.

Reference

Cande, S.C., and D.V. Kent, 1995, Revised calibration of the geomagnetic polarity timescale for the late Cretaceous and Cenozoic: *Journal of Geophysical Research*, v. 100, p. 6093-6095.

Figures



Figure 1. Geologists entered Argentina's Rio Iruya canyon, northwestern Argentina (Andean foreland), to collect a magnetostratigraphic section; results showed that the rocks in the wall were deposited 5-4 Ma..

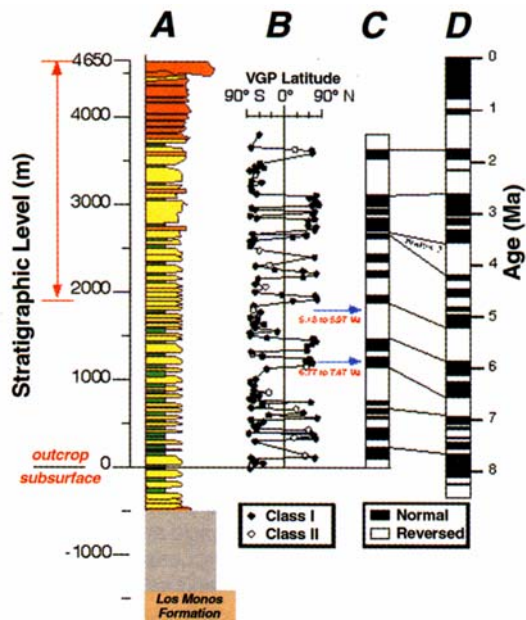


Figure 2 -Magnetostratigraphic study of the Quebrada la Porcelana section, northwestern Argentina (Andean foreland). Column A is the stratigraphic column with detail provided for exposed Neogene strata. Column B is a plot of VGP latitude vs. stratigraphic level of sample sites. Column C is correlated the GMPTS (column D) of Cande and Kent (1995) to determine reversal ages.

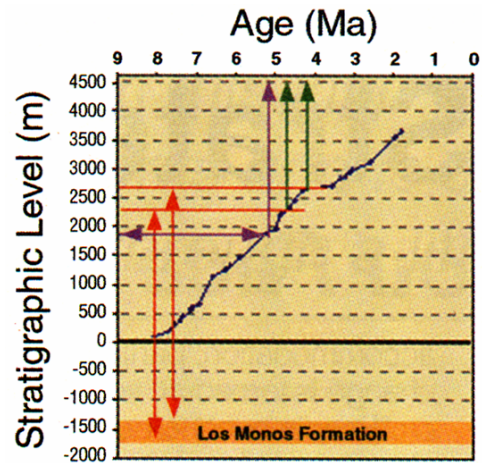


Figure 3 - Sediment accumulation history for the Quebrada la Porcelana area based on magnetostratigraphic dating of Neogene overburden strata: Using outcrop thicknesses, the Los Monos Formation passed through the generation depth (assumed to be 4 km; red arrows) during the 4.8-4.1 Ma interval (green arrows). Growth strata deposition commenced about 5.2 Ma (purple arrows).