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TITLE: APPLICATION OF ROCK VARNISH DATING OF QUATERNARY SURFICIAL DEPOSITS IN DETERMINING TIMES OF FAULT MOVEMENT

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APPLICATION OF ROCK VARNISH DATING OF QUATERNARY SURFICIAL DEPOSITS IN DETERMINING TIMES OF FAULT MOVEMENT

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ABSTRACT

Rock varnish, a coating commonly found on rock surfaces in arid and semiarid regions, has a significant potential in paleoseismic studies, as a wide variety of Quaternary surfaces and surficial deposits can be dated with the rock varnish technique. If the formation of geomorphic surfaces or surficial deposits can be related to times of faulting or if faulting has broken or deformed such features, then rock varnish dating can be used to constrain maximum and minimum times of motion on the related fault.

INTRODUCTION

Rock varnish, a ubiquitous, manganese and iron rich coating on boulders in arid and semiarid regions, has long been of interest as a potential age indicator. Recent work (Dorn, 1983; Harrington and Whitney, in press) has demonstrated that rock varnish is an effective medium for dating geomorphic surfaces and surficial deposits over an age range of several thousand to over a million years. The ratio of several minor elements within the varnish [(K+Ca)/Ti] has been shown to be age dependent and to decrease with time. Rock varnish cation ratios (VCRs) obtained for geomorphic surfaces which have been isotopically dated are used to construct calibrated VCR curves (area specific plots of VCR versus log time). These varnish curves can then be used to date varnish of unknown age throughout the region of calibration. Varnish ages from surface clasts represent the surface exposure time of the clasts. This in turn represents the time that the surface was incised and stabilized (ceased being a surface of active transport). Thus, using calibrated cation ratio curves, the time of initial varnish formation on surface clasts (a minimum age estimate for surface formation) can be determined for a variety of geomorphic surfaces within the region.

METHOD

Rock varnish is analyzed using a scanning-electron microscope (SEM) equipped with an energy dispersive x-ray analyzer. Whereas others detach the varnish before analysis (Dorn, 1983, Dorn and others, 1986), with the SEM elemental ratios are calculated for undisturbed varnish on portions of varnished clasts (Harrington and Whitney, in press). Eight to ten clasts are analyzed for each surface to be dated and a VCR is calculated for the surface by averaging the VCRs determined for all analyzed surface clasts. Geomorphic surfaces dated by a variety of isotopic techniques can be used to calibrate VCR curves. K-Ar, U-series, and U-trend dated surfaces (Harrington and Whitney, in press) and C^{14} dated surfaces (Dorn and others, 1986) have been used for VCR curve calibration.

Cation ratio curves have been constructed for the Coso Range and Mojave region in southern California (Dorn, 1983; Dorn and others, 1986) and for the Española basin, New Mexico and a portion of the Nevada Test Site (Harrington and Whitney, in press). The Española basin curve (Fig. 1) was calibrated for the time interval of 20 ka to 500 ka, using a combination of four uranium-series dated erosion surfaces and four surface ages based on carbonate accumulation in soils (Dethier and others, in press). The curve for the NTS (Harrington and Whitney, in press) was calibrated using three uranium-trend dated alluvial surfaces and two K-Ar dated lava flows, ranging in age from 40 ka to 1.1 Ma. Each of the curves possess a unique y intercept and slope, suggesting that cation ratio curves are specific to the region of calibration.

Regional differences in dust composition and depositional rates as well as rainfall type and amount may be possible causes for differences in VCR curves between regions. The size of an area over which a VCR curve can be used for dating is not yet known, but probably varies depending on the degree of variability of climatic factors across the region.

A critical assumption in curve calibration is that dated varnish is the same age as the dated deposit used for calibration. In addition it must be assumed that the deposit has been continually exposed throughout the time of varnish formation. Dorn and others, (1986) have noted that varnish formation begins soon (< than 200 years) after surface exposure of a deposit. Thus, for deposits for which continual exposure can be demonstrated, the assumption of equality in varnish and deposit age is likely valid. As deposit age increases the demonstration of continual exposure becomes progressively more difficult and for older deposits often can not be made with a high degree of certainty. In the case of K-Ar dated lava flows, an additional assumption must be that the time between flow deposition and varnish initiation on stable flow surfaces is short when compared to flow age.

Accuracy in the determination of the age of a geomorphic surface is most severely limited at present by our ability to recognize and select the most mature varnish from the surface to be dated. This becomes progressively more difficult and critical the younger the surface. Research directed at a better understanding of the manner and rate of varnish formation will permit better sample selection. Thus, the result will be reduced standard deviations for VCR calibration points, VCR curves that are better constrained, and greater apparent accuracy in age estimates.

A cation ratio curve can be extended into Holocene time by (1) using varnish cation ratios from surfaces or deposits of Holocene age dated by C^{14} or other isotopic techniques or (2) extrapolation from the calibrated interval. The standard deviation of VCR's for an individual surface is greater the younger the surface. Thus, calibration curve position is most poorly constrained in the youngest portion of the curve. Extrapolation of the curve into the Holocene from calibration points based on deposits considerably older than Holocene increases the uncertainty of curve position.

We have dated varnish formation on pediment surfaces, alluvial fans, fluvial terraces, colluvial hillslope deposits, stable eolian deposits, and geomorphic surfaces which have been faulted (Dethier and Harrington, 1986; Harrington, 1986a; Harrington, 1986b; Harrington and Dethier, 1987; Dethier and others, in press; Harrington and Whitney, in press). Ideal surfaces for rock varnish dating are those on deposits containing large clasts that project well above the soil surface.

APPLICATION OF ROCK VARNISH DATING IN PALEOSEISMOLOGY

Rock varnish dating of landforms has a high potential utility in paleoseismic investigations. The significance of rock varnish dating to paleoseismic studies lies in the large variety of geomorphic surfaces and deposits potentially datable by this technique. Many such deposits, especially those of coarse clastic material, may not be easily datable by conventional isotopic techniques. The age of these deposits, however, may be crucial in constraining times of movement on faults which deform the deposits or to which their formation is related. If formation of geomorphic surfaces or surficial deposits can be related to times of faulting then rock varnish dating can yield maximum and/or minimum times of motion for the related fault segments. Dating of surfaces which have been disrupted by faulting yields a maximum time since most recent fault motion. In like manner, varnish dating of surficial deposits, such as colluvial wedge material, which have been shed off of or over the scarp provide estimates of the minimum time since last fault motion occurred.

We have used rock varnish dating within the Española basin to determine the time of formation of landforms that are related to faulting in order to constrain the time of most recent fault motion. Four Quaternary erosion surfaces, formed along the western side of the basin, have been broken or deformed along three groups of related faults which are part of the Pajarito fault system. Estimates of surface ages and correlation of surfaces along the western side of the basin were based on rock varnish cation ratios from varnished surface clasts (Dethier and others, in press). The four erosion surfaces range in age from about 500 ka to 80 ka, and lie 200 to 15 meters above present base level, the Rio Grande (Fig. 2). The maximum time since movement has occurred on a fault can be constrained by the rock varnish age of the youngest erosion surface displaced by the fault.

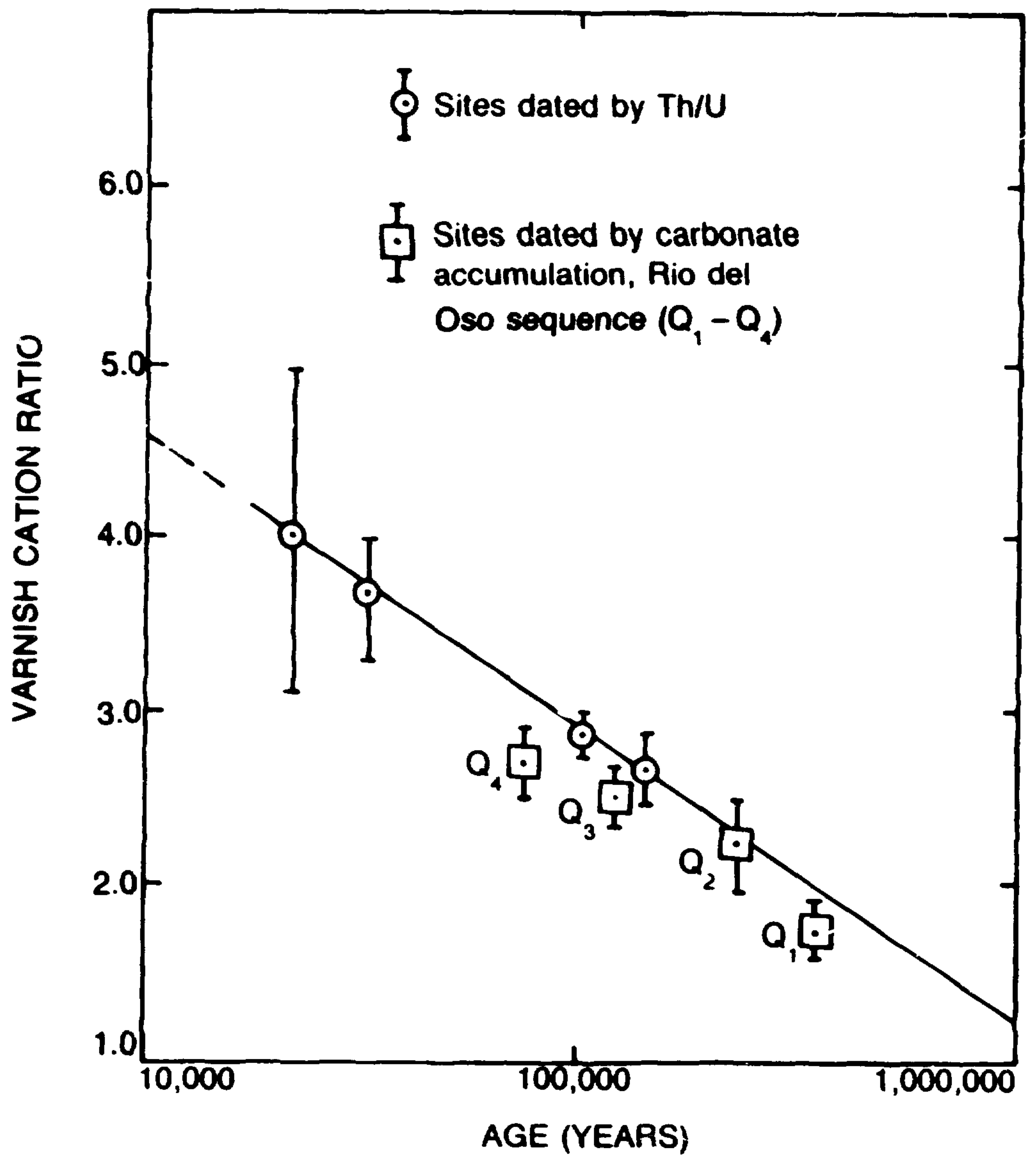
Each of the surfaces step down to the east along a series of north trending scarps which truncate the surfaces along a trend perpendicular to surface slope. Near Hernandez, New Mexico these north trending scarps are 8 to 20 m high and coincide with a series of north trending fault traces (Harrington and Dethier, 1987). Rock varnish dating has been used to establish the time of formation of one of these north trending scarps (Fig. 3). The surface that extends back from the top of the scarp yields a rock varnish age of 103 ka. Varnished clasts on sediment that was deposited on the surface at the foot of the scarp yields an age estimate of 72 ka, while clasts taken from the top of the scarp itself give an age estimate of 31 ka. We thus conclude that the scarp formed between 103 and 72 ka, and has undergone regrading until about 31 ka.

Rock varnish dating of other geomorphic features has also been used in the Española basin to constrain the time of last movement on faults. West of Hernandez, New Mexico a NNW trending fault showing recurrent movement offsets an erosion surface that has a rock varnish age of 240 ka, a minimum of 6 m. This fault appears to cut the sediment fill of a paleochannel. Varnished clasts from the surface of the paleochannel sediment fill yield an age estimate of 40 ka. Thus, if the fault cuts the paleochannel, then the 6 m of offset has occurred during a significantly shorter time period than the 240 ka derived by using the age of the erosion surface to constrain the timing of last fault movement.

CONCLUSIONS

The ages of surficial deposits and geomorphic surfaces broken by or related to faulting are often critical controls in constraining the timing of fault motion. Frequently, impercise relations between datable materials and pertinent geomorphic features significantly limits the applicability of isotopic techniques (Dohrenwend and others, 1986). It is possible, however, with rock varnish dating, to obtain ages for many such surfaces or features, especially those formed on coarse clastic materials.

Thus, rock varnish dating has a significant potential in paleoseismic investigations in arid and semiarid regions because of the large variety of surficial deposits and geomorphic surfaces which can be dated by the technique. Rock varnish dating offers the potential for both; (1) determining the age of many geomorphic surfaces and surficial deposits which may not be readily datable by isotopic techniques , and (2) evaluating whether an isotopic date is



Sites dated by Th/U
Sites dated by carbonate accumulation, Rio del Oso sequence (Q_1 - Q_4)
6.0
5.0
4.0
3.0
2.0
1.0
Q_4
Q_3
Q_2
Q_1
VARNISH CATION RATIO
10,000
100,000
1,000,000
AGE (YEARS)

an accurate portrayal of deposit age or instead, represents a later event which has reset the isotopic clock for that deposit.

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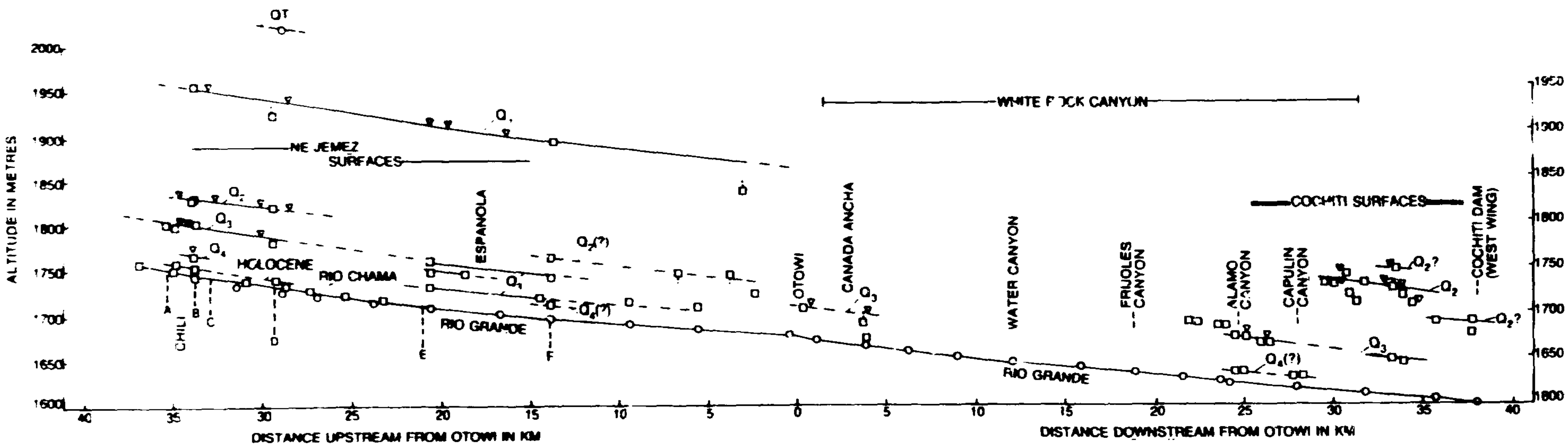
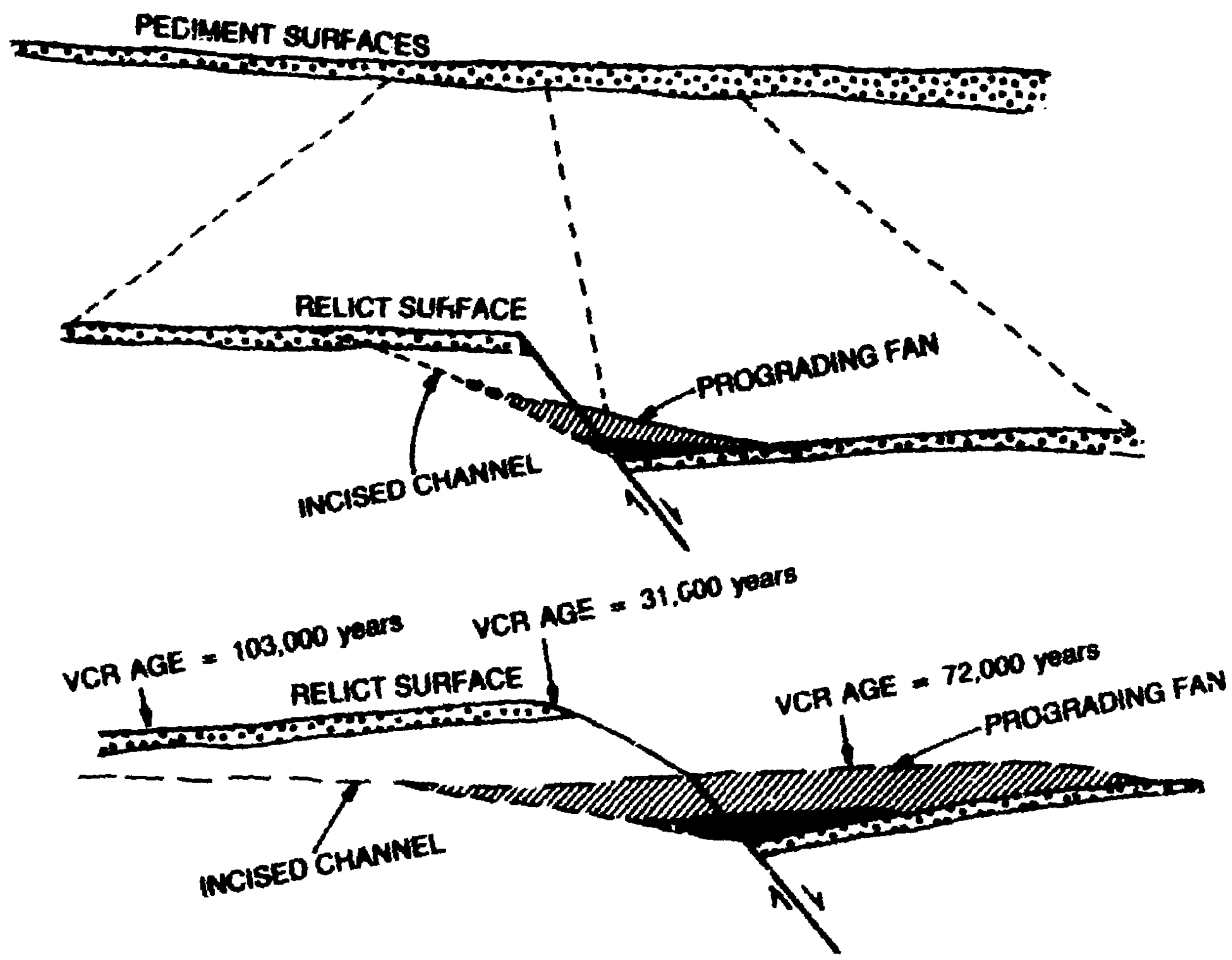
List of Figures

PROFILE OF GEOMORPHIC SURFACES PROJECTED TO THE RIO CHAMA - RIO GRANDE SYSTEM



EXPLANATION

- PROFILE OF RIO GRANDE
- PROFILE OF RIO CHAMA
- SURFACE ELEVATION PROJECTED TO RIO GRANDE OR RIO CHAMA
- MINIMUM LIMIT FOR SURFACE ELEVATION
- MAXIMUM LIMIT FOR SURFACE ELEVATION
- VARNISH MEASUREMENT
- A LOCATION OF ARROYO (See Caption)


PEDIMENT SURFACES
RELICT SURFACE
PROGRADING FAN
INCISED CHANNEL
VCR AGE = 103,000 years
VCR AGE = 31,000 years
RELICT SURFACE
VCR AGE = 72,000 years
PROGRADING FAN
INCISED CHANNEL