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AMINO ACID DATING OF QUATERNARY MARINE TERRACES AT BAHIA ASUNCION, BAJA CALIFORNIA SUR. MEXICO

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ABSTRACT

In the area of Bahia Asuncion, on the Pacific coast of the Bahia California peninsula, amino acid racemization dating has been used to estimate ages of mollusks from Quaternary marine terraces. Eighteen mollusks samples (of the genera Tivela, Saxidomus, and Chione) from ten localities have been analyzed. The high mean annual temperature for the region (greater than 20 degrees C) has resulted in extensive racemization in what are considered to be late Pleistocene low terrace localities. Racemization for most amino acids is effectively complete by about 300,000 years. Two amino acids, leucine and valine, demonstrate enough "resolving power" to be used to delineate different age groups among the terrace sites. Where these apparent groups are testable with stratigraphic or geomorphic evidence, they are generally consistent with the available geologic control. The ages estimated for the three aminostratigraphic groups recognized in this study are approximately 120,000, 200,000 and \geq 300,000 years.

INTRODUCTION

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Along the Vizcaino Peninsula, Baja California Sur, and, in particular, in the region of Bahia Asuncion (Figure 1), a series of Quaternary marine terraces exists that range in elevation from +2 to more than +200 meters (Troughton, 1974; Ortlieb, 1978, 1979a, 1979b, 1980; Malpica, 1980; and Malpica et al., 1981). The lowest terraces have been tentatively correlated on the basis of elevation and morphology and are thought to represent the last middle to late Quaternary high sea-stands corresponding to the



Figure 1: Sample locations, Bahia Asuncion, southern Vizcaino Peninsula (Baja California Sur, Mexico). oxygen-isotope curve of Shackleton and Opdyke (1973)(Ortlieb, 1978, 1979b, and 1979c).

Along the Pacific coast of North America, solitary corals have been dated by Uranium-series methods at the following low terrace localities: Cayucas, Calif. (Veeh and Valentine, 1967); Nestor Terrace (Ku and Kern, 1974) and Eel Point Terrace, Calif. (Muhs and Szabo, 1982); and Magdalena Bay, Baja California Sur, Mexico (Omura <u>et al</u>., 1979). The dates on these samples appear to represent the 120,000 to 130,000 year high sea-stand that is recorded by marine isotope records (Shackleton and Opdyke, 1973) and numerous tropical island coral terrace records (eg., Bloom <u>et</u> <u>al</u>., 1974). Also, on the Sonoran coast of the Gulf of California, several last interglacial radiometric dates have been obtained (Bernat <u>et al</u>., 1980).

Absolute dating of marine deposits by Uranium-series has not been totally successful in the Vizcaino Peninsula (Ortlieb <u>et al.</u>, in preparation). In this study, the majority of the samples analyzed were mollusks which are the most common macroinvertebrates found in Quaternary deposits. However, mollusks do not appear to be as reliable as coral for U-series dating (Kaufman <u>et al</u>., 1971). Also, Ortlieb <u>et al</u>. (in preparatiom) found that diagenetic alteration and contamination was widespread in the sample popualtion which did include a few corals.

Because abundant fossil molluscan material is often available in Quaternary deposits, samples of this type have been used by numerous workers in evaluation and application of the amino acid racemization (AAR) dating method. This recent method relies upon the conversion (racemization) of L-amino acids ("left-handed") present in living mollusk shells to an equilibrium mixture of 50% L-forms and 50% D-forms ("right-handed"). D/L values increase from 0.0 to 1.0 with increasing age of the sample, and individual clusters of D/L values are often recognized as "aminostratigraphic units" or "aminozones" within a specific geographic region (Miller and Hare, 1980). These amino acids represent the residuum of the original calcification protein, and the racemization of the amino acids is one of several diagenetic reactions that occur. Wehmiller (1982) has recently reviewed many of the applications of amino acid racemization dating to Quaternary coastal chronologic problems.

Amino acid racemization dating has been employed extensively in studies of Quaternary deposits of the Pacific coast of the United States (Wehmiller <u>et al</u>., 1977; Lajoie <u>et al</u>., 1979; Karrow and Bada, 1980; Kennedy <u>et al</u>., 1982; and Muhs, 1983). Results from Woods (1980), Wehmiller and Emerson (1980), and Emerson <u>et al</u>. (1981), permit the extension of the United States aminostratigraphic sequences to lower lattitudes (Wehmiller,

1982: Figure 6). These studies have demonstrated that D/L ratios increase in samples of increasing stratigraphic age, and in samples of equal age at lower lattitudes (higher temperatures). In addition, D/L analysis of different amino acids and different genera have permitted relative intrageneric and intergeneric racemization rates to be established. This allows for the conversion of the results for one genus into equivalent results for another genus thus enabling direct aminostratigraphic comparison (Lajoie et al., 1980; Wehmiller, 1982).

Calibration of the racemization kinetics to the local "effective temperature" can be made by using amino acid analyses of samples from localities that have been independently dated. Because several of these localities now exist for the mid-lattitude Pacific coast of North America, aminostratigraphic age estimates can be made by simple interpolation between the D/L data points for the 120,000 year dated sites (Wehmiller, 1982). Kinetic models of racemization are needed to extrapolate to age estimates for otherwise un-dated localities, and can be tested with data from calibration localities and information on the climatic history of the region. The mid-lattitude Pacific coast of North America has been an excellent region in which to study the combined effects of age and temperature on racemization. This is primarily due to the relative abundance of calibration sites and the moderate late Pleistocene temperature change recorded in this region.

The present investigation was undertaken to evaluate the utility of amino acid racemization methods in resolving discrete time intervals of terrace formation in a high temperature environment (current mean annual temperature is about 20 degrees C). Since samples from terraces of different elevations are available, the consistency of the aminostratigraphy with various geologic criteria could be evaluated, and the effective age limits at these temperatures could be determined. Three apparent aminostratigraphic units have been found for the Bahia Asuncion region and they generally conform to local stratigraphic control. Based upon kinetic modeling, it appears that the amino acid racemization methods employed in this area reach their limit of usefullness in approximately 300,000 years.

METHODS AND RESULTS

Ten localities (Figures 1 and 2) were sampled by one of us (L.O.) in 1977. Eighteen mollusk samples (of the genera <u>Tivela</u>, <u>Saxidomus</u>, and <u>Chione</u>) were analyzed from these sites. Ideally, more samples should be studied to improve the statistics of each aminostratigraphic group. Amino acid enantiomeric (D/L) ratio analyses were made by gas chromatographic methods described by Kvenvolden <u>et al</u>. (1972), Frank <u>et al</u>. (1977), Wehmiller <u>et al</u>. (1977), and Wehmiller and Emerson (1980). Using different derivitazation procedures, it has been possible to determine the



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Genus, sp.	Tivela s. <u>Tivela</u> s. <u>Tivela</u> s. <u>Chione</u> sp. <u>Tivela</u> s. <u>Sax</u> . n. <u>Tivela</u> s.	
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D/L values for as many as seven amino acids in most of the samples studied here. D/L data are reported in Table 1. Generally, there is good agreement between the two derivative procedures used (Table 1), although a slight conversion has been used (see Wehmiller and Emerson, 1980) for the comparison of leucine D/L values obtained by the different processes. The results reported in Table 1 represent the mean values of peak height ratio determinations from at least two chromatograms of each sample derivative. Overall precision of multiple sample analyses of well-preserved shells is usually between 5% and 10%. depending on the amino acid.

DISCUSSION

The mollusks examined in this study generally had relative intrageneric racemization rates similar to those observed by Lajoie et al. (1980): phenylalanine > alanine > proline > leucine > glutamic acid > valine. As the D/L values increased in the samples studied, these intrageneric trends became less pronounced and sometimes were inverted in the most extensively racemized samples. Valine, leucine, and glutamic acid were the only amino acids that were not racemic in the oldest samples. Valine and leucine form three apparent clusters of D/L data (Figure 3). Glutamic acid data are generally consistent with these clusters but are more variable because of the different analytical methods used (Table 1). Alanine, proline, phenylalanine, and aspartic acid are all so extensively racemized (or analytically variable, as in the case of aspartic acid) that they are of little value in aminostratigraphic applications at these temperatures.

The three well-resolved groups of leucine and valine D/L values are plotted in Figure 3. The mean values and standard deviations for these three groups are also plotted in Figure 3. These mean D/L values, and the corresponding group designations, are as follows: Group I, leucine, 0.660; valine, 0.508; Group II, leucine 0.746; valine, 0.671; Group III, leucine, 0.878; valine, 0.860. Saxidomus D/L values have been converted (by regression equations in Lajoie et al., 1980) to ratios that would be directly comparable to Tivela or Chione results. Valine differentiates the three populations more clearly because of its slower rate of racemization.

The ages represented by the three leucine-valine groups of Figure 3 are derived from the isochrons shown in Figure 4 (redrawn from Wehmiller, 1982). These isochrons are drawn for one amino acid, leucine, and one genus, (Protothaca, which is kinetically equivalent to Ch<u>ione</u> and <u>Tivela</u>) The isochron for "early Stage 5" represents the D/L data for 120,000 year calibration localities between central California and Magdalena Bay. All other isochrons drawn in Figure 4 are derived from the leucine kinetic model of Wehmiller and Belknap (1978), using the





Figure 3: D/L leucine and valine ratios for all mollusks examined in this study. Average values are reported for multiple samples of the same species from the same locality. D/L leucine ratios for <u>Saxidomus</u>, a fast racemizing genus, have been converted to equivelent values for slow racemizing genera by the regression equations of Lajoie et al. (1980). This was done to enable the comparison of Tivela and Chione (slow racemizing genera) ratios with those of Saxidomus. Average values for each group are also represented on this diagram. Symbols are as follows: Tivela, one sample (●), two samples, average (●); Saxidomus, one sample, (■), two samples, average (●); Chione, 2-3 samples, average (▲). Keenan, Ortlieb, and Wehmiller



Figure 4:

Aminostratigraphy and kinetic model interpretation of Pacific coast enantiomeric data, all depicted as Protothaca D/L leucine values. Modified from Wehmiller (1982: Fig. 4). The heavy line represents calibrated 120,000 year D/L data. Other isochrons represent D/L vs. effective temperature (inversely proportional to lattitude) as determined for D/L data for independently dated sites, extrapolating to higher D/L values with the kinetic model of Wehmiller and Belknap (1978). Bands labeled "Stage 5", Stage 7", etc., represent ranges of D/L values expected for terrace deposits formed during Stage 5, Stage 7, etc. Sites with U-series solitary coral calibration sites ate indicated by (+). Baja sites are also labeled. Groups I, II, and III (), fall in regions of early Stage 5, late Stage 7, and Stage 9 (or older), respectively.

,120,000 year isochron to establish the kinetics (or Effective . Temperature, as discussed in Wehmiller. 1982 and elsewhere) for a viven lattitude-temperature region. These isochrons demonstrate that D/L values in age-equivalent samples increase with decreasing lattitude and increasing temperature. Pairs of isochrons are drawn to represent the probable range of D/L data that could be observed for terraces deposited during Stages 3. 5. 7. 9. etc. for the marine isotope record, using the ages proposed by Shackleton and Opdyke (1973) for these stages. Above D/L values of 0.80, the isochrons become less steep as they converge to values of 1.0. Thus, the resolving power of the method is slightly decreased in this numerical range. Figure 4 can be used to estimate ages for D/L ratio groups such as those presented here by using the assumptions: 1) lattitudinal gradients of effective temperature can be smoothly interpolated between calibration sites; and 2) effective temperatures for a local area can be considered equal (or nearly so) for samples of different ages but with the same present temperature.

The Group I leucine data fall in the early Stage 5 portion of the isochron band shown in Figure 4. Therefore, those data are interpreted to represent a time of deposition approximately 120,000 years before present. Other Baja sites that fall within the same region of the 120,000 year isochron are those at Camalú (Valentine, 1980), Punta Santa Rosalillita (Woods, 1980), Bahia Tortugas (Emerson <u>et al</u>., 1980), and Magdalena Bay (Wehmiller and Emerson, 1980).

The Group II leucine data plot above all the Baja results thought to represent any portion of Stage 5. Because of the lack of calibration sites older than 120,000 years and the difficulty of extrapolating the kinetic model to D/L leucine values as high as those in either Group II or Group III, we can only tentatively propose an age of approximately 200,000 years (late Stage 7) for the samples representing Group II. Elevation and morphologic characteristics of the Group II terrace suggest that it is older than the Group I terrace (Ortlieb, 1978, 1979a, 1979b). Because the valine and glutamic acid D/L values for the Group II samples are significantly greater than those observed in nearby "Stage 5" samples (Wehmiller and Emerson, 1980; Emerson <u>et al</u>., 1981), we feel that the Group I terrace must represent a pre-120,000 event rather than Groups I and II representing a late and early Stage 5

Group III plots within the extrapolated isochron band for either Stage 9 or Stage 11 of the marine isotope record (Figure 4). Therefore, we propose that the age of the samples in this group is at least 300,000 years. In most cases the aminostratigraphic groups recognized here are consistent with the relative ages that could be inferred from local elevation differences between terrace sites. However, it is clear that elevation differences alone do not correspond to the

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aminostratigraphic groups when comparisons are made over distances of a few kilometers.

The most rigorous test of the relation between aminostratigraphic data and the morphostratigraphy of the terrace sites is found at sites LR464, LR470, and LR468 (Figures 1 and 2). A sample from the 11 meter terrace (LR464) falls into Group II (Figure 3; Table 1) while a sample from the 30 meter terrace (LR470)(Figure 3: Table 1) falls into Group III, thereby demonstrating consistancy between relative aminostratigraphic and geomorphic ages. However, two samples from LR468, a depositional surface at 6 meters on the flank of the 11 meter terrace, also fall into aminostratigraphic Group II (Figure 3; Table 1), even though geomorphic relationships imply a younger age (Stage 5) for the LR468 site (Ortlieb, 1978, 1979a). Either the shells at LR468 have been reworked from the higher deposit, or both LR464 and LR468 are penecontemporaneous and the aminostratigraphic data cannot resolve small age differences between what appear (from D/L data alone) to be Group II, 200,000 year terrace deposits.

Localities LR458 and LR461 (Figures 1 and 2) both fall into aminostratigraphic Group III (Figure 3; Table 1), yet their field relationships (Figure 2) suggest that they are stratigraphically separated by fluvial and eolian sediments that could represent one full glacial stage or substage. It appears that the leucine and valine enantiomeric ratios simply can not resolve the age difference (which could be as much as 100,000 years) between these samples. There is a suggestion that the glutamic acid data do conform to these known age differences. Clearly, the high effective temperatures at these lattitudes limit the utility of aminostratigraphic methods in resolving age differences to about the last 250,000 years.

In this area of the Pacific coast of Baja California, amino acid racemization dating gives better geochronological results than U-series methods (Ortlieb, 1982). The available fossil material in marine deposits of this area are essentially mollusks which are suitable for amino acid analysis but are of controversial use for U-series dating. Diagenetic alterations of the fossil tests are such that many U/Th age determinations cannot be done (Ortlieb <u>et al</u>., in preparation). However, amino acid racemization dating provides internally consistent results which, in most cases, are in agreement with morphostratigraphic interpretations. Also, amino acid racemization dating can distinguish samples of the last two interglacials (Stages 5 and 7) from older samples (Stage 9 and older), while U-series methods are not reliable enough to distinguish between Stage 7 and older fossils.

Comparison between apparent amino acid and U-series ages of samples at the same localities on the Vizcaino Peninsula as this

study are discussed elsewhere (Ortlieb <u>et al.</u>, in preparation). Four of the samples examined in this study have been submitted for radiometric dating. Two of these (LR459=458 and LR530) had an excess of Ionium while the other two yielded apparent ages of 235,000 (+40,000; -30,000) years (LR522) and greater than or equal to 400,000 years (LR470) (Ortlieb <u>et al</u>., in preparation). Radiometric ages cannot be calculated for the first two localities because of the excess of Io due to contamination. However, these two localities (LR458 and LR530) fall within aminostratigraphic Group III (Figure 3; Table 1). The U/Th apparent age of LR522 suggests that this locality corresponds to the Stage 7 high sea stand but both the morphostratigraphic interpretation and the aminostratigraphy of locality LR522 favor a Stage 5 age (120,000 years).

CONCLUSIONS

Amino acid racemization dating methods have been applied to Quaternary marine terrace localities (with elevations between 3 and 30 meters) at Bahia Asuncion, Baja California Sur. Three aminostratigraphic age groups have been recognized, the voungest of which appears correlative with U-series dated 120,000-year terrace localities at higher and lower lattitudes. The older aminostratigraphic groups appear to represent ages of about 200,000 years and 300,000 years or older. These apparent ages are generally consistent with geomorphic criteria for relative terrace ages. The high effective temperature for the central and southern Baja region limits the utility of amino acid racemization dating but it can be used to define ages representing either Stage 5 (early and late) or pre-Stage 5 depositional events without much difficulty, given adequate quantities of well-preserved samples. The long-term average uplift rates inferred from the age-elevation relationships reported here are all less than 0.1m/1000 years, at the low end of the range of uplift rates reported for coastal regions undergoing strike-slip deformation (Lajoie et al., 1979; Muhs, 1983).

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NEOTECTONICS AND SEA LEVEL VARIATIONS IN THE GULF_OF CALIFORNIA AREA, A SYMPOSIUM

Contributed papers for the Symposium on Neotectonics and sea level variations in the Gulf of California area, held in Hermosillo, Sonora, Mexico, April 21-23, 1984.

En à tale

Contribuciones para el Symposium sobre Neotectónica y variaciones del nivel del mar en el área del Golfo de California, llevado a cabo en Hermosillo, Sonora, México, 21-23 de abril de 1984.



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