U.S. DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

AMINO ACID RACEMIZATION AGE ESTIMATES FOR PLEISTOCENE MARINE DEPOSITS IN THE EUREKA - FIELDS LANDING AREA, HUMBOLDT COUNTY, CALIFORNIA

by

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ABSTRACT

Amino acid enantiomeric (D/L) ratios in fossil *Saxidomus* samples from four localities in the Eureka - Fields Landing area of the Humboldt Bay region, California yield age estimates of 180,000 to 280,000 years for exposed and slightly deformed bay and estuarine deposits.

INTRODUCTION

Recent interest in seismic safety standards for critical engineered structures in the Humboldt Bay area of northern California has created a need to reassess the tectonic setting of this seismically active region. In response to this need, we report here our recent findings on estimated ages of tectonically deformed bay and esturine sediments in the Eureka - Fields Landing area. These age estimates are presented for use by others more directly involved in the evaluation of the local geologic and tectonic setting. No detailed discussion of the tectonic setting of the area is presented here.

MATERIAL STUDIED

Paleontologic material used herein forms part of a systematic study of fossiliferous Pleistocene marine deposits and their associated faunas of the Pacific Northwest coast (Kennedy, 1977, written communication). Material submitted to Wehmiller from this region for amino acid analyses will form the basis of a forthcoming paper on the age and paleoenvironmental implications of marine terrace faunas in northern California. Future data may slightly modify the preliminary conclusions presented here.

Thick-shelled aragonitic bivalve mollusks yield the most consistent amino acid racemization data. Among these, species of the venerid clam Saxidomus yield the most reproducible results (Wehmiller, 1977, unpublished data). This is probably due to the internal shell structure as well as to the thickness of the hinge structure and the nymph plate, the area posterior to the hinge that supports the bivalve ligament, used in most analyses. Two species of *Saxidomus*, *S. giganteus* (Deshayes) and *S.* sp. cf. *S. nuttalli* Conrad, have been used for analyses. Differences in the rates of racemization of several amino acids are observed in different genera of mollusks but not among species of a given genus (Wehmiller, 1977, unpublished data), so we consider results for these two species as a group.

Specimens used for analysis were collected by us or were obtained from existing university and museum collections. General sample localities are shown in Figure 1. More precise sample localities for the Eureka - Fields Landing area are described in Appendix I and illustrated in Appendix II. The meanings of abbreviations used in fossil locality identification numbers are presented in note 2 at the end of Appendix I.

STRATIGRAPHIC TERMINOLOGY

Fossil material analyzed is from gray clayey siltstone and fine-grained sandstones exposed predominantly in road cuts in the Eureka - Fields Landing area. The stratigraphic units, Carlotta and Hookton formations (Ogle, 1953), are commonly used informally throughout the Humboldt Bay area even though they were formally defined in the southern part of the region on the south side of the Eel River basin. We believe present knowledge does not permit precise correlation of these formally defined units with other Pleistocene sediments exposed in the central and northern parts of the area. Therefore, to avoid ambiguity, we do not use any formation names in the discussion of the Humboldt Bay samples.

However, for comparative purposes we do include analyses of one sample from the Carlotta formation from the Scotia Bluffs [mapped originally as Scotia Bluffs sandstone by Ogle (1953); revised by Samuel D. Morrison (1977, written communication)]. Where appropriate we presented the formation name used by the person who collected the sample (Appendix I).

PROCEDURE

Amino acid molecules occur in two mirror-image configurations (enantiomers), designated D and L, which convert spontaneously from one to the other (racemization). In living organisms amino acids occur predominantly in the L configuration ($D/L \simeq 0$). In dead organisms at equilibrium the numbers of D and L molecules are equal ($D/L = 1$). The time necessary to reach equilibrium is inversely related to storage temperature. At ground temperatures typical of temperate latitudes equilibrium is reached in 1.0 - 1.5 my, so D/L ratios can be used as an age indicator over this period of time.

The D/L ratios of three amino acids, leucine, glutamic acid, and proline in fossil *Saxidomus* are reported here (Table 1). Age estimates are derived from D/L ratios of leucine (Table 2). The D/L data from proline and glutamic acid are used as a measure of sample reliability and analytical reproducibility.

All samples were analysed in the amino acid laboratory at the University of Delaware under the direction of J. F. Wehmiller. Analytical procedures follow those of Wehmiller (1977, unpublished data), and involve high-resolution capillary column gas chromatography of diastereoisomeric derivatives of the fossil amino acids. Two different

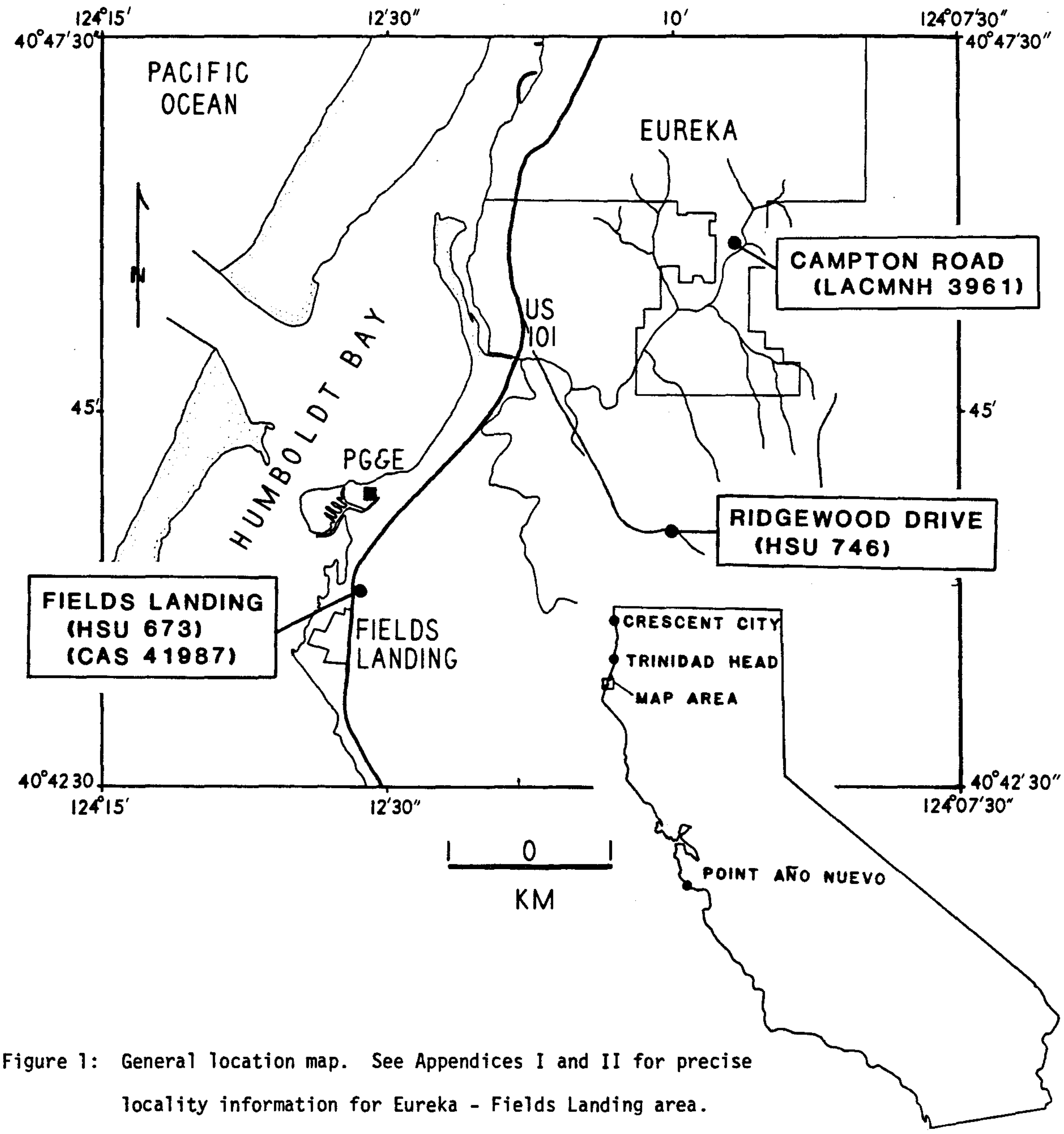

Figure 1: General location map. See Appendices I and II for precise locality information for Eureka - Fields Landing area.

capillary chromatographic columns are routinely used for these determinations. However, our results for leucine, glutamic acid, and proline were obtained from a single column only (OV225, 150' x 0.03" i.d.) and might be modified slightly (less than 2%) when more complete chromatographic analyses are available.

Our interpretations of the D/L ratios follow two approaches. First, comparison of the raw D/L ratios in samples from different localities permits the assignment of relative ages. Secondly, absolute ages are estimated by a kinetic model for the racemization of leucine alone (Wehmiller, 1977, unpublished data). Kinetic model ages have been assigned only to samples which yeild internally consistent ratios among the three amino acids (Tables 1 and 2). These age estimates (Table 2) probably will not be altered significantly when more complete chromatographic data from a second capillary column are obtained.

Amino acid D/L ratios are dependent on both time and temperature. Our inadequate knowledge of a sample's thermal history is the main source of uncertainty in assigning both relative and absolute ages. Modern climatic data are used to estimate relative temperatures for long-range correlations and relative age assignments. Estimates of Pleistocene temperatures from other sources (for example, playmology, and oxygen isotopes) are used in the kinetic model to estimate absolute ages (Wehmiller, 1977, unpbulished data).

For comparative purposes we include here D/L ratios for Saxidomus samples from three localities outside the immediate Humboldt Bay area (Tables 1 and 2). Trinidad Head and Crescent City lie 28 km and 104 km north of Eureka, respectively, and Point Año Nuevo lies 435 km south of

Eureka near San Francisco (Fig. 1). More complete data on the Trinidad Head and Point Año Nuevo samples are presented elsewhere (Wehmiller, 1977, unpublished data).

RELATIVE AGES

Relative age assignments of samples from a given region can be made if it is assumed that all samples have had the same thermal history. Based on present climatic conditions, which are fairly uniform throughout the northern California coastal region, we assume that samples from the Humboldt Bay area, Trinidad Head, and Crescent City have all experienced the same thermal history. This assumption permits assignment of the following relative ages, from youngest to oldest, based on increasing D/L ratios (Table 1):

Youngest (lowest D/L ratios)	Crescent City (LACMNH loc. 3943, 3944, 3946)
↓	Campton Road, Eureka (LACMNH loc. 3961); Near (?) Fields Landing (CAS loc. 54082)
↓	Ridgewood Drive (HSU loc. 746); Fields Landing (HSU loc. 673 and CAS loc. 41987)
↓	Trinidad Head (LACMNH loc. 3939)
Oldest (highest D/L ratios)	Carlotta fm, Scotia Bluffs (HSU loc. 997)

TABLE I

ENANTIOMERIC (D/L) RATIOS IN SAXIDOMUS[1]

LOCALITY AND (FIELD NO)[2]	SAMPLE NO.	SPECIES[3]	LEUCINE	GLUTAMIC ACID	PROLINE
Northern California:					
Humboldt Bay area:					
Campton Road, Eureka (LACMNH loc. 3961)	[4] 76 - 96	S.g.	[5] .47	.28	.61
	76 - 96a	S.g.	.43	.28	.60
Near (?) Fields Landing (CAS loc. 54082)	77 - 24	S.g.	.43	.29	.57
Ridgewood Drive (HSU loc. 746)	77 - 22	S.g.	.50	.35	.68
[6] Fields Landing (HSU loc. 673)	77 - 25a	S.sp.	.52	.36	.67
(CAS loc. 41987)	77 - 16	S.sp.cf.S.n	.52	.36	.71
	77 - 17	S.sp.cf.S.n.	.48	.34	.67
Scotia Bluffs; Carlotta fm (HSU loc. 997)	77 - 23[7]	S.sp.	.81	.85	.94
Other:					
Crescent City; Battery fm (LACMNH locs. 3943, 3944, 3946)	(avg. of 3)	S.g.	.358	.266	.506
Trinidad Head (LACMNH loc. 3939)	(avg. of 2)	S.g.	.62	.535	.72
Central California:					
Point Año Nuevo (USGS-M loc. 1960)	(avg. of 5)	S.g.	.449	.325	.564

NOTES:

1. All analyses performed in the amino acid laboratory of the University of Delaware under the direction of J. F. Wehmiller.
2. See Appendix I and II for location and source information.
3. S.g.: Saxidomus giganteus

   S.sp.: Saxidomus, species indeterminant

   S.sp.cf.S.n.: Saxidomus, species indeterminant but probably Saxidomous nuttali
4. **Analyses of two different shell samples.**
5. Similarity of D/L ratios indicate samples within each bracket are most likely the same age.
6. Same locality and possibly same fossil bed (See Appendices I and II).
7. Sample 77-23 was not well preserved. Note that the leucine ratio is lower than the glutamic ratio which is unique among all samples analysed. The leucine ration appears to be about 15% too low, therefore no kinetic model age is assigned to this sample.

The youngest samples (lowest D/L ratios; Table 1) are from the upper Pleistocene Battery formation, the deposits on the lowest emergent marine terrace at Crescent City (Addicott, 1963). The oldest sample (highest D/L ratios, Table 1) is from the Carlotta formation [mapped originally as Scotia Bluffs sandstone (Ogle, 1953); revised by Samuel R. Morrison (1977, written communication)] in the Scotia Bluffs near Rio Dell, which is either late Pliocene or early Pleistocene in age.

The samples from the Eureka - Field Landing area fall into two groups which show a slightly greater difference in enantiomeric ratios than is observed in duplicate samples from the same outcrop (Table 1). The difference in enantiomeric ratios between the two groups of samples most likely represents a finite age difference between the deposits from which the samples were derived.

The D/L ratios of samples from Campton Road (LACMNH loc. 3961) and near (?) Fields Landing (CAS loc. 54082) are very similar indicating the deposits exposed at these two sites are the same age and older than the Batter formation at Crescent City. The D/L ratios of samples from Ridgewood Drive (HSU loc 746) and Fields Landing (HSU loc 673 and CAS loc. 41987) are similar indicating the deposits exposed at these two sites are the same age and older than those exposed near (?) Fields Landing (CAS loc. 54082) and Campton Road (LACMNH loc. 3961).

The D/L ratios of samples from Point Año Nuevo (USGS-M loc. 1960) in central California are similar to those of samples from Campton Road (LACMNH loc. 3961) and near (?) Fields Landing (CAS loc. 54082) which, at face value, indicate age equivalence. However, present temperatures in central California are slightly higher than those in northern California indicating the thermal histories of samples from the two areas were probably different. Presently the best interpretation of the D/L ratios is that the Point Año Nuevo samples are younger than those from Campton Road (LACMNH loc. 3961) and near (?) Fields Landing (CAS loc. 54082) but older than those from the Battery formation in Crescent City (LACMNH locs. 3943, 3944, 3946).

The D/L ratios of samples from the marine sediments at Trinidad Head (LACMNH loc. 3939) north of Eureka indicates these beds are older than all those from which fossils were analysed in the Humboldt Bay area except the Carlotta formation at Scotia Bluffs (HSU loc. 997) (Table 1).

KINETIC MODEL AGE ESTIMATES

Absolute ages can be estimated by a kinetic model based on the racemization of leucine. This model is graphically shown in Figure 2 and is a plot of the variable $(X_E - X)/X_E$ vs. time, where X is the value of the ratio D/(D + L) at any time T and X_E is the D/(D + L) ratio at infinite time, the time of complete racemic equilibrium. For leucine $X_E = 0.50$. The model curves of Figure 2 are for Saxidomus leucine kinetics at temperatures of 8^{o}, 11^{o}, and 13^{o} C (model curves for other genera would differ slightly). These curves are calculated for various mean annual air temperatures, and are calibrated with radiometrically-dated Holocene and latest Pleistocene Saxidomus from uplifted marine deposits in the area of Puget Sound, Washington (Wehmiller, 1977, unpublished data). Although significant differences between air and ground temperatures are often observed, the particular method of calibration of the model curves compensates for these

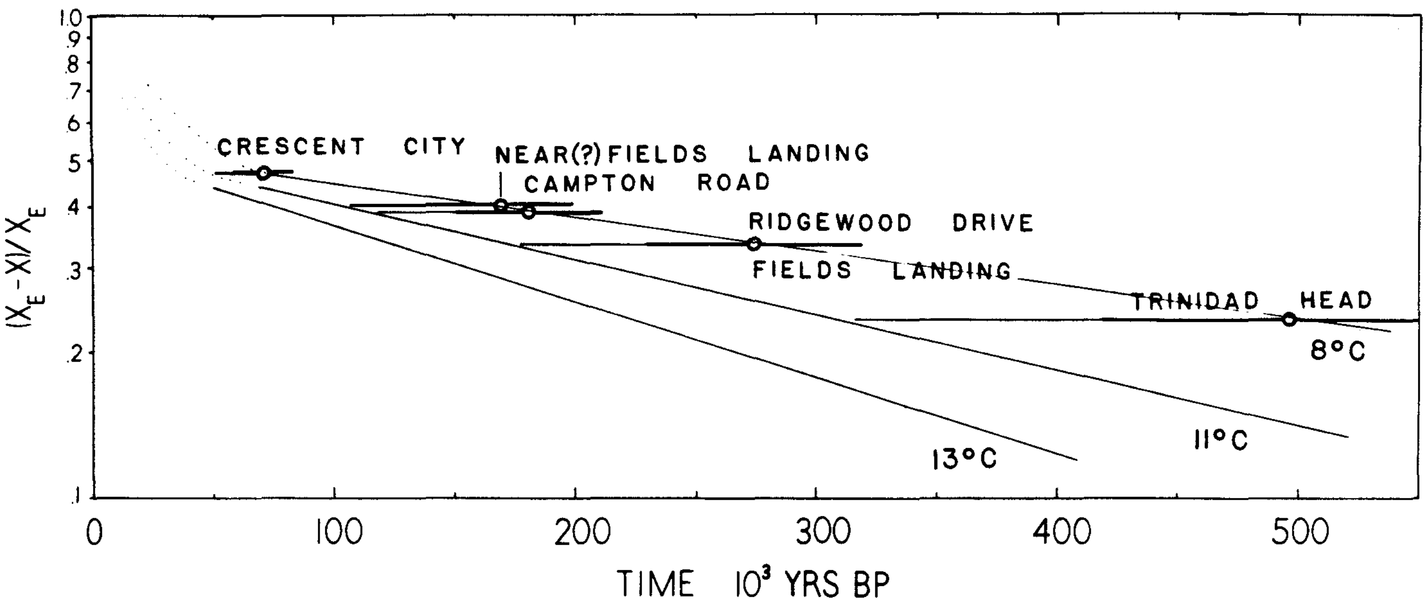

Figure 2: Leucine kinetic model showing the plot of the variable $(X_E - X)/X_E$ vs. time. Results are shown for Crescent City (LACMNH loc. 3943, 3944, 3946), Campton Road (LACMNH loc. 3961), near (?) Fields Landing (CAS loc. 54082), Ridgewood Drive (HSU loc. 746), three samples from Fields Landing (HSU loc. 673 and CAS loc. 41987), and Trinidad Head (LACMNH loc. 3939). Diagonal lines (8° C, 11° C, and 13° C) are model kinetics developed for Saxidomus in other areas, (Wehmiller, 1977, unpublished data). The circles indicate the age estimate assuming 8° C kinetics. The heavy horizontal bar is the uncertainty of ± 15% which is equivalent to a ± 0.75° C uncertainty in the effective temperature. The light horizontal lines define the range of age estimates possible within the assumptions of either 8° C or 11° C kinetics. Present day mean annual air temperature at these localities is about 11.1° C.

differences and permits ages to be estimated from mean annual air temperature records, which are much more readily available. The present mean annual air temperature in the Humboldt Bay area is 11.1° C.

An estimate of the effective diagenetic temperature, the integrated thermal history to which a sample has been exposed, must be made in the assignment of ages with the kinetic model. A full discussion of the procedures for estimation of effective diagenetic temperatures is found elsewhere (Wehmiller, Hare, and Kujala, 1976; Wehmiller, 1977, unpublished data; Wehmiller and Belknap, 1977). These studies indicate that samples from the California coast should be interpreted in terms of effective diagenetic temperatures about 3° C cooler than the present mean annual air temperatures at these localities. Effective diagenetic temperatures are lower than present-day temperatures because of temperture reductions during Pleistocene glacial cycles, but _effective temperature reductions_ are not as great as those of full-glacial periods (about -5° C) because of the exponential nature of the temperature dependence of racemization (Wehmiller and Belknap. 1977). As stated previously, we make the assumption that all samples from the Crescent City - Humboldt Bay area have experienced similar thermal histories, and therefore we interpret the data from all of these samples in terms of an effective diagenetic temperature of 8° C (about 3° C cooler than the present mean annual air temperature). Differences in the depositional environments of these samples might lead us to modify our assumptions of identical temperature histories, but probably by no more than ± 1° C.

The mean leucine enantiomeric ratio (in the form $(X_E - X)/X_E$) from each locality is platted in Figure 2. Two age estimates from each locality are derived from Figure 2 and are summarized in Table 2. Thefirst age is a minimum age estimate based on the assumption of constant temperature (equal to present-day temperature) throughout the history of the sample. Although this assumption is clearly erroneous, it is useful in placing uncertainty limits on our age assignments. The second age estimate is that derived from the assumed effective diagenetic temperature of 8^{o} C. The more probable age estimates are those derived from 8^{o} C curve, and age uncertainties of $\pm$ 15% (equivalent to temperature uncertainties of $\pm$ 0.75^{o} C) are given in Table 2 for these 8^{o} C age estimates.

The kinetic model ages for samples from the Eureka - Fields Landing area fall into two groups as reflected in the raw D/L ratios. Samples from Campton Road (LACMNH loc. 3961) and near (?) Fields Landing (CAS loc. 54082) are approximately 180,000 $\pm$ 30,000 years old. Samples from Ridgewood Road (HSU loc. 746) and Fields Landing (HSU Loc. 673 and CAS loc. 41987) are approximately 280,000 $\pm$ 45,000 years old.

COMPARISON TO OTHER LOCALITIES

Results from Crescent City and Trinidad Head are also plotted in Figure 2. Age assignments of these other localities are estimated by procedures identical to those described for the Humboldt Bay samples (Table 2). Also given in Table 2 for comparative purposes are the age assignments for shells from Point Año Nuevo, in central California, (Wehmiller, 1977, unpublished data). The kinetic model ages of Crescent

TABLE 2

KINETIC MODEL AGE ESTIMATES

LOCALITY[1]		AGE (10^3 YEARS)[2] EFFECTIVE TEMPERATURE = 11°C (PRESENT-DAY TEMPERATURE)	AGE (10^3 YEARS)[2] EFFECTIVE TEMPERATURE = 8° C (PRESENT-DAY TEMPERATURE - 3°C)
Northern California:			
Humboldt Bay area:			
Campton Road, Eureka (LACMNH loc. 3961)	7 ⎡	120[3]	180 ± 30[4]
Near (?) Fields Landing (CAS loc. 54082)	⎣	110	170 ± 30
Ridgewood Drive (HSU loc. 746)	7 ⎡	180	280 ± 45
8 ⎡ Fields Landing (HSU loc. 673)		180	280 ± 45
⎣ (CAS loc. 41987)	⎣	180[5]	280 ± 45[5]
Scotia Bluffs: Carlotta fm (HSU loc. 997)		-[6]	-[6]
Other:			
Crescent City (LACMNH loc. 3943, 3944, 3946)		50	80 ± 15
Trinidad Head (LACMNH loc. 3939)		315	500 ± 75
Central California:			
Point Año Nuevo (USGS-M loc. 1960)		90[9]	110 ± 20[9]

NOTES:

1. See Appendices I and II for location and source information.
2. Age estimates derived from Figure 2 using leucine D/L ratios in Table 1.
3. Age estimate derived using average of data from samples 76-96 and 76-96a (Table 1).
4. ± values are age uncertainties of ± 15% based on tem perature uncertainties of ± 0.75° C.
5. Age estimate derived using average of data from samples 77-16 and 77-17 (Table 1).
6. No age calculated due to poor leucine data.
7. Similarity of D/L ratios and derived age estimates indicate localities within each bracket are the same age.
8. Same locality and possibly same fossil bed (see Appendices I and II).
9. Effective temperature = 13.0° - 13.7° C.

City (80,000 ± 15,000 yrs.) and Point Año Nuevo (110,000 ± 20,000 yrs.) relate these shallow-water open-coast marine terrace deposits to recognized periods of eustatic high sea level (Bloom and others, 1974). Geologic data indicate the Trinidad Head samples, which appear to be approximately 500,000 years old, were deposited during a lowstand of sea level (T. A. Stephens, 1977, written communication). The Humboldt Bay samples are from esturine deposits which should be related directly to the eustatic record and represent sea level highstands. However, the age estimates reported here, 180,000 and 280,000 years BP (Table 2), do not correspond precisely with the ages of well documented middle to late Pleistocene high stands (roughly every 100,000 years) recorded elsewhere (Bloom and others, 1974). These apparent age discrepancies may be related to the uncertainties in the temperatures used to derive the amino acid age estimates.

ACKNOWLEDGEMENTS

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REFERENCES CITED

Andicott, W. O., 1963, Interpretation of the invertebrate fauna from upper Pleistocene Battery Formation near Crescent City, California: Proc. California Acad. Sci., ser. 4, 31 (13), p. 341-147.

_______________, 1966, Late Pleistocene marine paleoecology and zoography in central California: U.S. Geol. Surv. Prof. Paper 523-C; p. 1-21.

Bloom, A. L., Broecker, W.S., Chappell, J. M. A., Matthews, R. K., and Mesolella, K. J., 1974, Quaternary sea level fluctuations on a tectonic coast: New $^{230}Th/^{234}U$ dates from the Huon Peninsula, New Guinea: Quat. Res., 4(2), p. 185-205.

Ogle, B. A., 1953, Geology of Eel River valley area, Humboldt County, California: State California, Dept. Nat. Res., Div. Mines Bull. 164, p. 1-128.

Wehmiller, J. F., and Belknap, D. R., 1977, Alternative kinetic models for the interpretation of amino acid enantiomeric ratios in Pleistocene mollusks: examples from California, Washington, and Florida: Quat. Res. (in press).

Wehmiller, J. F., Hare, P. E., and Kujala, G. A., 1976, Amino acids in fossil corals: Racemization (epimerization) reactions and their implications for diagenetic models and geochronological studies: Geochim, Cosmochim. Acta, 40(7), p. 763-776

APPENDIX I

Locality Descriptions[1]

CAS[2] loc. 41987:	West-facing roadcut on east side of U.S. Highway 101 north of Fields Landing, Humboldt County, California. Fields Landing 7.5' Quad. Collected by R. R. Talmadge, 1969. Carlotta fm. (Ogle, 1953). This is the same roadcut exposure as HSU loc. 673 but precise stratigraphic relationship is not known. See Appendix II for location map. Blue clay.
CAS loc. 54082:	"Hookton marine", near (?) Fields Landing, Humboldt County, California. Collected by J. W. Durham 1968-1969. More precise information for this locality not available.
HSU loc. 673:	West-facing roadcut on east side of U.S. Highway 101 about 0.46 km north of Fields Landing, Humboldt County, California. Fields Landing 7.5' Quad. Elevation 15-20 m. Collected by Lloyd Barker and Karen Wiancko in 1970. This is the same roadcut exposure as CAS loc. 41987 but precise stratigraphic relationships are not know. See Appendix II for location map.

HSU loc. 746: Roadcut on NE side of Ridgewood Drive 2.03 mi. (3.76 km) SE of U.S. Highway 101, south of Eureka, Humboldt County, California. Fields Landing 7.5' Quad. Elevation 70-75 m. Collected by Robery Doerkson and Roy R. Kohl in 1969. See Appendix II for lacation map. Gray blue silty clay.

HSU loc. 997: Near Nanning Creek on east side of Eel River 2 km east of Rio Dell, Humboldt County, California. Fortuna 15' Quad. Carlotta fm. Mapped originally as Scotia Bluffs sandstone (Ogle, 195); revised by Samuel D. Morrison (1977, written communication). Collected by Samuel D. Morrison in 1974, See Appendix II for location map.

LACMNH loc. 3939: Low seacliff exposure on northeast side of Trinidad Head, Trinidad, Humboldt County, California. Trinidad 7.5' Quad. Elevation 2-4 m. Collected by George L. Kennedy in 1973. Coarse, fossiliferous sandstone and coquina.

LACMNH locs. 3943, 3944, and 3946: Seacliff exposrures in and just north of Crescent City, Del Norte County, California. Crescent City, 7.5' Quad. Elevation 2-5 m. Collected by George L. Kennedy in 1973. Fossiliferous sand.

LACMNH loc. 3961: Roadcut on the NE side of Campton Road at street address, 4015 Campton Road, Eureka, Humboldt county, California. Elevation 15-17 m. Collected by George L. Kennedy in 1974. Gray blue silty clay.

USGS-M loc. 1960: Seacliff exposure on south side of Point Año Nuevo, San Mateo County, California. Ano Nuevo 7.5' Quad. Elevation 6-8 m. Collected by W. O. Addicott in 1962, and J. F. Wehmiller and K. R. Lajoie in 1974. Locality described by Addicott (1966).

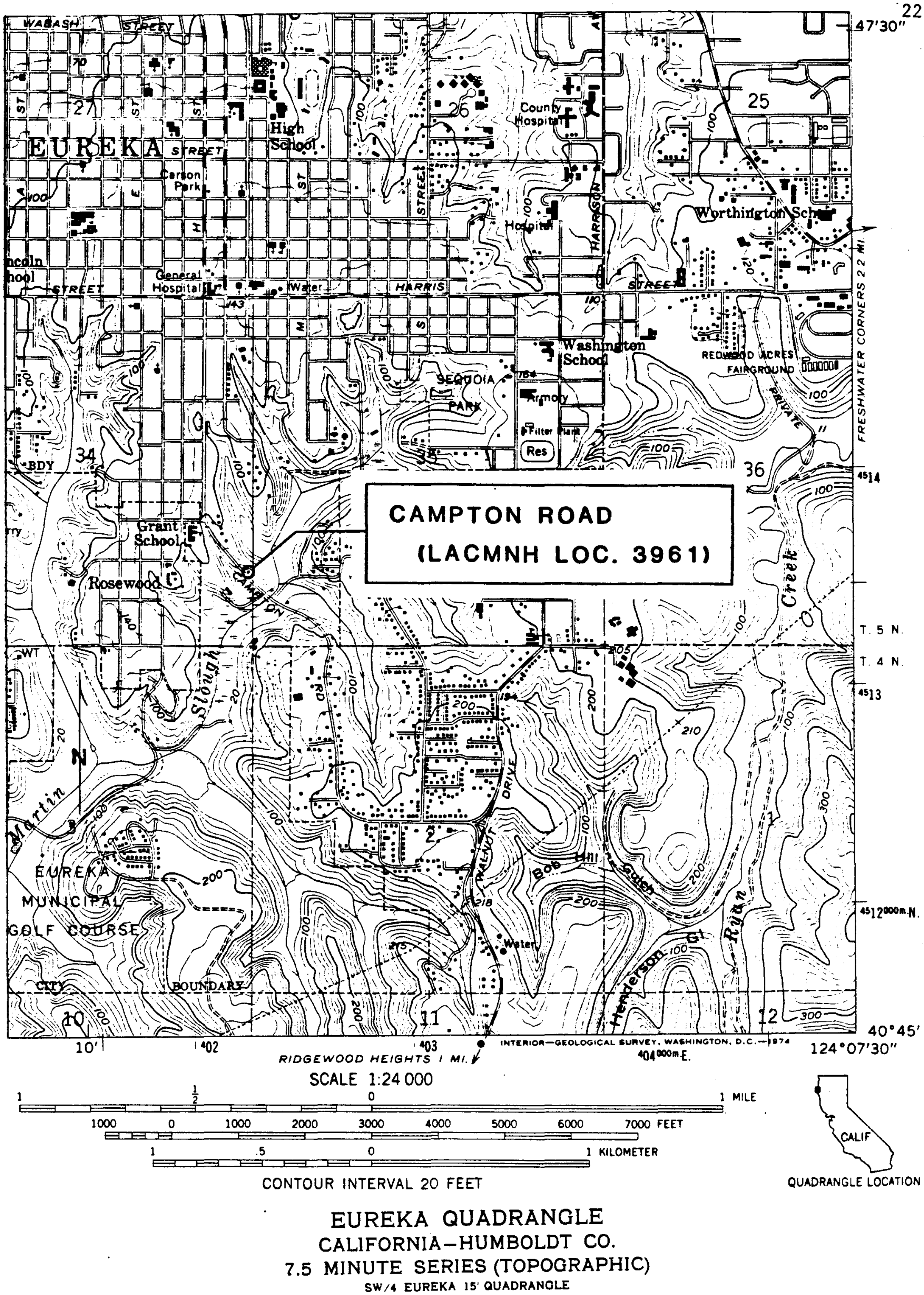
NOTES:

1. See Appendix II for map locations of LACMNH loc 3961, CAS loc. 41987 and HSU locs. 673, 746, and 997.
2. Abbreviations:

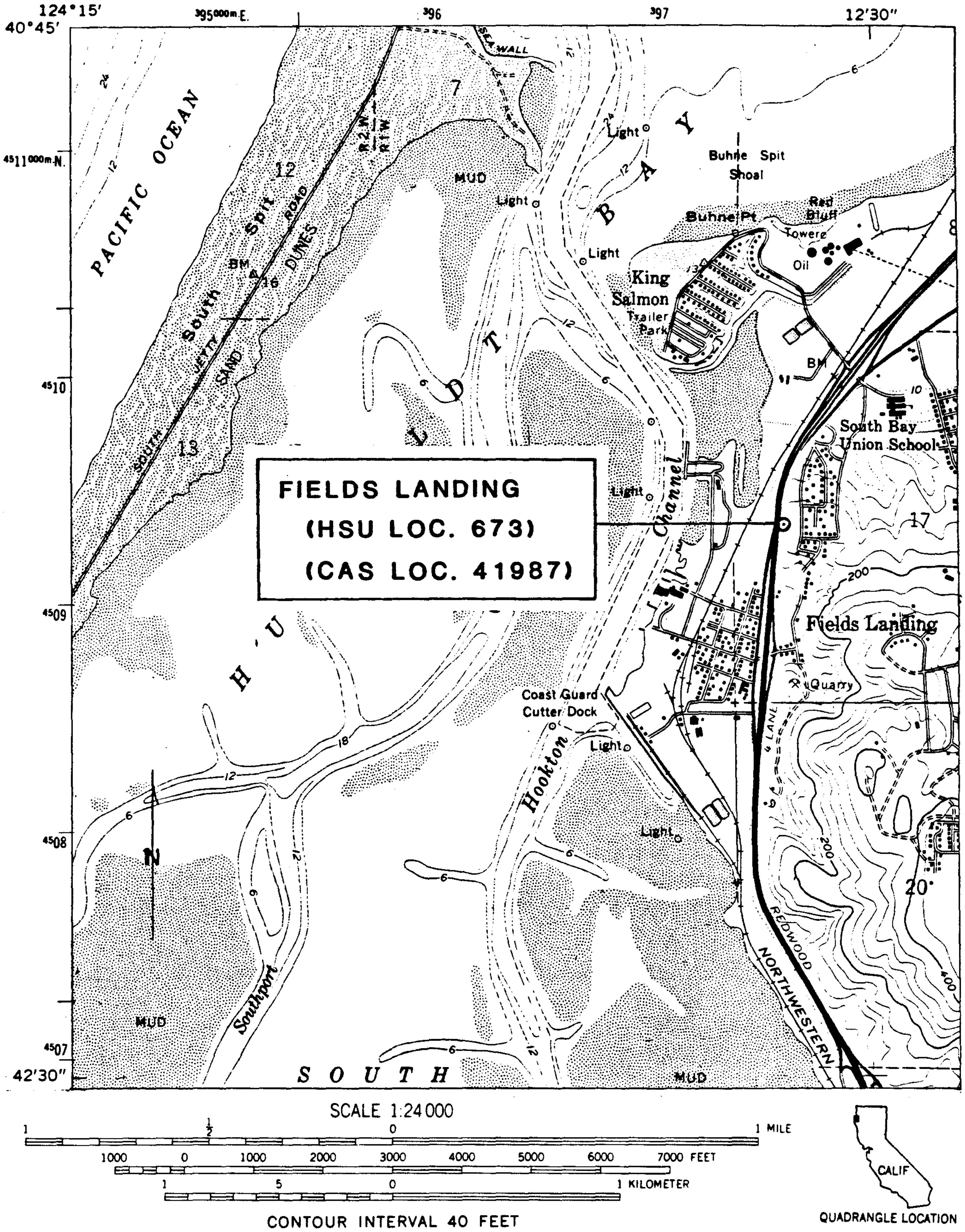
CAS:	California Academy of Sciences, San Francisco
HSU:	Humboldt State University, Arcata
LACMNH:	Los Angeles County Museum of Natural History, Los Angeles
USGS-M:	U.S. Geological Survey, Menlo Park

APPENDIX II

Locality Maps: Eureka - Fields Landing area

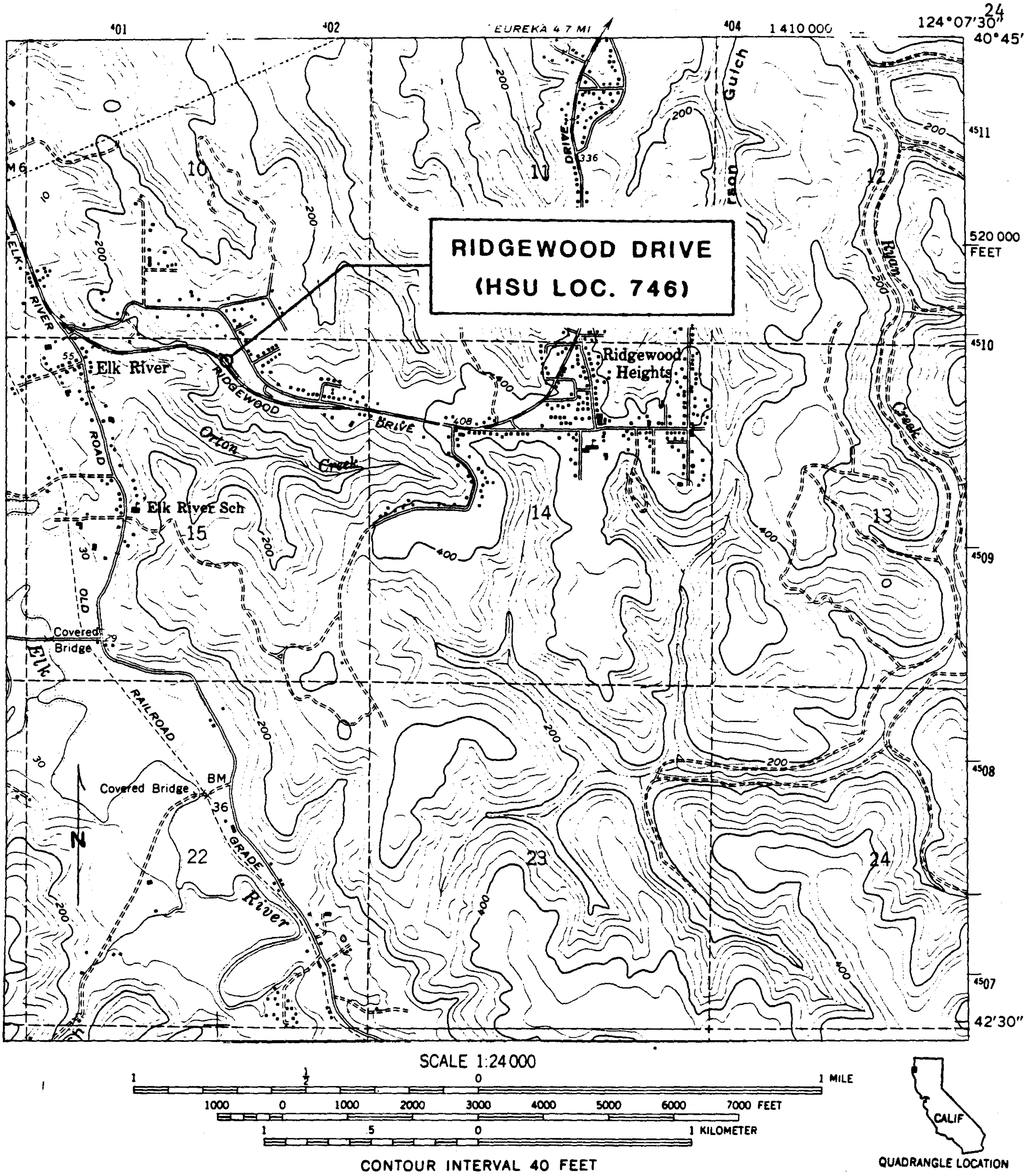


IIA: Campton Road locality (LACMNH loc. 3961)



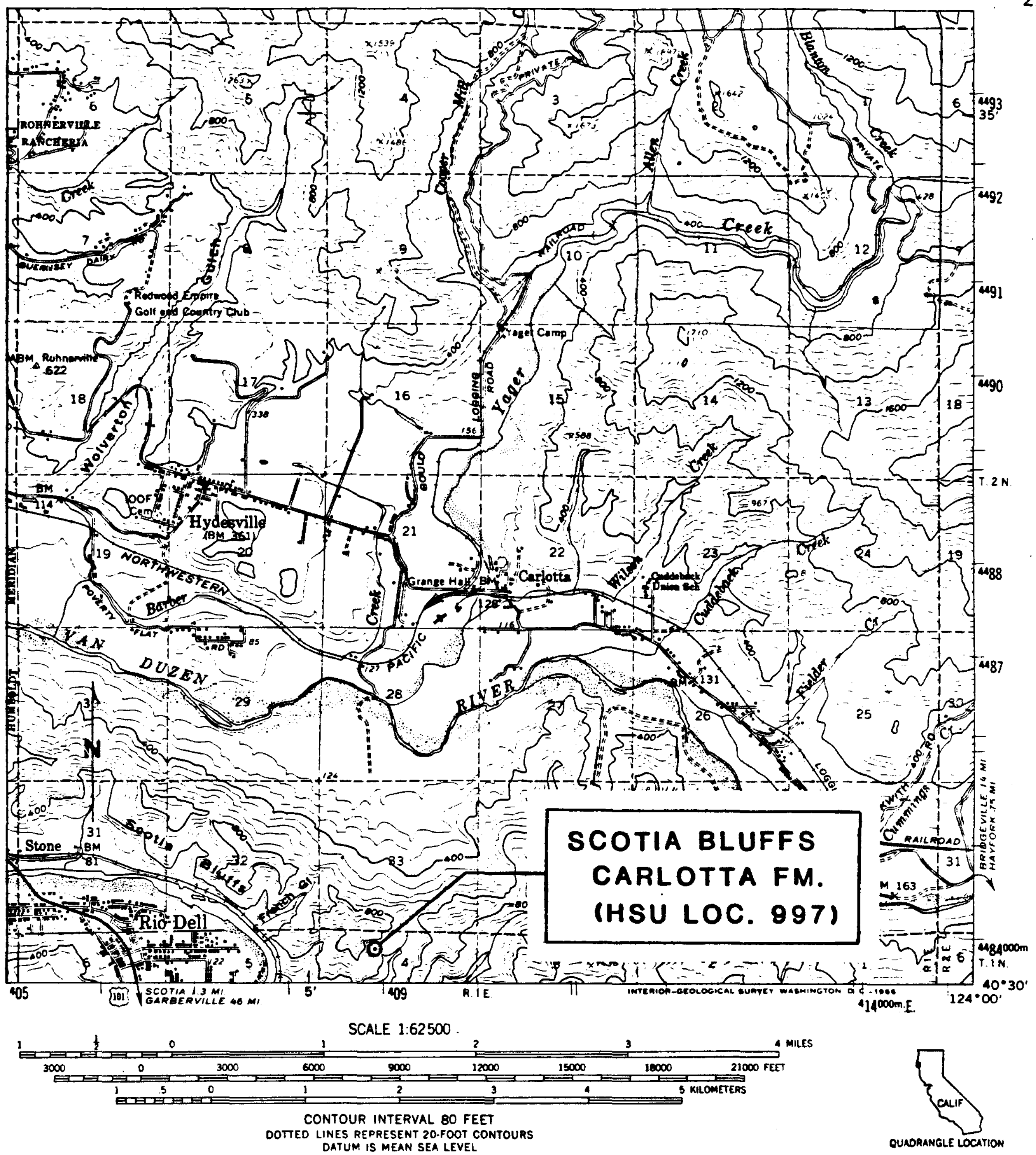
FIELDS LANDING QUADRANGLE
CALIFORNIA–HUMBOLDT CO.
7.5 MINUTE SERIES (TOPOGRAPHIC)

IIB: Fields Landing locality (HSU loc. 673; CAS loc. 41987)



FIELDS LANDING QUADRANGLE
CALIFORNIA–HUMBOLDT CO.
7.5 MINUTE SERIES (TOPOGRAPHIC)

IIC: Ridgewood Drive locality (HSU loc. 746)



FORTUNA QUADRANGLE
CALIFORNIA–HUMBOLDT CO.
15 MINUTE SERIES (TOPOGRAPHIC)

IID: Scotia Bluffs, Carlotta fm. locality (HSU loc. 997)