that Mitchell's penlight procedure was insufficient to completely destroy his dark adaptation, and that one must be reasonably well adapted to the dark to observe the phenomena. Evidently, the flashes are subtle and usually near threshold. This explains the need to concentrate to notice the events.

Table 2 lists the mean time between events after dark adaptation for each observer, and the average value for all observers for each session. The errors given were computed by using the 68 percent confidence limits from the summed Poisson distribution for the number of events seen by each observer after dark adaptation. The session averages were computed by weighting the individual values according to the corresponding dark adapted observing times. Table 2 also includes the dark adaptation times.

A close examination of Table 2 reveals an interesting anomaly. The TEC sessions have a considerably greater mean time between events than the translunar coast (TLC) sessions, and the average dark adaptation times for the TEC sessions is twice that for the TLC sessions. Also, most of the crew members commented that the flashes seemed not only less frequent during the TEC sessions but also much less brilliant. The most dramatic example of this anomaly occurred on Apollo 17, when all three crewmen reported that no events were seen during the entire 1-hour TEC session (*8*). During the similar TLC session the two observing crewmen reported a total of 28 events. We believe that the data and the subjective comments are evidence for a real effect.

In an attempt to understand this anomaly, we examined the following possible mechanisms that would decrease the flux of cosmic rays of $Z \geqq 6$ during the TEC sessions relative to the TLC sessions: geomagnetic shielding effects from the earth's magnetosheath tail, the relative difference in spacecraft shielding, and possible flux modulation due to solar activity. None of these mechanisms was capable of explaining the anomaly. We conclude the cosmic ray flux was the same inside the spacecraft during the TEC and TLC sessions on each flight, and thus have no physical explanation for the anomaly. However, we still believe that the light flash phenomena are caused by some portion of the ($Z \geqq 6$) cosmic ray flux.

Finally, even though all the crew members reported feeling well rested and alert for the TEC sessions, and no fatigue or vision impairments were reported, it is still conceivable that the TEC light flash suppression was due to some physiological effect.

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8. The crew did report seeing some flashes during sleep periods before and after the TEC observing session. However, no objective rate measurements are available.
9. We acknowledge the contribution to this investigation by scientist astronauts P. K. Chapman and J. P. Allen. C. Goodman provided essential support, and many helpful comments and suggestions were made by P. J. McNulty, V. P. Pease, and T. F. Budinger. Finally, we acknowledge the unfailing assistance of the flight controllers and personnel at the Johnson Space Center, Houston, Texas, and the enthusiasm, competence, and cooperation of all Apollo crew members with whom we worked.
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Eustatic Sea Level 120,000 Years Ago on Oahu, Hawaii

Abstract. *Extensive dating of the fossil corals associated with the Waimanalo shoreline on Oahu has shown that 120,000 years ago the ocean was approximately 7.6 meters above its present level. Corals grown during that time constitute a major portion of the subaerial reef-derived material on the island, with exposures ranging from about 10 meters to near sea level. This evidence corroborates the notion that 120,000 years before the present was the last time during which the sea stood significantly higher than it does today. The reported benches at 3.7, 1.5, and 0.6 meters, if not of Recent origin, could be features created by brief halts of the sea during rapid regression shortly after the Waimanalo high stand.*

The eustatic rise and fall of sea level resulting from Pleistocene glaciation and deglaciation are recorded along shorelines in the form of marine erosional benches and depositional terraces. The times of interglacial periods can be determined by age-dating of the coralline material associated with the terraces. However, the absolute positions of sea stands during these times are relatively difficult to ascertain. One major complication is the difficulty of identifying tectonically stable coasts.

The island of Oahu (Fig. 1) in the Hawaiian Archipelago provides good opportunities for studying past fluctuations in sea level, since reef limestones fringe about 30 percent of its shoreline (*1*) and the island is considered to have been tectonically undisturbed at least since its so-called Waimanalo shoreline was formed. This ancient strandline occurs extensively in the archipelago (notably on Oahu but also on Maui, Molokai, and Lanai) at about 7.6 m (25 feet) (*2, 3*). Its type locality is defined by wave-cut features, thus making it possible to obtain more precise information on the elevation of the former sea level than that deduced from littoral deposits (*4*).

We report here the results of our age measurements on fossil corals collected from Oahu (Fig. 1). The ages were determined from the ratios of ^{230}Th to ^{234}U (*5, 6*), and in many cases the results were checked with the measurements of $^{231}Pa/^{235}U$ (*7, 8*) and $^{234}U/^{238}U$ (*9*) ratios. We analyzed the uranium and thorium isotopes by alpha spectrometry, using ^{232}U and ^{228}Th as yield tracers (*10*); ^{231}Pa was assayed by proportional counting with ^{233}Pa used as the yield tracer (*8*).

Table 1 presents the results, together with pertinent information on the nature and occurrence of the samples analyzed. The calcite/aragonite ratios, as determined from the x-ray diffraction patterns, are given to show that the samples were carefully selected to exclude materials affected by recrystallization or the precipitation of secondary calcite (*11*). Also listed in Table 1 are the analytical data on two control specimens: a living coral (A) and a sample of uraninite 1600×10^6 years old (B) (*12*).

The ages were calculated on the assumption that all the observed ^{230}Th and ^{231}Pa were produced in situ and that these corals initially had a $^{234}U/^{238}U$ activity ratio of 1.14. For the following reasons we are confident of the age estimates: (i) ages derived independently from the $^{230}Th/^{234}U$, $^{231}Pa/^{235}U$, and $^{234}U/^{238}U$ ratios are, in general, consistent with one another; (ii) in terms of the uranium and thorium contents and the calcite/aragonite and $^{230}Th/^{232}Th$ ratios, the samples all meet the "reliability criteria" suggested by previous study (*6*); and (iii) good reproducibilities in age estimates were obtained from duplicate measurements (*13*).

The literature on the Oahu terraces is extensive, but it contains conflicting views. Several marine benches below the well-recognized Waimanalo stand have been described, namely, those at elevations of 3.7, 1.5, and 0.6 m (*2*). Their ages of formation are not at all certain. Radiocarbon analyses have furnished inconsistent results (*3, 14*). In some cases the dates were not finite. For example, ages of > 38,000 years for mollusk shells collected at an elevation of 7.6 m, ⩾ 37,000 years at 5.2 m, and ⩾ 30,000 years at 2.1 m have been reported (*3, 14*). These ages have been used to interpret the lower terraces as having formed during the regression of the sea from 7.6 m in the last interglacial to 100 m or more below the present level at the Wisconsin maximum (*3*). Veeh (*15*) has measured the $^{230}Th/^{238}U$ ratios of four corals from emerged reefs (collected at 1.5 to 3 m) and obtained ages between 110,000 and 140,000 years. In a more recent interpretation of the history of sea level on Oahu (*16*), Stearns interpreted the Waimanalo stand as occurring at 120,000 years before the present (B.P.). Stearns also envisaged the three lower stands, those at 3.7, 1.5, and 0.6 m, as halts of the sea on its way down from the Waimanalo stand to −100 m (?) (Kawela low stand) but further asserted that the sea had returned to near its present level from the Kawela low in Middle to Late Wisconsinan age and named this elevation the Leahi II stand.

Our samples were collected from approximately 10 m down to the present sea level. We have obtained samples from various coastal exposures in outcrops thought to represent the Waimanalo shoreline. In Table 1, these samples are listed as samples C1 to C12. Sample C13 is from the type locality of the Ulupau 3.7-m stand (*17*). Different stages of formation have been depicted for two of the Black Point samples: sample C14 represents deposits formerly thought to be of an old stand of the sea at 30 m, the Kaena stand, whereas sample C15 represents deposits of the 1.5-m stand (*16*). Of the two samples from Diamond Head, sample C16 is from the type locality of the 0.6-m Leahi I shoreline named by Stearns (*16*) and sample C17 is from the Waimanalo (?) deposits. Sample C18 from Kahuku Point is thought to be of either Leahi I or Leahi II age.

It is apparent from Table 1 that, within the analytical errors, all the ^{230}Th ages center about 120,000 years

Table 1. Analytical results on corals from Oahu; A and B are control specimens (see text). The errors assigned are standard deviations (1σ) derived from counting statistics. Sample locations are shown in Fig. 1 and described in (*29*). The thorium contents of all fossil corals range from 0.02 to 0.09 part per million (ppm); thus the $^{230}Th/^{232}Th$ activity ratios vary between 65 and 290. We calculated the ages, using 75,200 and 34,300 years for the half-lives of ^{230}Th and ^{231}Pa, respectively; Pr, *Porites* sp.; Pc, *Pocillopora* sp.

Sample No.	Elevation (m)	Coral type	Calcite/Aragonite	U (ppm)	$^{234}U/^{238}U$	$^{230}Th/^{234}U$	$^{231}Pa/^{235}U$	^{230}Th age ($\times 10^3$ years)	^{231}Pa age ($\times 10^3$ years)
A	0	Pc	< 0.01	2.58 ± 0.02	1.14 ± 0.01	0.001 ± 0.001	0.001 ± 0.001	< 0.2	< 0.1
B				69.6 × 10⁴	1.00 ± 0.01	0.99 ± 0.02	1.01 ± 0.02	> 400	> 200
C1	7.6	Pr	< 0.01	3.06 ± 0.06	1.10 ± 0.02	0.67 ± 0.02	0.91 ± 0.02	118 ± 7	120^{+11}_{-9}
C1	7.6	Pr	< 0.01	3.10 ± 0.08	1.08 ± 0.02	0.66 ± 0.02	0.88 ± 0.03	115 ± 6	105^{+15}_{-11}
C2	7.6	Pr	< 0.01	2.64 ± 0.03	1.11 ± 0.01	0.67 ± 0.01		118 ± 3	
C3	7.6	Pr	< 0.01	2.41 ± 0.04	1.09 ± 0.02	0.68 ± 0.02	0.88 ± 0.04	121 ± 7	105^{+19}_{-15}
C3	7.6	Pr	< 0.01	2.47 ± 0.03	1.10 ± 0.01	0.65 ± 0.02	0.94 ± 0.04	112 ± 6	138^{+80}_{-24}
C4	6.7	Pr	< 0.01	2.77 ± 0.04	1.10 ± 0.02	0.67 ± 0.02	0.85 ± 0.03	118 ± 7	94^{+11}_{-10}
C4	6.7	Pr	< 0.01	3.06 ± 0.04	1.11 ± 0.02	0.66 ± 0.02	0.88 ± 0.04	115 ± 6	105^{+19}_{-14}
C5	7.6	Pr	< 0.01	2.86 ± 0.03	1.09 ± 0.01	0.70 ± 0.02	0.93 ± 0.04	128 ± 8	130^{+42}_{-22}
C6	8.1	Pr	0.02	2.66 ± 0.04	1.08 ± 0.02	0.68 ± 0.02	0.91 ± 0.03	121 ± 7	120^{+18}_{-15}
C7	6.1	Pc	0.07	2.57 ± 0.03	1.11 ± 0.01	0.68 ± 0.01		121 ± 4	
C8	7.5	Pr	< 0.01	2.76 ± 0.04	1.12 ± 0.02	0.68 ± 0.02	0.90 ± 0.04	121 ± 7	113^{+25}_{-16}
C8	7.5	Pr	< 0.01	2.98 ± 0.03	1.08 ± 0.01	0.67 ± 0.01	0.92 ± 0.04	118 ± 3	124^{+32}_{-19}
C9	3.7	Pc	0.02	2.85 ± 0.04	1.09 ± 0.01	0.66 ± 0.02		115 ± 6	
C10	7.8	Pr	< 0.01	2.56 ± 0.06	1.13 ± 0.02	0.71 ± 0.02		131 ± 8	
C11	11	Pc	0.04	2.92 ± 0.02	1.09 ± 0.01	0.72 ± 0.02		134 ± 7	
C12	0.5	Pc	0.03	2.78 ± 0.10	1.08 ± 0.04	0.73 ± 0.03		137 ± 11	
C13	1.5	Pc	0.04	2.65 ± 0.10	1.07 ± 0.04	0.67 ± 0.03	0.88 ± 0.03	118 ± 9	105^{+15}_{-11}
C14	1.8	Pr	0.02	2.72 ± 0.06	1.11 ± 0.03	0.73 ± 0.03	0.94 ± 0.06	137 ± 11	$138^{+\infty}_{-33}$
C15	2.2	Pr	0.03	2.83 ± 0.02	1.11 ± 0.01	0.69 ± 0.03		124 ± 9	
C16	2.5	Pr	< 0.01	3.05 ± 0.03	1.09 ± 0.01	0.68 ± 0.01	0.86 ± 0.03	121 ± 4	96^{+14}_{-9}
C16	2.5	Pr	< 0.01	3.35 ± 0.03	1.11 ± 0.01	0.68 ± 0.01	0.84 ± 0.03	121 ± 4	91^{+10}_{-9}
C17	0.1	Pr	0.02	2.44 ± 0.03	1.09 ± 0.01	0.70 ± 0.02	0.89 ± 0.03	128 ± 8	109^{+15}_{-13}
C18	1	Pr	0.02	3.22 ± 0.06	1.13 ± 0.02	0.66 ± 0.02		115 ± 6	

[the mean value of the 23 measurements is $122{,}000 \pm 7{,}000$ (standard deviation, $1\ \sigma$) years]. These ages are supported by the $^{231}Pa/^{235}U$ and $^{234}U/^{238}U$ data (*18*) except for sample C16. Whether or not the $^{231}Pa/^{235}U$ ratio of this sample could be too low because of the incomplete release of protactinium during sample dissolution is unclear. This was a problem we noticed in the early phase of the study (*19*). Our results confirm Veeh's dates (*15*) and should supersede the radiocarbon ages mentioned earlier.

That 120,000 years B.P. represents a warm peak in the Pleistocene glaciation-deglaciation cycles has been well documented from studies of deep-sea cores and stranded shorelines (*20*). Estimation of the height of the sea at that time has been based mainly on the work of Veeh on subaerial coral flats at several locations in the Pacific and Indian oceans, including Oahu. Elevations varied from 1.5 to 10 m above the present level. The spread is not unexpected in view of the fact that reefs are constructional features descending progressively offshore (*21*). In contrast, the Waimanalo stand of 7.6 m is marked at its type locality, for instance, by horizontal notches made in lithified sand dunes of uniform texture and grain size (*4*). A detailed morphometric analysis of the island has also given a value of 7.59 ± 0.74 ($1\ \sigma$) m for the height of the Waimanalo level (*3*). Therefore, we conclude that 120,000 years ago the shoreline lay within ± 2 m of 7.6 m above its present elevation (*22*).

It has been recognized that this high stand was followed by several periods of Pleistocene deglaciation at about 105,000, 80,000, 65,000, and 40,000 years B.P. The evidence is derived from studies of raised coral reefs found on islands that have experienced considerable tectonic uplift, such as Barbados, New Guinea, and Kikai-Jima in the Ryukyu Islands (*23*). On the assumption that the strandlines around 120,000 years ago were at or near 7.6 m, it can be shown that during those later warming episodes the sea probably never rose to within 10 m of its present elevation (*23, 24*). The fact that we have yet to find corals grown during those later deglaciations on Oahu serves to demonstrate further the stability of the island. It also adds veracity to the idea that the last time the sea stood significantly higher than it does today occurred about 120,000 years ago (*20*), particularly in light of the recent oxygen isotopic measurements on deep-sea cores and the waning evidence for Holocene high sea stands (*25*). Because the polar ice caps potentially contain enough water to raise the level of the world oceans about 50 m, the suggestion (*26*) cannot be dismissed that during the Late Pleistocene the Antarctic ice played minor roles in sea level changes.

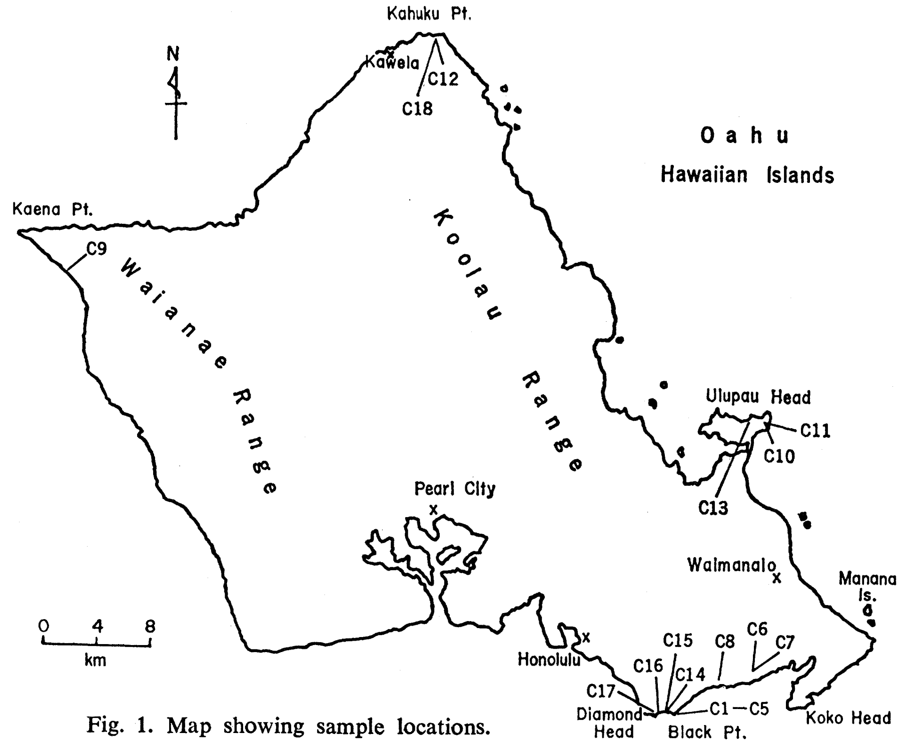

Fig. 1. Map showing sample locations.

Corals previously considered to be associated with terraces other than the 7.6-m bench appear to be indistinguishable in age from products of the Waimanalo sea. This finding leads to the following conclusions:

1) Large variability in the physical appearance of the Waimanalo deposits precludes their recognition on the basis of gross lithology alone. Neither can identification be made solely on the basis of the heights of occurrence. Their material could have been deposited in deep water presumably lower than the present sea level as well as in the supralittoral zone of up to 11 to 12 m above the present level on sloping shores.

2) The lower subaerial nips and benches may be formed by the cutting of the sea into the Waimanalo reefs during marine regression from the 7.6-m level. The rate of recession was rapid enough so that any halts would have occurred within 10,000 years or so after 120,000 years B.P. and thus would lie within the analytical error of our dating techniques. Evidence from the Barbados has also indicated a rapid drop of sea level to -71 m from the 120,000-year high in less than 20,000 years (*24*).

3) It is conceivable that at least some, if not all, of the terraces lower than 7.6 m could have formed as a result of storm waves (*27*), water-level weathering, or solution benching (*1, 28*); such changes have no bearing on Pleistocene eustatic levels.

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12. Sample K-120-a of W. R. Eckelman and J. L. Kulp [*Geol. Soc. Am. Bull.* **68**, 1117

(1957)]; this uraninite gives concordant uranium-lead ages.
13. A duplicate measurement of a solution of sample B by two of us (T.L.K. and M.A.K.) showed complete agreement (*19*). The paired measurements shown in Table 1 are not "duplicates" in the strict sense because the analyzed material of a sample consisted of coral fragments that were not completely homogenized. Thus the data, although showing reproducible age estimates, indicate some inhomogeneities in the uranium distribution in the coral.
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29. Sample locations may be described as follows: samples C1 through C5: conglomerate of basalt and massive coral boulders in a matrix of semilithified bioclastic sand; samples taken from the east side of the head of a gully leading down to the beach, southwest of the end of Black Point Road (samples C1 to C4 were collected by Dr. J. Resig of the University of Hawaii); sample C6: semilithified beach sand and conglomerate with abundant mollusks and coral cobbles; sample taken from the west side of the Kaalakei Street–Kawaihae Street intersection; sample C7: unlithified beach sand with basalt boulders, coral cobbles, and abundant mollusks, above Koolau volcanics and overlain to the north by unlithified aeolianite up to 15 m above sea level; sample taken on the east side of the Kaalakei Street–Kawaihae Street intersection; sample C8: lithified limestone with abundant mollusks and corals; sample taken north of the roadcut (before present widening) opposite 5494 Kalanianaole Highway on the south end of Hawaiiloa Ridge; sample C9: conglomerate with coral and *Strombus* shells in a semilithified sand matrix; 0 to 4 m above sea level; sample taken about 300 m west of the end of paved Farrington Highway; sample C10: conglomerate 1 to 2.5 m thick with bedded beach sand and abundant waterworn corals and mollusks; base of the deposits at 7.5 to 9 m above sea level and unconformably lying upon clay, silt, and tuffaceous sediments; sample found about 300 m east-northeast of Building 1584 in the Kaneohe Marine Corps Firing Range on the east side of Ulupau Head [photo and cross section of the locality presented by H. T. Stearns and K. N. Vaksvik, *Territ. Hawaii Div. Hydrogr. Bull.* **1** (1935), plate 17A, p. 89; figure 10, p. 122]; sample C11: same locality as sample C10, on top of a platform formed by the conglomerate deposits; sample C12: reef limestone cropping out of recent beach sand; sample taken about 1.8 km east of Kakuku Point north of the RCA radio station [see figure 8 in (*16*)]; sample C13: beach conglomerate cemented in a solution cavity in a coral reef of Waimanalo age at the northeastern end of the sand beach at the abandoned concrete Mokapu Landing on Mokapu Point, Ulupau Head (samples supplied by H. T. Stearns); sample C14: well-indurated reef limestone with oyster shells and basalt boulders, overlain unconformably (?) by a hard limestone conglomerate 15 to 30 cm thick from which sample C15 was taken, this in turn overlain by 15 to 30 cm of red soil and 1 to 5 m of black ash; sample taken about 300 m east of the southern end of Kulamanu Place at Black Point [see (*16*), p. 61, and figure V-5 in (*2*)]; sample C16: semilithified conglomerate with cobbles and boulders of coral and shell fragments in coarse calcareous matrix, in two pockets on Diamond Head tuff and overlain by Leahi aeolianite; sample taken on the cliff face 165 m east of Diamond Head lighthouse [see figure 7 in (*16*) for photo of the locality]; sample C17: well-indurated limestone with sparse coral cobbles cropping out in a patch surrounded by Diamond Head tuff at about mean tide level; sample found 120 m east of the end of Diamond Head Road; sample C18: coral embedded in calcareous soil of the Kawela soil of Stearns on pitted surface of reef limestone from which sample C12 was taken; sample taken about 8 m west of the site of sample C12.
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Immunoglobulin Structure: Amino Terminal Sequences of Mouse Myeloma Proteins That Bind Phosphorylcholine

Abstract. *The amino terminal sequences of five light and heavy immunoglobulin chains from myeloma proteins of the BALB/c mouse with binding activity to phosphorylcholine are presented. Except for a single substitution in position 4, all five heavy chains have identical amino terminal sequences through the first hypervariable region. Proteins which share unique (idiotypic) antigenic determinants are identical through the first hypervariable region of their light and heavy chains. Proteins with differing idiotypic determinants have light chains of differing amino acid sequence. These observations suggest that the heavy chain plays a more important role than the light chain in determining the phosphorylcholine binding site.*

For the past several years, myeloma immunoglobulins produced by plasmacytomas in the BALB/c mouse have been screened against a limited series of antigens (*1*). Approximately 5 percent of these proteins have been shown to exhibit specific binding activity. In many instances it has been possible to assign this binding activity to chemically defined haptens. Indeed, groups of proteins have emerged which bind the same haptenic determinant, for

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Chain                                  Residue

                                                          <------------HV_I------------>

         5       10       15       20       25       31               32     36
                                                     a b c d e f
H8    D-I-V-M-T-E-S-P-T-F-L-A-V-T-A-S-K-K-V-T-I-S-C-T-A-S-Z-S-L-Y-S-S-K-H-K-V-H-Y-L-A-W
T15   ---------------------------------------------------------------------------------
S107  ---------------------------------------------------------------------------------
M603  ----------------S-S--S--S--G-E-R----M----K-S----------L-B--G-B-Z-K-B-F-----
M167+ -------I--Q-B-E-L-S-D-P-----S-G-E-S--S--T--
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Fig. 1. The amino terminal sequences of κ chains from myeloma proteins with binding activity to phosphorylcholine. HV_I indicates the extent of the first hypervariable region; H8 indicates HOPC 8; T15 indicates TEPC 15; M603 indicates MOPC 603; and M167 indicates MOPC 167 [see (*14*)]. The one-letter amino acid code is: glycine, G; alanine, A; valine, V; leucine, L; isoleucine, I; serine, S; threonine, T; proline, P; cysteine, C; methionine, M; histidine, H; lysine, K; arginine, R; aspartic acid, D; glutamic acid, E; asparagine, N; glutamine, Q; aspartic acid or asparagine, B; glutamine or glutamic acid, Z; tyrosine, Y; phenylalanine, F; tryptophan, W. The numbering of residues for these chains is that taken from a homologous mouse κ chain, MOPC 41 (*19*).