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Holocene Sea Levels in Southeast Alaska: Preliminary Results

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ABSTRACT. Natural raised marine deposits and archaeological sites recently discovered in southeastern Alaska have been measured relative to mean sea level and radiocarbon dated. Plots of sites on Heceta and Prince of Wales islands are compared to those developed for British Columbia. The Heceta Island curve is comparable to that of the Queen Charlotte Islands, in which pre-Holocene shorelines were lower than present until about 10 000 B.P. and then rose to a maximum of 15 m asl by 8500 B.P., when gradual emergence began to bring the sea level down to its present position. In contrast, the Prince of Wales Islands data indicate that sea level remained a few metres above its present position beteen 10 000 and 7000 B.P. — a time when the shores of mainland British Columbia were as much as 15 m below present sea level. Because Holocene sea levels are a function of isostatic rebound due to removal of glacial ice, as well as global sea level changes and tectonic activity, the implication is that whereas Heceta Island underwent processes and magnitudes of glaciation and isostatic rebound similar to the Queen Charlotte Islands, Prince of Wales Island was subjected to a pattern of glaciation and isostatic rebound different from that of the Queen Charlotte Islands and mainland of British Columbia.

Key words: Alaska, Alexander Archipelago, archaeology, eustacy, geomorphology, glaciation, Holocene, isostacy, sea level, Quaternary

RÉSUMÉ. On a étudié les dépôts marins soulevés naturellement et les sites archéologiques récemment découverts dans le sud-est de l'Alaska pour mesurer leur position relative au niveau moyen de la mer et établir leur datation au carbone. On a comparé les tracés des sites sur l'île Heceta et l'île du Prince-de-Galles à ceux élaborés pour la Colombie-britannique. La courbe de l'île Heceta est comparable à celle des îles de la Reine-Charlotte, dont les côtes étaient plus basses pendant la période de l'holocène antérieur qu'à l'heure actuelle, jusqu'en 10 000 avant notre ère, époque où elles commencèrent à monter pour atteindre un maximum de 15 m au-dessus du niveau de la mer vers 8500 avant notre ère, au moment où l'émergence progressive commença à faire baisser le niveau de la mer à sa position actuelle. Par opposition, les données de l'île du Prince-de-Galles indiquent que le niveau de la mer est resté quelques mètres au-dessus de sa position actuelle entre 10 000 et 7000 ans avant notre ère, à une époque où les côtes de la Colombie-britannique continentale étaient situées jusqu'à 15 m au-dessous du niveau actuel de la mer. Vu que les niveaux de la mer pendant l'holocène dépendaient du relèvement isostatique dû à l'élimination de la glace des glaciers, ainsi que des changements du niveau de la mer et de l'activité tectonique en général, il ressort de cette étude que, tandis qu'à l'île Heceta les processus de glaciation et de relèvement isostatique, et leurs amplitudes, étaient semblables à ceux de l'île de la Reine-Charlotte, les modèles de glaciation et de relèvement isostatique à l'île du Prince-de-Galles étaient différents de ceux des îles de la Reine-Charlotte et de la Colombie-britannique continentale.

Mots clés: Alaska, archipel Alexander, archéologie, eustatisme, géomorphologie, glaciation, holocène, isostasie, niveau de la mer, quaternaire

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INTRODUCTION

Sea level curves in southeastern Alaska provide indirect evidence for the presence and magnitude of glaciation (Hicks and Shofnos, 1965; Hudson *et al.*, 1982). Furthermore, Holocene sea level fluctuations are relevant to researchers interested in paleoenvironments of prehistoric coastal settlement (Hobler, 1978; Borden, 1975; Duff, 1981), the timing and routes of man's entry into mid-latitude North America (Fladmark, 1975, 1978, 1979), and the possibility of coastal refugia for plants and animals during the late Pleistocene (Klein, 1965; Moodie and Reimchen, 1976; Mathewes and Clague, 1982). This paper reports new data and summarizes the current status of Holocene sea level research in southeastern Alaska.

Changes in sea level during the Quaternary can be attributed to the interplay of three factors: eustatic fluctuation due to formation or melting of continental glaciers; isostatic fluctuation of the earth's crust in response to the formation or removal of loads such as thick sediment sheets or ice; and tectonic movements such as faulting or folding. The exact relationships of these factors as reflected in relict shorelines can be difficult to decipher in areas of extreme tectonic and glacial activity, such as the southeast coast of Alaska and British Columbia. Here, at sites less than 100 km apart, sea level histories can be quite dissimilar. This situation has prompted researchers in British Columbia to seek and record (using almost 400 radiocarbon dates) numerous Holocene shorelines in close proximity to each other, thereby controlling for regional variability and providing relatively precise models of sea level fluctuation during the last 13 000 years (Andrews and Retherford, 1978; Clague, 1975, 1980, 1981, 1985; Clague *et al.*, 1982).

In comparison, most research in southeastern Alaska has been conducted only at a reconnaissance level, producing isolated reports of dated and undated marine shorelines (Table 1). Undated elevated marine features ranging from 11 to 150 m asl were described in early reports (Dall, 1904; Knopf, 1912; Schofield and Hansen, 1922; Buddington and Chapin, 1929; Chapin, 1918; Twenhofel, 1952), but subsequently, radiocarbon dating was used to document the ages of such features. Miller's (1973) 15 radiocarbon dates from raised marine deposits (he did not consider them necessarily beaches) near Juneau suggested that the glacially depressed terrain was submerged to a depth of over 200 m asl by 12 900 B.P. but emerged soon thereafter at a rapid rate. At Orton Ranch, near Ketchikan (Fig. 1), a raised beach at 10 m asl produced dates of 8420 ± 120 and 7230 ± 115 B.P. (Stuckenrath, 1971). At Karta Bay, on Prince of Wales Island, Stuckenrath (1971) discovered a raised beach at 1 m above high tide dated 500 ± 45 B.P. (Table 2). Near Petersberg, barnacle and pelecypod shells in fine sand matrices (indicative of a shore environment, according to the author) yielded dates of 12 170 ± 400 B.P. at an elevation of 38 m asl, and 9970 ± 300 B.P. at an elevation of 8 m asl (Yehle, 1978). Another date of 12 400 ± 800 (W-1734) was obtained on shell from an elevation of 65 m asl near Petersberg (Yehle, 1978), but species analysis did not necessarily indicate a shore environment of deposition. At Harris River, on Prince of Wales Island, raised beaches at about 9 m

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TABLE 1. Radiocarbon dates for raised marine deposits in southeastern Alaska, excluding Heceta and Prince of Wales islands

Dates	Sample #	Material	Elevation (m)	Ref. point	Location	Source
7230 ± 115	SI-906	Shell	10	asl	Orton Ranch	Stuckenrath, 1971
8420 ± 120	SI 905	Shell	10	asl	Orton Ranch	Stuckenrath, 1971
9700 ± 350	W-2326	Shell	21	asl	Wrangell	Lemke, 1974
9700 ± 800	W-2393	Shell	17	—	Juneau	Swanston, 1984
9970 ± 300	W-1738	Shell	8	—	Petersburg	Yehle, 1978
11 020 ± 400	W-2294	Shell	15	—	Haines	Lemke and Yehle, 1972
12 130 ± 110	SI-2082	Shell	70	—	NE Chichagof	Mann, 1986
12 170 ± 400	W-2327	Shell	38	asl	Petersburg	Yehle, 1978
13 350 ± 100	SI-2114	Shell	12-15	asl	Glacier Bay	Mann, 1986
9220 ± 80	SI-2112	Charcoal	12-15	asl	Glacier Bay	Mann, 1986
13 420 ± 130	SI-2082	Shell	10-15	modern beach	Icy Strait	Ackerman *et al.*, 1979
11 630 ± 145	SI-2113	Shell	10-15	modern beach	Icy Strait	Ackerman *et al.*, 1979

TABLE 2. Radiocarbon dates for raised marine deposits on Heceta and Prince of Wales islands, southeastern Alaska

Dates	Sample #	Material	Elevation (m)	Ref. point	Location	Source
500 ± 45	SI-914	Shell	1	high tide	⃠ Karta Bay	Stuckenrath, 1971
7620 ± 120	BETA-20555	Shell	1.7	asl	⃠ Red Bay	Ream and Saleeby, 1987
7630 ± 80	BETA-9488	Shell	2.5	asl	⃠ Yatuk Creek	Mobley, 1984
7970 ± 90	BETA-20557	Shell	2-3	asl	⃠ Exchange Cove	Ream and Saleeby, 1987
8310 ± 80	BETA-20554	Shell	0-1	asl	⃠ Big Creek	Ream and Saleeby, 1987
8440 ± 100	BETA-9487	Shell	3	asl	⃠ ULMB Site	Mobley, 1984
9410 ± 130	WSU-3239	Shell	2	asl	*Rice Creek	Ackerman *et al.*, 1985
9510 ± 280	I-1621	Shell	9	asl	⃠ Harris River	Swanston, 1969
9510 ± 90	BETA-20556	Shell	1.2	asl	⃠ Red Bay	Ream and Saleeby, 1987

Symbols indicate sites plotted in Figure 2 for Heceta Island (*) and Prince of Wales Island (⃠).

asl dated 9510 ± 280 B.P. (Swanston, 1969). On the northeast shore of Chichagof Island are marine shells dated 12 130 ± 110 B.P. in a deposit 70 m in elevation (Mann, 1986). Ackerman *et al.* (1979) refer to dates of 13 420 ± 130 and 11 630 ± 145 B.P. from marine terraces in the Icy Strait area and mention a nearby marine terrace of 10-15 m asl at Ground Hog Bay, while Mann (1986) reports a sequence of marine terraces farther north at Glacier Bay consisting of a 12-15 m asl terrace dating to between 13 350 ± 100 and 9220 ± 80 B.P., a 5-6.5 m asl terrace thought to be older than 9000 B.P., and a 3.5 m asl terrace estimated to date to 3500-3000 B.P. Isolated marine terraces are reported at 15 m near Haines dated 11 020 ± 400 (Lemke and Yehle, 1972), at 21 m near Wrangell dated 9700 ± 350 B.P. (Lemke, 1974), and at 17 m near Juneau dated 9700 ± 800 B.P. (Swanston, 1984). Other raised beaches at about 15 m asl near Coal Bay on Prince of Wales Island are undated (Sainsbury, 1961), as are marine terraces above 60 m near Ketchikan (Berg, 1973).

NEW DATES ON RAISED MARINE BEACHES

More recently, six raised marine deposits have been dated on the north and west sides of Prince of Wales Island (Fig. 1). At Rice Creek on Heceta Island, Ackerman *et al.* (1985) report a marine clay containing marine shells at an elevation of 2 m asl dated 9410 ± 130 B.P. (Table 2). In the Naukati Bay area on the west side of Prince of Wales Island, two natural raised marine shell deposits originally dated and reported by Mobley (1984) now have revised elevation measurements. The ULMB (unnamed lake marine beach) site contained marine shells (Carlson, 1984) at a (revised) elevation of approximately 3 m asl dated 8440 ± 100 B.P. (Mobley, 1984). A natural marine shell deposit dated 7630 ± 80 B.P. formed the basal strata at Yatuk Creek Rockshelter, at a (revised) elevation of approximately 2.5 m asl (Mobley, 1984). In the case of the ULMB site, the original elevation figure supplied by the Forest Service of 15 m asl was revised downward based on new measurements, whereas in the case of the Yatuk Creek site the revised elevation is computed from the original measurement made relative to the high tide mark (National Oceanic and Atmospheric Administration, 1987).

Four dates have been reported for three elevated marine beaches on the north side of Prince of Wales Island. A 0.5 m thick deposit of marine sand and shells at Red Bay at an elevation of 1.7 m asl (here taken to indicate the top of the deposit) yielded dates of 9510 ± 90 B.P. and 7620 ± 120 B.P. from the bottom and top of the strata respectively (Ream and Saleeby, 1987). A date of 8310 ± 80 B.P. was obtained from marine shells exposed through erosion at Big Creek at an elevation "at or slightly above" msl (Ream and Saleeby, 1987). And at Exchange Cove, at an elevation estimated by the authors to be about 50 cm above the high tide mark, a marine shell bed was dated at 7970 ± 90 B.P. (Ream and Saleeby, 1987). Using the difference between high tide and mean tide at Red Bay (Ream and Saleeby, 1987) as an estimator, the Exchange Cove site is here considered to be between approximately 2-3 m asl.

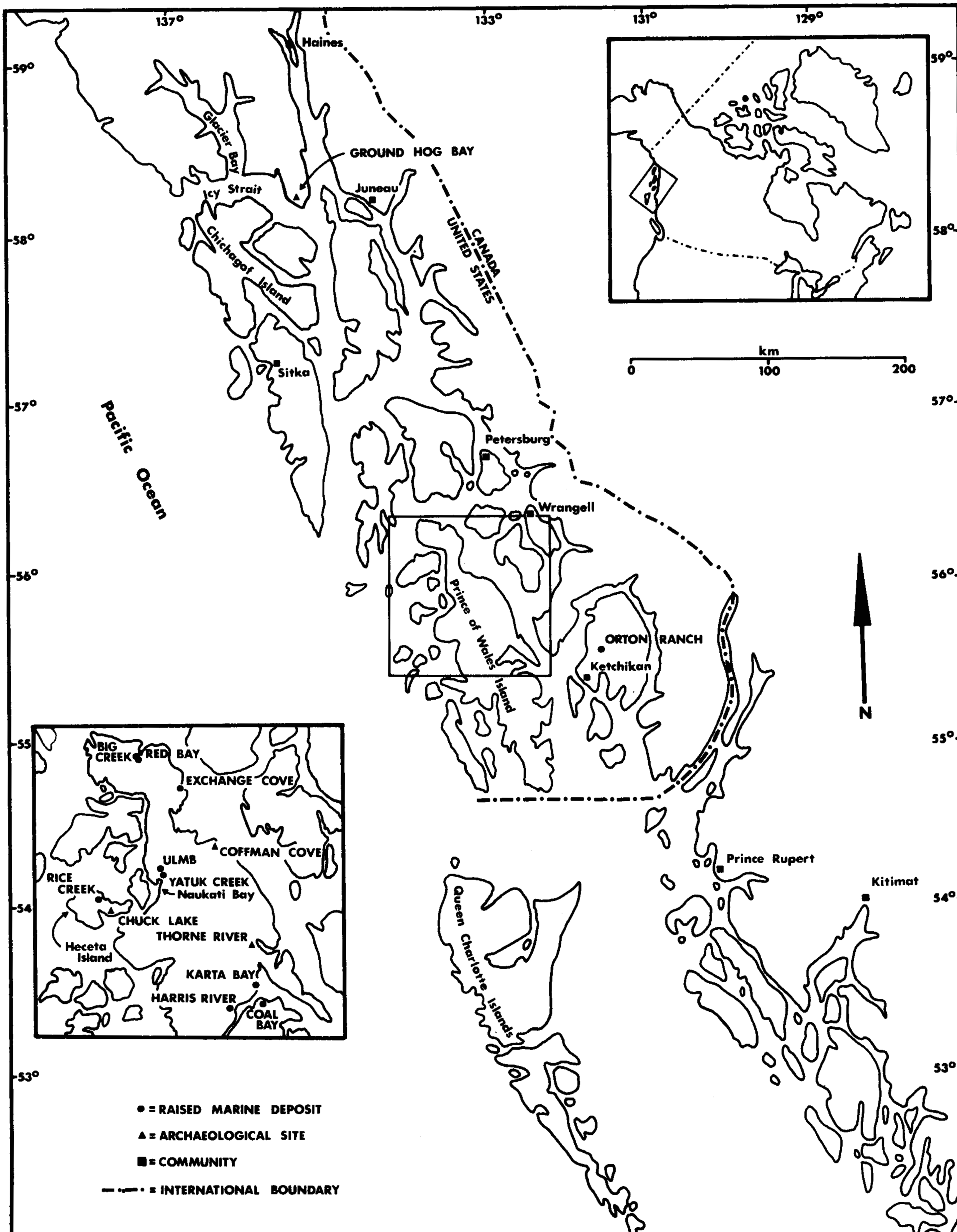

FIG. 1. Map of southeastern Alaska and adjoining British Columbia.

NEW DATES ON ARCHAEOLOGICAL SITES

Archaeological sites have provided additional information on sea level fluctuation in southeastern Alaska, using the assumptions that ancient midden deposits reflect human occupation very near contemporary sea level and that primary deposition did not occur in the intertidal zone. Some of this information has been synthesized (Mobley, 1984; Campbell, 1986; Arndt *et al.*, 1987), but the collection of dated archaeological middens in southeastern Alaska is growing (Table 3). The Coffman Cove midden site on Prince of Wales Island, which appears to have had relatively continuous human occupation back to 4000 years ago (Clark, 1979, 1980; Arndt *et al.*, 1987), is approximately 11 m above sea level (Campbell, 1986). Three middens near Chuck Lake on Heceta Island have been reported, yielding three dates of around 8200 B.P. for Locality 1 at 15-18 m asl, a date of 5240 ± 90 B.P. for Locality 3 at 12-16 m asl, and a date of 5140 ± 90 B.P. for Locality 2 at 13-15 m asl (Ackerman *et al.*, 1985). The Thorne River site (Holmes, 1987a,b), although containing no midden material, has three dates within 200 years of 7500 B.P. (Holmes, pers. comm. 1988) and is shown on Forest Service maps prepared with an analytical stereoplotter as lying between the 60 ft (18 m) and 80 ft (24 m) contours. Other prehistoric coastal sites have been dated and reported for southeastern Alaska, but in most cases they lack precise elevation data.

DISCUSSION

The new geological and archaeological information bearing on Holocene sea levels in southeastern Alaska must still be considered reconnaissance level data. Most of southeastern Alaska is managed as the Tongass National Forest, and as Campbell (1986) points out, much of the recent data has been collected through a series of archaeological surveys contracted by the Forest Service's Ketchikan Area office (Mobley, 1984; Ackerman *et al.*, 1985, 1987a,b; Ream and Saleeby, 1987), yielding a geographical bias in favor of the southern part of the region. Problems remain in dating, measurement of elevation, and the validity of certain assumptions made for archaeological contexts, and there continues to be a significant lack of control for spatial and temporal variability. The search for analogous models requires consideration of the British Columbia data (Clague *et al.*, 1982) to compare with that of southeastern Alaska (Fig. 2).

Plotted in Figure 2 are the natural and cultural deposits from Heceta Island, spanning the time between 5000 and 9500 B.P. The lowest marine deposit occurs 9500 years ago at 2 m asl, the highest deposits occur between 7000 and 8500 years ago at 15-18 m asl, and deposits at 12-16 m asl occur about 5000 years ago. The Heceta Island data points appear to portray a different sea level curve than that indicated for Prince of Wales Island, although the number of data points is small.

Also plotted in Figure 2 are eight natural marine shell deposits at scattered localities on Prince of Wales Island. All the data points occur between 7500 and 9500 years ago, and all are above present sea level. Differing elevations are apparent between the Harris River feature at 10 m asl and the Red Bay feature at 1.2 m asl, both dating to 9510 years ago. Among the group of eight sites plotted, the Red Bay and Harris River sites (at almost 100 km apart) are the most distant from each other. Interpolation directly between the eight points suggests that Prince of Wales Island has been slowly emerging since 9500 B.P. Comparison with the British Columbia data is warranted.

Radiocarbon-dated marine and terrestrial deposits have been used to construct seven sea level curves for British Columbia, three of which are near Prince of Wales Island: the Queen Charlotte Islands, the Prince Rupert area on the mainland, and the Kitimat area about 100 km east of Prince Rupert (Clague *et al.*, 1982:Fig. 1). The Prince Rupert and Kitimat curves differ considerably from the Queen Charlotte Islands curve, in that for the latter shorelines were lower than present from before 13 700 B.P. until about 10 000 B.P., eventually rising to a maximum of 15 m asl by 8500 B.P. (Fig. 2). Gradual emergence then brought the shoreline down to its present level. In contrast, the Prince Rupert area follows a pattern in which rapid emergence after deglaciation was followed by more gradual emergence between 8500 and 6000 B.P. Subsequent submergence has slowly brought the shoreline to its present position. The Prince Rupert data

TABLE 3. Radiocarbon dates for archaeological sites bearing on Holocene sea levels for Heceta and Prince of Wales islands

Dates	Sample #	Material	Elevation (m)	Ref. point	Location	Source
810 ± 95	SI-4477	Charcoal	11	asl	⦸ Coffman Cove	Arndt *et al.*, 1987
1430 ± 70	SI-3787	Charcoal	11	asl	⦸ Coffman Cove	Arndt *et al.*, 1987
2885 ± 85	SI-4466	Charcoal	11	asl	⦸ Coffman Cove	Arndt *et al.*, 1987
3235 ± 85	SI-3788	Charcoal	11	asl	⦸ Coffman Cove	Arndt *et al.*, 1987
3295 ± 90	SI-4468	Charcoal	11	asl	⦸ Coffman Cove	Arndt *et al.*, 1987
3360 ± 65	SI-4467	Charcoal	11	asl	⦸ Coffman Cove	Arndt *et al.*, 1987
3525 ± 110	SI-4476	Charcoal	11	asl	⦸ Coffman Cove	Arndt *et al.*, 1987
3535 ± 170	SI-4471	Charcoal	11	asl	⦸ Coffman Cove	Arndt *et al.*, 1987
3635 ± 70	SI-3789	Charcoal	11	asl	⦸ Coffman Cove	Arndt *et al.*, 1987
3640 ± 120	SI-4473	Charcoal	11	asl	⦸ Coffman Cove	Arndt *et al.*, 1987
3825 ± 85	SI-4469	Charcoal	11	asl	⦸ Coffman Cove	Arndt *et al.*, 1987
4100 ± 75	SI-4475	Charcoal	11	asl	⦸ Coffman Cove	Arndt *et al.*, 1987
4105 ± 75	SI-4478	Charcoal	11	asl	⦸ Coffman Cove	Arndt *et al.*, 1987
5140 ± 90	WSU-3245	Shell	13-15	asl	*Chuck Lake #2	Ackerman *et al.*, 1985
5240 ± 90	WSU-3244	Shell	12-16	asl	*Chuck Lake #3	Ackerman *et al.*, 1985
7360 ± 270	WSU-3242	Charcoal	15-18	asl	*Chuck Lake #1	Ackerman *et al.*, 1985
8180 ± 130	WSU-3243	Shell	15-18	asl	*Chuck Lake #1	Ackerman *et al.*, 1985
8220 ± 125	WSU-3241	Charcoal	15-18	asl	*Chuck Lake #1	Ackerman *et al.*, 1985

Symbols indicate sites plotted in Figure 2 for Heceta Island (*) and Prince of Wales Island (⦸).

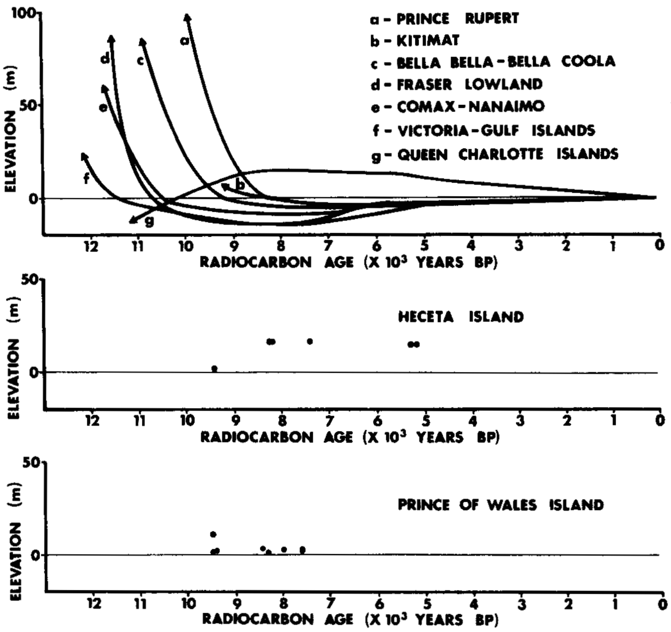

FIG. 2. Sea level curves for British Columbia (from Clague *et al.*, 1982: Fig. 12), compared with plots of new raised marine deposits and cultural sites from Heceta Island and raised marine deposits from Prince of Wales Island. Omitted are data points not measured relative to mean sea level.

differ from that of more southern parts of British Columbia (such as the Bella Bella, Fraser, Comax, and Victoria regions), where emergence occurred between 13 000 and 10 000 B.P. and shorelines fell from 100 m asl to as low as 10 m asl by 6000-9000 B.P.

Comparison of the Heceta Island data points with the sea level curves from British Columbia would imply that Heceta Island has experienced a pattern of marine transgression similar to that of the Queen Charlotte Islands (Fig. 2). The data suggest that after 9500 B.P. Heceta Island was submerged by rising sea levels until sea level temporarily stabilized at an elevation of 15-18 m asl between 8500 and 7000 B.P., after which the land slowly emerged to form shorelines at an elevation of 12-16 m asl by 5000 B.P. Despite minor differences in elevation and timing, and the lack of very old and very recent data points for Heceta Island, the similarity between the two curves has been taken to imply similar sea level histories for Heceta Island and the Queen Charlotte Islands (Campbell, 1986; Arndt *et al.*, 1987).

The data from Prince of Wales Island does not clearly follow either the Queen Charlotte Islands or the British Columbia mainland patterns (Fig. 2). All the sites are above msl, spanning the last 9500 years, which characterizes neither the Queen Charlotte Islands nor the mainland British Columbia curves. The absence of data points older than 9500, and the relative flatness of the "curve," provides little indication as to whether the sites reflect gradual emergence or submergence since that time. The discrepancy between the 1.2 m asl elevation at Red Bay and the 9 m asl elevation at Harris River is particularly vexing, since plotting the higher elevation alone would suggest Prince of Wales Island to have had an emergent coastline pattern similar to that of the British Columbia mainland. It would appear that, whereas the uplift rate of British Columbia coastlines exceeded the rate of inundation to such a degree that shorelines formed between 9000 and 6000 B.P. were subsequently submerged, the emergence rates on Prince of Wales Island almost kept pace with gradually rising sea level since about 9500 B.P.

Reconnaissance data often suffer from problems of quality and small sample sizes, and the southeast Alaska sea level information is no exception. For both the Prince of Wales and Heceta Island curves, errors in dating or elevation measurement could radically affect interpretation of the curve, especially if the older data points were consequently revised. Errors can be introduced to the elevation measurements and their interpretation by not recording elevations strictly relative to mean sea level (Clague *et al.*, 1982; Campbell, 1986). Species identification of shells in the marine deposits are not always able to verify that a shell deposit in question was formed near former msl (Miller, 1973). Assumptions necessary to use the archaeological data points must also be evaluated. For example, the lack of midden deposit at the Thorne River site suggests the existence of human groups with a non-marine adaptation 7500 years ago, in which case their occupation sites might have been well up and away from the contemporary shoreline. Furthermore, the Coffman Cove site documents a marine-adapted human group continuously occupying a site now measuring 11 m asl for a 3300 year span, implying that their settlement location was not shifted to accommodate any horizontal and vertical changes in the nearby shoreline caused by presumed isostatic adjustments. If the Chuck Lake data from Heceta Island are also the result of humans living well above the shoreline existing at that time, then the degree of emergence implied since then would be exaggerated.

Data for southeastern Alaska are still insufficient to develop adequate geographically specific reconstructions of Holocene sea levels for most regions. The models developed by Clague *et al.* (1982) and others for British Columbia may serve as useful guides in evaluating patterns of glaciation and isostacy in southeastern Alaska, but the two regions have quite different distributions of islands and fiords relative to the mainland. Campbell (1986) proposes an extension of the British Columbia model into southern southeastern Alaska that would define three zones of differing glaciation, isostatic rebound, and sea level fluctuation. The Heceta Island sea level curve compares well with that of the Queen Charlotte Islands to constitute an outer zone. The Prince of Wales Island curve, differing from the mainland British Columbia pattern in that emergence almost kept pace with rising sea levels during the last 8500 years, may represent a middle zone. And an inner zone, comparable to the mainland British Columbia pattern and perhaps reflected by reconnaissance data from the Juneau area, may exist along the entire mainland of southeastern Alaska. Confirmation and refinement of these patterns must await further research.

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