

indicate that CKI-1 represents a terrane at least that old. Other reasonable growth curves (for example, a single-stage growth curve with a $^{238}\text{U}/^{204}\text{Pb}$ value of about 8.5 and Th/U value of about 6) yield model lead isotopic ratios similar to those in CKI-1 at about 2,900 Myr ago. The actual age of the xenolith (or strictly speaking, the age of granulite metamorphism) is probably slightly greater than 2,900 Myr because no correction has been applied to the observed isotopic ratios to account for *in situ* decay of U and Th isotopes. This correction is not large for CKI-1 due to its low U and Th contents. Acid leaching studies are in progress to estimate more closely the initial lead isotopic composition of this rock. The other xenoliths are somewhat more radiogenic than CKI-1 in accordance with their higher U and Th contents. The model age for CKI-1 is supported by a $^{207}\text{Pb}/^{204}\text{Pb}$ - $^{206}\text{Pb}/^{204}\text{Pb}$ secondary isochron age of 2,870 Myr for the pair of xenoliths, CKI-1 and 70-40. However, a secondary isochron age of 3,760 Myr is indicated for the pair, SI-1 and CKI-1; this result probably reflects complex pre-metamorphic evolution of the lead in these two rocks. Further work is required to define the pre-metamorphic history of the COM xenoliths.

All of the xenoliths have high K/Rb ratios (730 to 1,360) and very low U contents and two have low Th contents. These geochemical features are characteristic of high-grade metamorphic terranes⁵. Considering their primitive lead isotopic compositions, it is clear that the low U and Th contents reflect depletions of these elements during an ancient

metamorphic event and cannot have resulted from interaction with the host lavas. Thus it is clear that these few samples record the presence of a deep Archean basement complex at least several hundred kilometres west of other known outcrops in the northern Rocky Mountains. Archean metasedimentary rocks (2,500 Myr) occur south of the Snake River Plain in the Albion Range⁶, but these are of a lower metamorphic grade than the COM xenoliths.

Sr isotropic ratios for the COM xenoliths are high and, with the low Rb/Sr ratios, provide a further indication of the antiquity of the underlying crust. The few available Rb-Sr data¹ are too scattered to provide a whole-rock isochron. If the model lead age is accepted, it is likely that the xenoliths were characterised by varied initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratios unless the Rb-Sr systematics have been disturbed.

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Biopedological origin of peatlands in South East Alaska

F. C. Ugolini & D. H. Mann

College of Forest Resources, University of Washington, Seattle, Washington 98195

Peatlands are the final stage in plant succession on level surfaces in South East Alaska, a region where bogs and forests in the process of turning into bogs occupy nearly as much surface area as do forests proper¹⁻³. Plant succession in this area is in part conditioned by progressive bogging⁴; however, no previous attempts have been made to relate paludification to soil development. We now propose that the formation of peatlands in the Lituya Bay area of South East Alaska is caused by the deterioration of the internal drainage of the soil as an iron-cemented pan develops during the process of podzolisation. This situation provides a clear example of soil-induced bog formation, a process that may be important in other parts of the world.

Along the coast of the Gulf of Alaska, in Glacier Bay National Monument, tectonic uplift along the active Fairweather Fault and eustatic sea-level changes have produced marine terraces (Fig. 1). The wave-planed, seaward-sloping bedrock of the terraces is covered by 2-4 m of beach sands and gravels. The terraces provide a chronosequence of surfaces on which plant communities and soils have developed.

Terrace A, the lowest, is 150 m wide with an average elevation of 9 m above sea level; its minimum age is estimated at 400 yr from the ages of the oldest trees (Fig. 2). Terrace B is approximately 250 m wide with an average elevation of 26 m; its estimated age is $2-3 \times 10^3$ yr (ref. 5). Terrace C is 1,600 m wide with an average elevation of 80 m, and is estimated to be $6-8 \times 10^3$ yr old⁵.

We investigated five transects across these terraces near Lituya Bay. For each transect, soils and the vegetation were described, and the ages of the largest trees determined by coring.

We will describe here the results from a representative transect, the Steelhead Transect, 10 km south-east of Lituya Bay (Figs 1, 2).

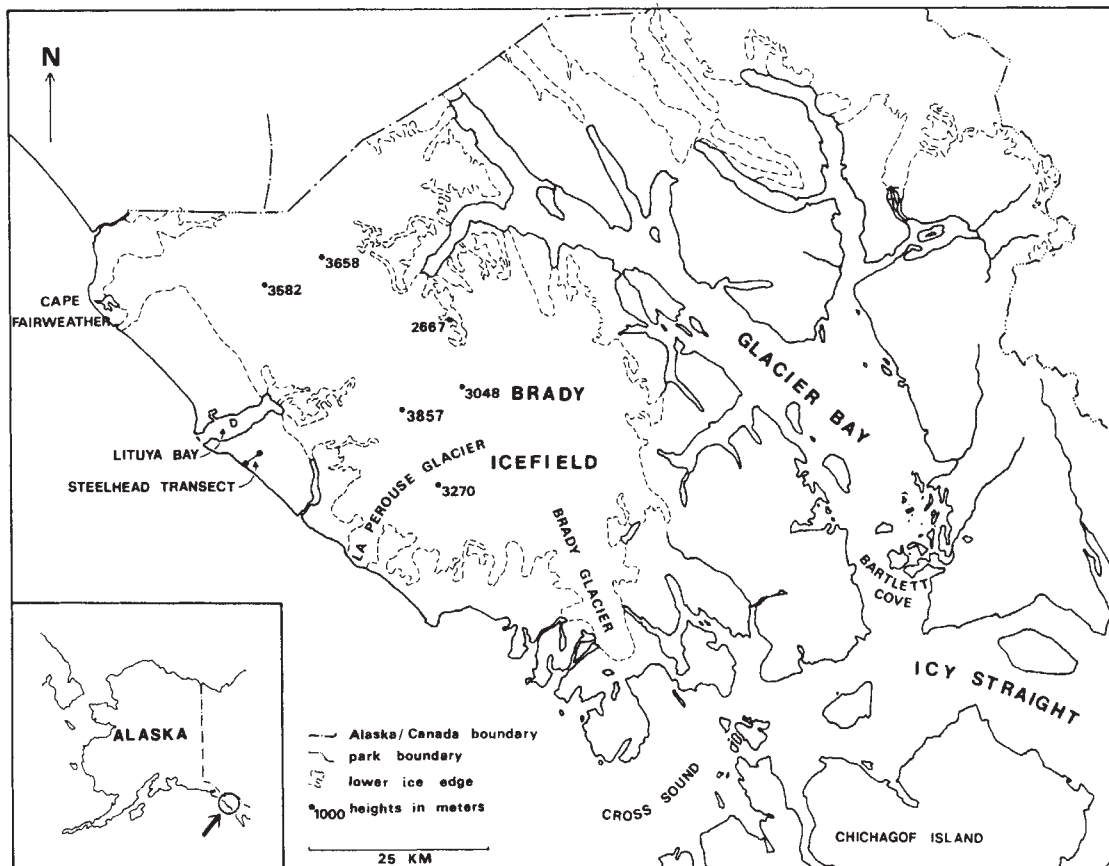
The seaward edge of terrace A is covered by rye grass (*Elymus arenarius*) and supports immature soils with A/C sequences (regosols or typic udipsamments). A Sitka spruce (*Picea sitchensis*) forest occupies the inland side of this terrace, and the soil has weakly developed B horizons with A(B)C profiles.

The seaward side of terrace B is covered by Sitka spruce with western hemlock (*Tsuga heterophylla*) in the understory. Soils on the seaward side are mature typic haplorthods or placorthods (podzols) with an A2, a friable B2hr and a firm or cemented B2ir horizon. The inland side of terrace B is dominated by western hemlock and Alaska yellow cedar (*Chamaecyparis nootkatensis*). The soils exhibit thick organic horizons, impervious B horizons (placic horizons) and impeded drainage.

Alaska yellow cedar and mountain hemlock (*Tsuga mertensiana*) form a stunted forest on the seaward edge of terrace C. Soils in this forest are histosols (peat soils) with some spodic (podzolic) characteristics, but the organic horizons are in excess of 1 m and extremely poorly drained. The rest of terrace C is occupied by peatland vegetation dominated by sphagnum, sedges and ericaceous shrubs growing on 1.5-2.0 m of well decomposed peat. This peat lies on a thin (15 cm), compacted, iron-stained layer, rich in woody organics, resting on sand which shows no morphological or chemical evidence of B2hr or B2ir horizons. Biotic remains in this profile indicate a successional change from forest to peatland. The basal woody layer contains remains of a carabid beetle, *Patrobus fossifrons*, which normally does not inhabit sphagnum bogs⁶; abruptly above this level seeds of the bog plant *Menyanthes trifoliata* appear.

The successional sequence is further described by the following chemical, physical and biological parameters of the soil. With distance from the sea, the organic horizon thickness increases from 2 to 20 cm across terrace A and from 22 to 35 cm across terrace B. On terrace C, a 100-fold increase occurs across the stunted forest/peatland boundary. The abundance of collembola and mites in organic horizons provides an index of the decomposition due to aerobic organisms. These soil arthro-

Fig. 1 Map of Glacier Bay National Monument, Alaska, showing the Lituya Bay and the location of study site.



Pods disappear rapidly inland along the transect, reaching lowest numbers in the stunted forest of terrace C. The pH decreases with increasing age and development of the soil. It decreases 2.5 units between the beach meadow and the bog, the greatest drop occurring at the start of the conifer forest. The amount of iron in the B horizon, as crystalline, inorganic amorphous, and organically complexed, parallels the soil development; it increases from 0.16% in the beach meadow to a maximum of 1.84% in the B2_h of the seaward side of terrace B. It decreases rapidly on terrace C as the soils become more poorly drained. The organically complexed iron increases from 0.60% in the B2 horizon at the rear of terrace A to a maximum of 1.00% in the B2_h of the seaward side of terrace B. Such iron is progressively depleted at the rear of terrace B and on terrace C. Virtually the only form of iron left in the profile at the bog site is organically complexed and associated with the basal layers of woody peat. The log of saturated flow of intact soil cores decreases from 1 ml min⁻¹ cm⁻² in the B2 of terrace A to -3.5 ml min⁻¹ cm⁻² in the B2_h of terrace C. Field observations revealed an abundant flow of water along the surface of the B2_h in several profiles on terraces B and C.

The above observations clearly show that the terraces near Lituya Bay comprise a soil and vegetation chronosequence spanning about 8,000 yr and telescoped into an horizontal distance of less than 1 km. The rapid rates of both soil formation and plant succession are favoured by the maritime climate of South East Alaska which allows an unusually long growing season for this latitude⁷. Heavy precipitation (280 cm) and low evapo-transpiration encourage lush plant growth and rapid mineral weathering.

The terrace chronosequence near Lituya Bay offers a new perspective on the interaction between soil development, paludification and plant succession in South East Alaska. We propose the following sequence of events for peatland development on the terraces south-east of Lituya Bay (Fig. 3). (1) Soil-forming processes initiate the development of genetic horizons on surfaces newly emerged from the sea. (2) The

accumulation of sesquioxides in the B horizon, induced by podzolisation, results in the formation of placic horizons. In South East Alaska placic horizons are known to appear after about 500 yr⁸. (3) Placic horizons cause deterioration of the soil's internal drainage, creating anaerobic conditions in the overlying horizons with attendant lowering of the decomposition rate of organic matter in the forest floor. Field observations show that placic horizons form an effective barrier to plant roots. (4) Because of slowed decomposition, litter accumulation on the forest floor proceeds rapidly. (5) At some point, equivalent to the stunted forest zone of terrace C, the litter layer surpasses a critical mass and becomes capable of retaining water the whole year round to maintain anaerobic conditions without the help of impervious B horizons. (6) In the face of continuous anaerobic conditions, the iron-cementing agents of the placic B horizons become reduced and removed in the groundwater. (7) Organic acids have lowered the pH and conditions are right for

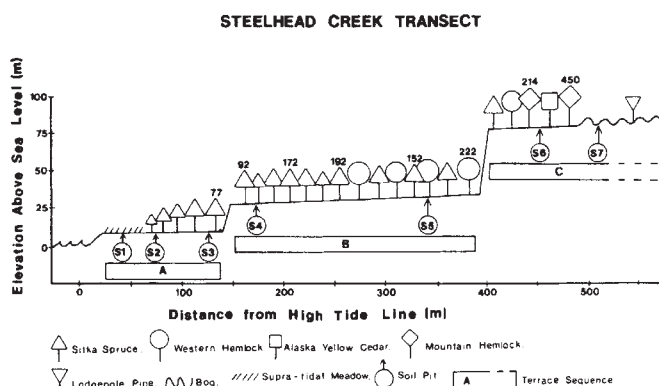


Fig. 2 Cross-section of the Steelhead Transect showing soil pit locations and tree ages across the raised terraces.

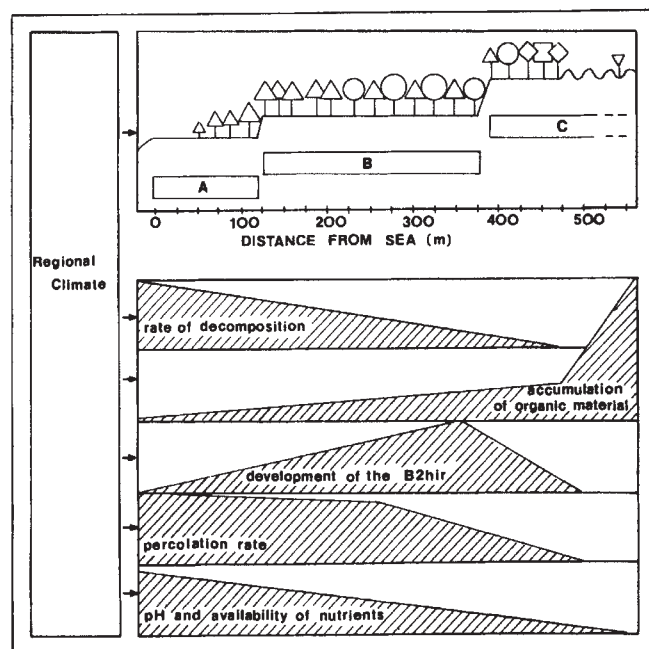


Fig. 3 A model of bog formation near Lituya Bay, South East Alaska.

the succession of bog vegetation onto a surface which once supported a well drained spruce forest.

Along this chronosequence of marine terraces, forest paludification is seen to accompany the development of spodosols. Iron cementation of B horizons, thickness of organic horizons, and hydraulic conductivity in these soils suggest a causative role for placic horizons in the paludification process. Other possible mechanisms of bog formation such as lake-infilling or the presence of impermeable parent material can be eliminated as alternative causes of paludification at this site. The spodosols responsible for paludification disappear in the anaerobic conditions occurring once the bog is established. Hence, little evidence for a pedogenic origin is available under existing bogs; a surface chronosequence seems necessary to document this process.

The role of soil development in peatland formation has been mentioned but seldom documented in the literature, and never previously assigned a major role in widespread paludification⁹⁻¹¹. The data and model presented above suggest that pedogenically induced bog formation may be more common in South East Alaska and perhaps in other regions of the world than previously recognised.

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Behavioural access to short-term memory in bees

Randolf Menzel

Institut für Tierphysiologie, Freie Universität Berlin, Grunewaldstrasse 34, 1000 Berlin 41, FRG

Memory formation proceeds in temporal phases which differ in their effectiveness in controlling subsequent behaviour and in their susceptibility to amnesic treatments¹. The initial phase of memory formation, frequently termed short-term memory, is generally considered a necessary precursor to long-term memory. However, the course of short-term memory differs widely between animal species and is dependent on experimental procedure. Information may even bypass the short-term phase en route to the long-term one^{2,3}. Experiments reported here using honey bees in a behavioural learning situation suggest that the greatest significance of short-term memory is its function as a mode of memory storage which may be altered effectively by new and contradictory information. Freely flying honey bees were presented two colour alternatives and rewarded on first one and then the other in a reversal learning paradigm. Subsequent colour preference was dependent on the interval between the two trials. Several new features of short-term memory are described. It is concluded that a single mechanism of short- to long-term memory transfer cannot account for the observed bimodal interval dependent behaviour. Two mechanisms are proposed.

The experimental procedure resembled that used in previous studies in which freely flying bees were taught to associate food with a colour stimulus²⁻⁵. Several bees are trained to use a feeding station. A newly recruited bee is marked as the experimental animal and given three pretraining trials to a neutral grey background. Two coloured cards, blue and yellow, are then presented and spontaneous choice test used to establish that the bee has no colour preference. Actual training starts by rewarding the bee once on one of the two colours. Choice behaviour is tested after each reward. The experimental protocol is illustrated in Fig. 1. The first reward is on blue, the second on yellow. A reversed order of colour training gives the same results. Time interval between these trials is varied between 10 s and 10 min. This scheme tests the effects of information initiated by the second trial on that stored during the first. In addition, the effects of temporal separation of the two training trials are also elucidated. Previous results^{2,3,5} suggested that the information capacity of short-term memory is both limited and time dependent. Thus variation of the inter-trial interval is a tool to describe short-term memory by a simple behavioural method. Another test after a second reversal learning trial gives information on the stability of these effects. Results are shown in Fig. 2.

Spontaneous choice activity was 50%. The results of learning and reversal learning in the long term are shown by arrows on the right ordinate of Fig. 2; reward duration was 60 s, and the interval between learning and reversal trials 10 min. The time course of interference between initial and reversal learning in the short term is examined by shortening the inter-trial interval. This is accomplished by decreasing reward duration to only a few seconds, making intervals as short as 10 s possible. The percent of choice behaviour has been shown to be independent of both duration and quantity of reward^{2,6}. Accordingly, reward durations of 5 and 15 s were used. In both situations there was a dominant reduction in response to the initially rewarded blue colour mark for inter-trial intervals of 3 to 5 min. During this period information from the second trial, the first reversal trial