by no means complete. But the collected data (a total of 218 observations) come from 25 deep-sea drilling sites during ten legs of DSDP's D/V *Glomar Challenger* and are therefore a representative set of observations. The reworked and displaced shallow-water benthonic fossils found in deep-sea sediments bear evidence of the former nature of the many depositional environments of shoals that once reached into the photic zone and were the locale of extensive carbonate deposition (*4, 5*). Most of the central Pacific guyots have been found to be made up of lower and upper Cretaceous carbonates (*6*) and volcanic rocks of highly variable composition (*9*). It has been assumed that most of the late Mesozoic tropical and subtropical (*3*) Pacific shallow-water carbonate environments have ceased to exist as a result of submergence due to rapid eustatic sea-level rises (*4*).

The occurrences of neritic fossils in central Pacific pelagic sediments (Fig. 2) document the repeated injection of debris derived from shallow water into the adjacent deep-sea basins throughout the late Mesozoic and the entire Cenozoic as a sequence of short-lived episodic events separated by intervals when little or no benthonic fossil material derived from shallow water reached the floor of the deep-sea basins. With the exception of the Campanian-Maastrichtian event, there is a correlation with low eustatic sea-level stands (*10*). The displaced fossils are therefore probably the product of erosional processes at or close to sea level during those intervals. The Campanian-Maastrichtian event is a special case because it is the most important one of the late Mesozoic paleoenvironment (Fig. 2). This event apparently did not coincide with very low eustatic sea levels (*10, 11*), but it was coeval with a major phase of widespread volcanic activity (*9*) in the central Pacific which led to the deposition of volcanic ashes in the Mariana Basin (site 199), along the Line Islands (sites 165, 315, and 316), and on Horizon Guyot (sites 171 and 313) in the Mid-Pacific Mountains. The occurrence of neritic fossil debris in central Pacific deep-sea sediments that is not coeval with its time of redeposition is apparently restricted entirely to the Cenozoic intervals of a few drilling sites (Fig. 2), for example, sites 76, 165, 209, 315, and 462. They occurred during a time span when sea level is believed to have fallen persistently from its upper Cretaceous high approximately 500 m above the modern sea surface (*12*).

The data from the tropical and subtropical central Pacific Ocean are important for the explanation of the onlap of coastal deposits in marine sequences which, based on seismic data, have been described from continental margins; these deposits are believed by some to be the result of true sea-level fluctuations (*10*), but others (*12*) have related them to changes in the rate of sea level fall. All the sites in the central Pacific Ocean are located on oceanic crust or on aseismic rises of volcanic origin. Their depositional record is therefore a priori not linked to events along continental margins in a very direct way. The repeated and episodic injection of neritic fossils from shallow areas that are located adjacent to certain deep-sea drilling sites (Fig. 1) in the central Pacific and the erosion of noncoeval neritic sediments are more easily understood under the assumption of short-lived true eustatic sea-level fluctuations (*10*), which affected simultaneously the shallow areas close to continental margins and which have modulated the long-term trend of falling sea level since late Cretaceous times.

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13. The effort to collect the data used in this report has been shared by numerous colleagues whose skillful work is greatly acknowledged. I thank O. Eldholm (Oslo) for comments on early drafts of this manuscript. The Deep Sea Drilling Project is operated by Scripps Institution of Oceanography with advice from the Joint Oceanographic Institutions.

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Stable Lead Isotopes as a Tracer in Coastal Waters

Abstract. *The natural abundances of the stable isotopes of lead are used to identify natural and industrial sources of lead in the coastal waters of British Columbia, Canada. The* ^{206}*Pb/*^{207}*Pb ratios, used to characterize the lead source, had values of* ~ *1.24 for coastal oceanic water,* ~ *1.22 for fjord waters receiving lead from mine tailings, and* ~ *1.163 for waters near urban centers. The lead concentration data are in agreement with presently accepted seawater values.*

The concentrations and sources of lead in seawater are poorly known, because of gross contamination by industrial artifact lead during sampling, handling, and analysis (*1*). We report here a number of stable lead isotopic compositions and lead concentrations determined for seawater collected during a survey along the coastline of British Columbia, an area characterized by a relatively small number of lead sources.

Lead may be characterized by its stable isotopic composition. There exists a systematic variation in the natural abundance of the stable isotopes ^{204}Pb, ^{206}Pb, ^{207}Pb, and ^{208}Pb, found in common lead, which reflects the geological evolution or age of the ore body, or both (*2*). The latter three isotopes are derived radiogenically from ^{238}U, ^{235}U, and ^{232}Th, respectively, whereas ^{204}Pb has remained essentially constant with geologic time. This radiogenesis and incorporation in an ore body are not halted until the ore is segregated within the earth's crust. Thus the isotopic composition established in the ore at crystallization will depend, in simple cases at least, upon the uranium/lead and thorium/lead ratios of the source material. Hence, old lead ores tend to contain the least ^{206}Pb and ^{207}Pb, whereas the youngest ores are enriched in these radiogenic products. Soils, rivers, and oceans received the most recent additions to these products and thus tend to be more radiogenic (hence called "modern lead") than ore leads. The simultaneous measurement of ^{204}Pb, ^{206}Pb, and ^{207}Pb provides characteristic (but not necessarily unique) ratios with which to identify the lead source. The ratio ^{206}Pb/^{207}Pb is often used as an indicator in comparing lead sources (*3, 4*).

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Lead sources in the present study area (Fig. 1) are relatively few and are isotopically distinct (*5*) or geographically well separated. They are as follows: (i) gasoline lead in aerosols from Vancouver and Victoria, $^{206}\text{Pb}/^{207}\text{Pb} \sim 1.16$ (the isotopic composition of lead in gasoline is identical to that found in urban city air) (*6*); (ii) gasoline lead from the Seattle area, $^{206}\text{Pb}/^{207}\text{Pb} \sim 1.23$, entering the Juan de Fuca by way of Puget Sound; and (iii) lead from mining activities occurring at Alice Arm or Brittania Beach (near Vancouver), $^{206}\text{Pb}/^{207}\text{Pb} \sim 1.22$ and 1.18, respectively.

Surface seawater samples were collected in rigorously cleaned (*7*) conventional polyethylene (CPE) bottles held just beneath the surface from the bow of a small boat while proceeding upstream. The bottles were uncapped and closed while under the surface of the water so as to exclude the surface layer. Subsurface samples were peristaltically pumped through CPE tubing weighted with a solid Teflon weight. All sample bottles were triple-bagged in CPE. The pump arrangement provided reliable test results at the level of 150 ng of lead per kilogram of water (procedural blank < 1 ng) in a NATO experiment (*8*).

Lead concentrations were determined by stable isotope dilution according to the method of Patterson *et al.* (*3*) and were yield-corrected by double spiking. We determined the dissolved lead by extracting untreated water with dithizone. We determined the total lead by boiling the sample to salts in the presence of aqua regia, redissolving in quartz-distilled water, and extracting with dithizone into chloroform. We determined the total lead results obtained prior to September 1978 by heating an acidified (0.1 percent HCl) sample at 55°C for 24 hours and extracting with dithizone into chloroform. Because of ultraclean room techniques, we were able to obtain blank levels of 0.1 ng/kg in 1979 ($\simeq$ 0.4 ng/kg in 1978) and quartz-distilled water levels of 0.05 ng/kg. Lead isotope compositions were measured on a 90°, 30-cm, single-focusing mass spectrometer (Nuclide Corporation). Mass discrimination, corrected by standardization with National Bureau of Standards sample SRM 981, was 0.24 percent per atomic mass unit.

The lead concentration data (Table 1) are in general accord with presently accepted seawater values (*3*, *9*); that is, the values do not exceed 50 ng/kg except for samples taken near large lead sources. Moreover, dissolved lead in open water constitutes the bulk of the total lead whereas the converse is found in the sediment-rich waters directly above the mine tailing dump in Alice Arm. In the relatively low-lead, coastal waters near Victoria, lead concentrations appear to be fairly stable with time and location (compare, for example, the values of Patterson *et al.* (*3*) of 24 ng/kg for Juan de Fuca in 1976 with 19 to 22 ng/kg in this study). The total lead values, 20 to 36 ng/kg, from Patricia Bay and Saanich Inlet may be an artifact of the mild acid treatment that we used at that time versus the rigorous approach with aqua regia used subsequently. This difference could indicate that some of the lead is associated with suspended matter such as plankton (*3*). Although the subsurface samples from Patricia Bay have been taken at different times, the generally lower values are taken as an indication that lead does in fact decrease with depth, an observation in accord with that of Patterson *et al.* (*3*, *10*).

The natural abundance data (Table 1) give more conclusive evidence on the lead source. The $^{206}\text{Pb}/^{207}\text{Pb}$ data, plotted versus distance along the coast (Fig. 2), appear to indicate that seawater data can be arranged into three distinct groups, each apparently identifiable with a particular lead source. (i) Values for $^{206}\text{Pb}/^{207}\text{Pb}$ of ~ 1.163, found in air (1979) and seawater (1978–1979) in the Saanich Inlet–Vancouver area, have an isotopic composition that is concordant at 1σ levels (σ is the standard deviation) with Bathurst mine lead (*5*). It may be safely assumed that the observed lead in both the lead-rich waters of Vancouver and the relatively low-lead waters of Saanich Inlet–Patricia Bay is predominantly gasoline lead. (ii) Values for $^{206}\text{Pb}/^{207}\text{Pb}$ of ~ 1.23 to 1.25, the most radiogenic lead observed, were found in the coastal oceanic waters north of Vancouver Island. This most likely is derived from modern lead. (iii) A value for $^{206}\text{Pb}/^{207}\text{Pb}$ of ~ 1.22, identical at the 2σ level to Alice Arm mine lead, was found in seawater directly overlying the mine tailing dump.

Mixing of waters containing two different lead types can yield an intermediate isotopic composition. The ratios generated by mixing various proportions of the lead types would lie along a line

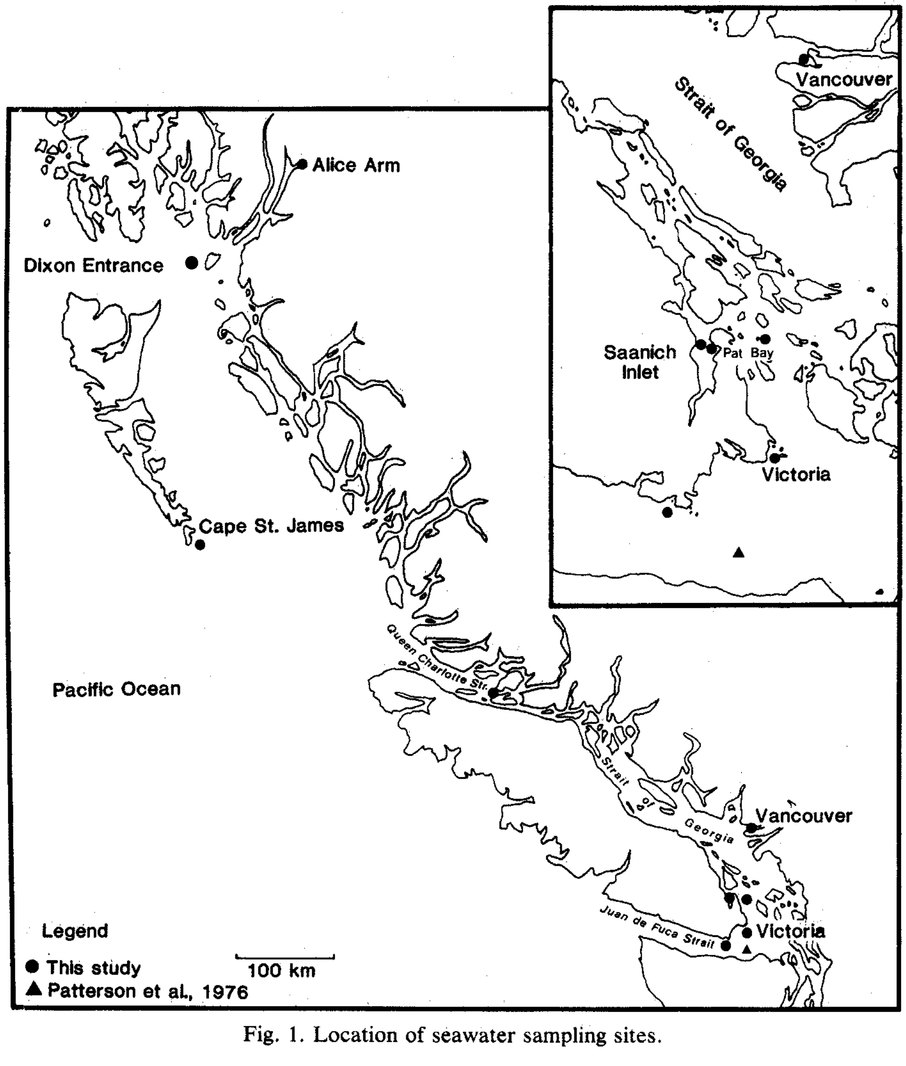

Fig. 1. Location of seawater sampling sites.

joining the characteristic ratios. Moreover, more radiogenic (higher ^{206}Pb/^{207}Pb) values than the end-member values could not occur. For example, there appears to be no measurable incursion of waters or aerosols, or both, containing the more radiogenic lead of American gasoline from the southeast (by way of Puget Sound) or from Brittania Mines to the northeast (^{206}Pb/^{207}Pb = 1.2263 and 1.1849, respectively) into the Vancouver–Saanich Inlet area (~ 1.163). The exit of significant quantities of water with ^{206}Pb/^{207}Pb ~ 1.163 to the north by way of Queen Charlotte Strait is not evident. Although a downward trend in the ratios, which were judged to be attributable to modern lead, is suggested in a northerly approach to the strait (Fig. 2), the data are concordant at the 2σ level. Observed circulation patterns (*11*) indicate that 7 percent of the net outflow from the Strait of Georgia is by way of Queen Charlotte Strait. Similarly, Alice Arm lead (~ 1.22) is not evident in the radiogenic water of Dixon Entrance (~ 1.25).

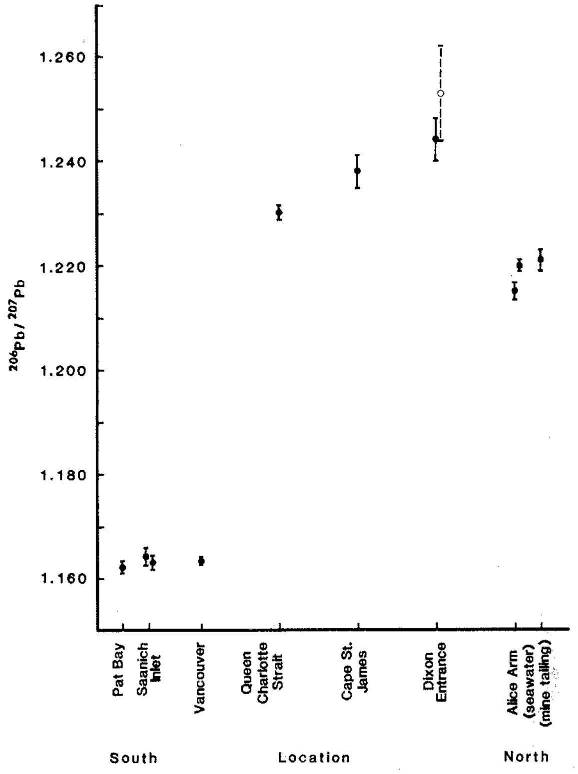

Fig. 2. Geographical distribution of the ^{206}Pb/^{207}Pb values. Samples are plotted approximately with distance along the British Columbia coastline. A dashed line indicates that the sample has been corrected for 8.6 ng per kilogram of gasoline lead contamination. Errors are 1σ.

One may estimate the maximum concentration of natural lead (that is, preindustrial) in local seawater by using the error limits in the isotopic composition of the seawater and a two-source, mixing model with at least one well-defined end-member. If one assumes that the isotopic composition of the end-members are (i) ^{206}Pb/^{207}Pb ~ 1.25, ^{206}Pb/^{204}Pb ~ 20.6, represented by the most radiogenic waters encountered, such as that of Dixon Entrance, and (ii) ^{206}Pb/^{207}Pb ~ 1.1631, ^{206}Pb/^{204}Pb ~ 18.178, for that of the Bathurst lead (that is, local gasoline lead), then the position of the Saanich Inlet–Patricia Bay data (1.1631 ± 0.0011, 18.40 ± 0.12) along this line indicates that 3 ± 2 percent of the lead in local water can be attributed to a modern composition. That is, 1.1 ± 0.7 ng/kg (1σ) may be natural lead. Patterson's group (*9, 10*) based their estimate of 0.5 ng/kg for the natural lead concentration in surface waters upon a rigorous study of lead concentration profiles in the open Pacific.

Thus, the determination of the natural abundances of stable lead isotopes is a powerful tool in identifying lead sources and in tracing lead pathways in coastal waters. Although the values of 20 to 35 ng/kg found in Saanich Inlet–Patricia

Table 1. Concentration and isotopic composition of lead in seawater. Errors quoted are ± 1σ; each value is the mean of two or three separate analyses. N.D., not determined.

Sample location	Date	Lead concentration (ng kg^{-1})		^{206}Pb/^{207}Pb	^{206}Pb/^{204}Pb	^{206}Pb/^{208}Pb
		Total	Dissolved			
Alice Arm	October 1978	1200 ± 10	190 ± 2	1.215 ± 0.002	19.25 ± 0.04	0.4929 ± 0.0019
Alice Arm	October 1978			1.220 ± 0.001		
Dixon Entrance	October 1978	14.8 ± 0.1	11.5 ± 0.2	1.244 ± 0.004	20.78 ± 0.27	0.5039 ± 0.0027
Dixon Entrance	October 1978			1.253 ± 0.009	20.48 ± 0.34	0.5034 ± 0.0026
Cape St. James	March 1979	N.D.		1.238 ± 0.003	20.59 ± 0.24	0.4993 ± 0.0009
Queen Charlotte Strait	March 1979	N.D.		1.2302 ± 0.0013	19.66 ± 0.07	0.5063 ± 0.0007
Vancouver (English Bay)	October 1978	170 ± 2	100 ± 2	1.1634 ± 0.0007	18.42 ± 0.06	0.4824 ± 0.0019
Haro Strait	July 1978	30 ± 2				
Saanich Inlet	April 1979	32 ± 5	26 ± 1	1.1630 ± 0.0012		0.4793 ± 0.0012
Saanich Inlet	April 1979	35 ± 1		1.1642 ± 0.0016	18.28 ± 0.15	0.4813 ± 0.0007
Saanich Inlet	April 1978	24 ± 2				
Patricia Bay	September 1978	35.6 ± 0.5		1.1621 ± 0.0010	18.52 ± 0.07	0.4774 ± 0.0005
Patricia Bay*	September 1978	36.6 ± 0.4				
Patricia Bay†	September 1978	20 ± 2				
Patricia Bay‡	April 1980	8.4 ± 0.6				
Patricia Bay§	October 1979	4.3 ± 0.5				
Juan de Fuca						
Victoria	April 1979	19 ± 1				
Becher Bay	August 1978	22 ± 2				

*Analysis performed at C. Patterson's laboratory at the California Institute of Technology. †Samples separated by ~ 200 m from the above two. ‡25 m, obtained by peristaltic pump. §40 m, obtained by peristaltic pump.

Bay may be representative of relatively low-lead coastal waters, the natural abundance data indicate that virtually all the lead is derived from Canadian gasoline lead, a conclusion that cannot be drawn on the basis of concentration determinations alone.

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Detection of a Milk Factor That Facilitates Folate Uptake by Intestinal Cells

Abstract. *Folate binding proteins in milk were tested for their effect on folate absorption. The uptake of bound folate by isolated mucosal cells from the rat small intestine was twice that of free folate and differed from it in being more effective with progression down the small intestine, in not being affected by glucose or Dilantin, in having a higher* pH *optimum, and in being affected by calcium concentration. This milk factor may enhance folate absorption in infants, whose risk of folate deficiency is high.*

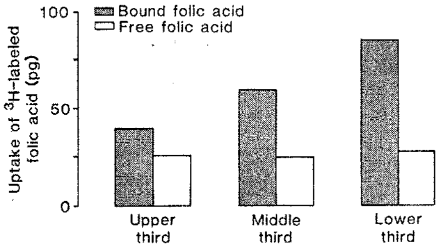
The detection of folate binding proteins in milk (*1–3*) and their subsequent characterization (*4*) led to numerous studies of their function (*5–9*). None provided a coherent explanation for their role in milk. Studies of these proteins in the milk of cows, goats, and humans (*4, 9–11*) demonstrated that they, along with the corresponding serum binders, (i) are glycoproteins with a molecular weight approximating 40,000, (ii) have isoelectric points in the neutral range, and (iii) dissociate at acid *p*H and can rebind folate when neutralized. Since the binders impair the transport of folate into both dividing cells and bacteria (*5–7*), we thought that it might be productive to study their effects on intestinal absorption.

Intestinal absorption of folate is a two-stage process. First there is obligatory hydrolysis of folate polyglutamates in food to the monoglutamate form (*12*), a process that apparently occurs in the mucosal brush border (*13*). In the second stage, the monoglutamates traverse the mucosal border at a rate modified by *p*H, fluid and electrolyte shifts, and other factors (*14*). A third stage, involving methylation and formylation of folates, may occur in mucosal cells but is not required for absorption (*15*). The absorbed folates then enter the portal circulation and are transported to the liver. In this report we show that folate binding proteins in milk mediate the folate absorption process.

The milk binder was obtained fresh from Sri Lankan goats (*16*) after the second week of lactation, centrifuged, skimmed, and freeze-dried for storage. After reconstitution, a solution of the milk (5 g per 100 ml) was incubated, without purification, with saturating quantities of ^3H-labeled pteroylglutamic (folic) acid for 30 minutes, dialyzed for 18 hours against three changes of buffer, and used in the various assays. To avoid possible artifacts caused by particulate matter, we centrifuged the dialyzed samples at 100,000*g* for 1 hour and used only the supernatant.

Mucosal cells were isolated from rat small intestine by vibration (*17*). The small bowel was resected from anesthetized nonfasted rats, everted over a glass spiral, and agitated at an amplitude of 1 mm for 8 minutes at 60 vibrations per second. The dislodged cells were strained through a grid with 0.4-mm^2 apertures, washed at 1000*g*, and suspended in tris-buffered Hanks solution with phosphate buffer. After incubating 10^6 cells for 1 hour at 37°C, we washed the cells three times at 1000*g*, extracted the folate by autoclaving them with 1 ml of ascorbate solution (1 g per 100 ml), and measured the radioactivity of the extracts.

Uptake of folate bound to milk binder not only exceeded that of free folate, it increased more than twofold between cells from the upper third of the intestine and cells from the lower third (Fig. 1). Free folate uptake did not change with a change in site of origin of the intestinal cells. Uptake of bound folate differed from that of free folate in being neither enhanced by 40 n*M* glucose nor inhibited by 2 m*M* Dilantin (Fig. 2). Nonradioactive free folic acid (90 m*M*) had no inhibitory effect. Calcium and EDTA barely affected free folate uptake, whereas bound folate was absorbed twice as rap-



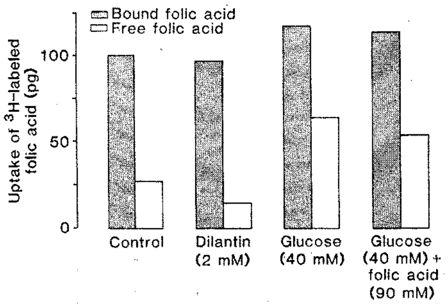


Fig. 1 (left). Effect of folate binding protein on folate uptake at *p*H 6.5 by isolated mucosal cells from the upper, middle, and lower thirds of the rat small intestine. Each incubation flask contained 10^6 cells, 1.1 ml of 0.1*M* phosphate buffer, bound or free labeled folic acid, and tris-buffered Hanks solution to a final volume of 2.5 ml (*p*H 6.5). Fig. 2 (right). Uptake of labeled folic acid by isolated cells of the rat small intestine under the influence of Dilantin and glucose.

0036-8075/81/0327-1427$00.50/0