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16. The 15-channel Coulter counter model T was calibrated with Dow-Corning polystyrene beads of known diameters. Stock microparticulate suspensions were diluted 1:20 with filtered seawater, and their size spectra were determined. The results were as follows: NA, 97.1 percent < 5.49 μm in diameter, 99.9 percent < 10.98 μm; SM, 99.5 percent < 5.49 μm, 99.9 percent < 10.98 μm; NPM, 99.9 percent < 5.49 μm. The modal particle diameters were as follows: NA, 2.74 μm; SM, 2.18 μm; and NPM, 0.67 μm.

    We determined the dry weights of microparticulates by filtering 100-ml portions of stock particle suspensions at low vacuum (125 mm-Hg) onto predried and tared Millipore filters. These filters were dried in a vacuum drying oven at 60°C to constant weight as determined with an analytical balance (Mettler H20T). Corrections were made for the dry weight of salt retained by the filters. The dry weights of the four diatom species were estimated from measurements of cell dimensions, calculation of cell volumes, and conversion to dry weight units according to data presented in T. R. Parsons, K. Stephens, and J. D. H. Strickland [*J. Fish. Res. Board Can.* **18**, 1001 (1961)] and R. R. Strathman [*Limnol. Oceanogr.* **12**, 411 (1967)]. Cell numbers were determined with an improved Neubauer hemacytometer or Coulter counter model T equipped with a 400-μm aperture.
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    $$X/m = KC_{eq}{}^{1/n}$$

    where K and $1/n$ are constants. The usual plot of log C_{eq} as a function of log X/m results in a linear relationship with log K as the y-intercept and $1/n$ as the slope. The empirical relationship described by the Freundlich adsorption isotherm is related to the multilayered nature of the adsorption mechanism.
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Phanerozoic Peridotitic and Pyroxenitic Komatiites from Newfoundland

Abstract. *Peridotitic and highly magnesian pyroxenitic komatiites, thus far known to occur almost exclusively in the Archean (before 2.5 × 10⁹ years ago) terranes, are reported from an Ordovician (0.5 × 10⁹ years) ophiolite suite in Newfoundland. Their occurrence as pillow lavas or as chilled dikes, their possession of quench textures and geochemical parameters such as high contents of magnesium oxide, nickel, and chromium and low contents of titanium dioxide and potassium monoxide, low ratios of iron to iron plus magnesium, and values of the ratio of calcium oxide to aluminum oxide of close to unity demonstrate that they were formed through the rapid cooling of a highly mobile komatiitic melt. These features resemble those of many Archean peridotitic-pyroxenitic komatiites and indicate that the Archean-type magmatism did prevail in the younger segments of the earth's history although perhaps in a more erratic manner.*

I know of no report of definitive peridotitic and associated pyroxenitic komatiites (*1*) from Phanerozoic rocks. With the exception of two alleged Proterozoic occurrences in Manitoba and Quebec (*2*, *3*), all such komatiites are confined to various shield areas of Archean age (*3*-*9*). This observation has led some scientists (*10*) to postulate that certain unique geotectonic conditions must have prevailed during the early part of the earth's history. I present here evidence for the existence of peridotitic and high-Mg pyroxenitic komatiites from an Ordovician ophiolite suite exposed at Betts Cove (55°47′46″W, 49°49′11″N) in the Newfoundland Appalachians and suggest that the komatiite-based argument for the geotectonic uniqueness of the Archean may no longer be tenable.

The komatiites reported herein occur as thin dikes and pillow lavas within the Betts Cove ophiolite suite, which consists of four well-developed members: ultramafite, gabbro, sheeted dike, and pillow lava. This suite has been described and interpreted as a remnant Appalachian oceanic crust-mantle sequence (*11*). The sheeted dikes consist of diabase and less commonly clinopyroxenite and peridotite. Field and petrochemical evidence shows that the dikes acted as feeders to the overlying pillow lavas. The ophiolite is known to be of Early Ordovician age (*12*). The entire suite has undergone greenschist metamorphism without any significant obliteration of igneous textures. The komatiites of Betts Cove represent a complete compositional spectrum ranging from peridotitic through pyroxenitic to basaltic varieties. The compositions of four peridotitic and three high-Mg pyroxenitic types are presented in Table 1 (columns 2 through 8); three selected Archean peridotitic komatiites are also listed for comparison (columns 9 through 11) (*13*). The peridotitic and pyroxenitic komatiites consist chiefly of clinopyroxene with variable amounts of serpentinized olivine. Chromite occurs in all specimens although the content varies. The five pillowed samples possess sparse globules consisting chiefly of high-Mg, devitrified glass with or without minor amounts of quartz and other silicic material; similar glass and silicic material also occur in the matrix of these pillow lavas (*14*). Crystalline plagioclase is extremely rare or absent in these samples.

All the Betts Cove komatiites discussed here contain subequant or bladed skeletal crystals of olivine or clinopyroxene, or both. The two most magnesian samples (samples 70S168 and 70S215) possess very sparse subequant skeletal

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olivine phenocrysts that show irregular reentrants (embayments) with varying degrees of idiomorphism (Fig. 1, a and d). Some of these exhibit a remnant compositional zonation similar to that described from the skeletal olivines of komatiites from Barberton, South Africa (*15*), and the spinifex blades of Ontario occurrences (*7*). These skeletal and associated solid phenocrysts are set out in a matrix of high-Mg glass and finer laths of skeletal as well as solid clinopyroxene (Fig. 1, b and c). The shapes of these subequant skeletal olivines are in contrast to the bladed "spinifex" forms of Archean komatiites but closely resemble their "porphyritic" (*8, 9, 15*) varieties. Similar subequant quench ("hopper") crystals have also been reported from the Tertiary picritic sills of Scotland (*16*), and in a recent work Donaldson (*17*) has demonstrated that these crystals were formed in situ. He has further theorized that the subequant skeletal olivines, like those in the layered komatiites of Ontario (*3*) and elsewhere, resulted from an in situ crystallization of a homogeneous melt. From this and other data, such as the presence of the highly magnesian glassy matrix and zoned phenocrysts, it can be interpreted that the olivine and clinopyroxene crystals in these two Betts Cove samples crystallized during rapid cooling of a highly mobile komatiitic melt in which the crystals underwent very limited, if any, transportation. A pertinent analogy can be made with an Apollo 15 basaltic vitrophyre, which is texturally similar to sample 70S168 and has been interpreted as having arrived at the lunar surface in "an essentially entirely liquid state" (*18*). In sample 70S215, however, certain textural features such as the occurrence of somewhat less pronounced skeletal crystals and a less abundant glassy matrix suggest that some phenocrysts might have been carried in suspension during a relatively slower cooling of the parental melt. This sample may therefore be analogous to the "spinifex-free komatiites" of Ontario (*3*) and elsewhere. The remaining five (pillow lava) samples contain over 75 percent clinopyroxene, the bulk of which occurs as quench crystals in the form of long blades, sheaves, or acicules marked by high ratios of length

Table 1. Major oxide contents, Ni-Cr contents, and CIPW norms (from the initial letters in the names of those who originated the norm system, Cross, Iddings, Pirsson, and Washington) of the periodotitic and pyroxenitic komatiites from Betts Cove and selected (*13*) peridotitic komatiites from Barberton, Rhodesia, and Ontario. Oxide contents are expressed in percentages by weight (recalculated on a volatile-free basis), and Ni and Cr contents are in parts per million. The CIPW norms were calculated on the assumption that the ratio of Fe^{3+} to Fe^{2+} is 1:9; ND = not determined, T = trace amount, LOI = loss on ignition. Samples described in columns 2 and 3 come from subvertical dikes, each approximately 30 cm thick, that cut across the basal ultramafic member of the ophiolite; those described in columns 4 through 8 are pillow lavas. Petrographic descriptions follow (clinopyroxene in all of these is partially or wholly replaced by tremolite or actinolite). Sample 70S168 consists of skeletal and solid phenocrysts (20 to 25 percent; average size, 2 mm) of serpentinized olivine, in a matrix of much finer-grained skeletal and solid clinopyroxene and high-Mg glass. In sample 70S215 (4-cm chilled margin of the dike) the outer 1 cm possesses randomly oriented microscopic blades of clinopyroxene in a glassy matrix; the inner 3-cm zone contains subequant skeletal and solid phenocrysts of serpentinized olivine (15 to 20 percent of the zone; average length, 2 mm) in a matrix that resembles the outer 1-cm zone. Sample 7255 consists of phenocrysts of olivine-clinopyroxene pseudomorphs (~6 percent; average size, 1 mm, some with suggestions of skeletal forms) and globules of magnesian glass surrounded by smaller-sized, randomly oriented blades and sheaves of clinopyroxene (~90 percent) in a matrix of magnesian glass and primary silicic material. The globules and some of the olivine-clinopyroxene pseudomorphs carry quartz or epidote, or both; this quartz and the associated silicic material are interpreted to have grown through liquid immiscibility and subsequently redistributed within the rock. Sample ST10A is like sample 7255 except that the globules and the phenocrysts carry little or no quartz or epidote. Sample JL1813 is like sample 7255 except that the silicic material is more pronounced. Sample 7236 consists chiefly of clinopyroxene phenocrysts (~7 percent with suggestions of skeletal forms) and globules (~7 percent) in a matrix of clinopyroxene blades and sheaves (~85 percent). The growth and redistribution of silicic material is very pronounced. Sample JN191 is like sample 7236 except that carbonate is also associated with quartz and silicic material.

(1) Component	Sample							Average of samples		
	(2) 70S168	(3) 70S215	(4) 7255	(5) ST10A	(6) JL1813	(7) 7236	(8) JN191	(9) 87J and 88J, Barberton (*4*)	(10) NG213 and NG214, Rhodesia (*9*)	(11) 8, 9, and 10, Ontario (*6*)
SiO_2	47.46	50.18	48.88	48.44	52.57	51.77	51.73	48.26	49.06	45.58
TiO_2	0.03	0.06	0.01	0.06	0.18	0.04	0.17	0.63	0.38	0.40
Al_2O_3	8.52	7.35	9.73	9.54	9.61	10.84	8.94	3.39	6.88	8.90
Fe_2O_3	1.23	1.63	1.82	1.08	0.76	1.59	1.15	7.34	3.29	12.54
FeO	7.85	7.45	8.64	9.75	9.92	7.56	8.32	5.34	7.90	
MnO	0.18	0.17	0.18	0.18	0.19	0.17	0.17	0.20	0.20	0.23
MgO	25.68	23.51	21.62	20.88	19.15	18.93	18.13	24.88	24.56	22.39
CaO	8.16	8.72	8.60	8.61	8.15	7.46	9.86	8.51	7.20	9.46
Na_2O	0.09	0.19	0.18	0.17	1.05	0.16	0.07	0.49	0.25	0.64
K_2O	0.02	0.03	0.36	0.40	0.16	0.77	0.43	0.05	0.17	0.09
P_2O_5	0.03	0.03	T	ND	ND	T	0.03	ND	0.08	0.02
Total	99.25	99.32	100.02	99.11	101.74	99.29	99.00	99.09	99.97	100.25
LOI	7.46	6.62	5.50	4.60	4.40	5.90	6.00	5.56	7.10	4.40
Ni	610	810	466	391	406	523	482	707		894
Cr	2065	2400	1143	1127	961	1189	1158	2532		3333
					CIPW norms					
Quartz	0.00	0.00	0.00	0.00	0.00	0.00	0.19	0.00	0.00	0.00
Orthoclase	0.11	0.16	2.11	2.33	0.88	4.50	2.50	0.27	1.00	0.50
Albite	0.73	1.57	1.51	1.41	8.86	1.31	0.57	4.13	2.09	5.40
Anorthite	22.77	19.09	24.63	24.07	21.04	26.60	22.79	6.89	17.12	21.12
Clinopyroxene	13.89	19.06	14.43	14.92	15.55	8.33	20.78	28.24	14.42	20.54
Orthopyroxene	31.74	43.00	36.09	35.76	45.52	55.73	51.57	29.05	40.85	23.05
Olivine	28.33	14.59	19.50	18.72	9.10	1.24	0.00	26.48	21.40	28.89
Magnetite	1.43	1.43	1.64	1.71	1.71	1.41	1.48	1.92	1.74	1.80
Ilmenite	0.04	0.10	0.01	0.10	0.33	0.07	0.31	1.18	0.71	0.76
Apatite	0.06	0.06	T			T	0.06		0.16	0.03

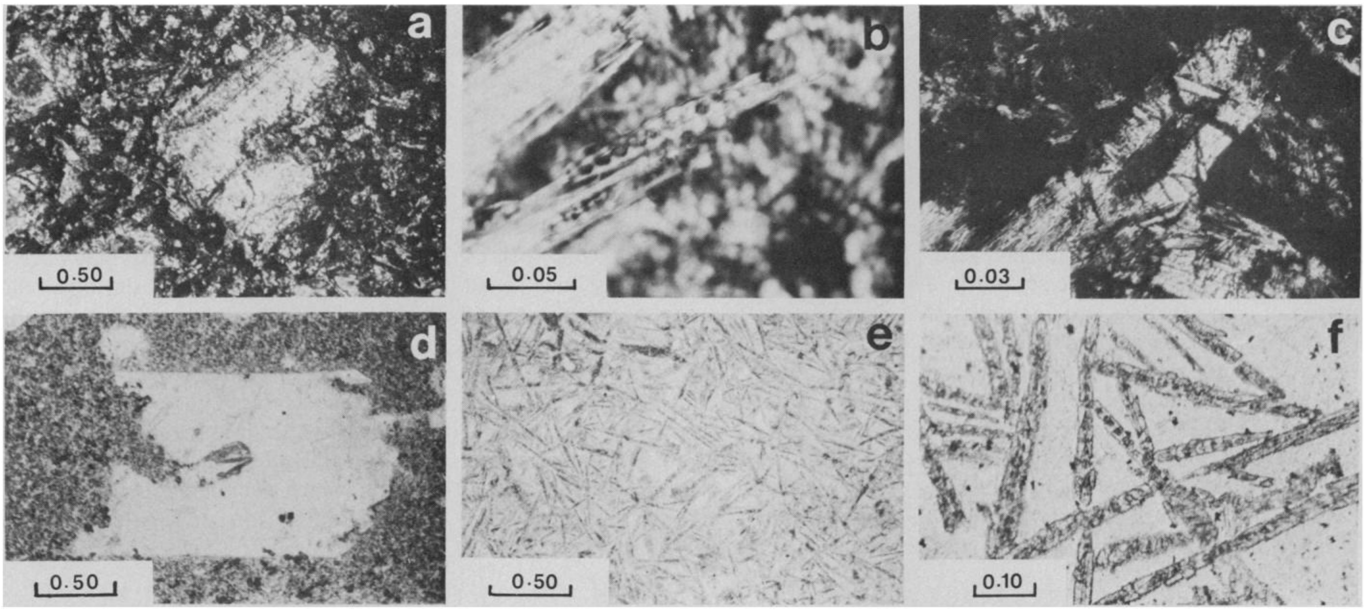

Fig. 1. Photomicrographs of Betts Cove komatiites. (a) Skeletal and embayed serpentinized phenocryst of olivine in a matrix of glass (black) and tiny crystals of clinopyroxene (sample 70S168, crossed polars). (b) Matrix clinopyroxene of sample 70S168 showing skeletal bladed form (plane light). (c) Another matrix clinopyroxene of sample 70S168 occurring in a skeletal subequant form (crossed polars). (d) Skeletal and embayed ("hopper") serpentinized olivine crystal set out in a matrix of fine-grained clinopyroxene and glass (sample 70S215, plane light). (e) Randomly oriented skeletal blades of clinopyroxene in a matrix of devitrified high-Mg glass (sample 7236, plane light). This texture is almost identical to those of samples 7255, ST10A, JL1813, and JN191. (f) Skeletal clinopyroxene blades in a magnesian pillow lava sample (analyses not presented in Table 1). Note the chain-like skeletal patterns in one crystal (center) and their obliteration due to alteration in several others (plane light). The scale bars are in millimeters.

to width although the skeletal growth patterns seem to have been obliterated in most by alteration (Fig. 1, e and f). Unlike the ultrabasic lavas of Cyprus (*19*), cumulate layers are not discernible in any of these seven komatiites from Betts Cove.

The Betts Cove samples are notably rich in MgO, Ni, and Cr and poor in TiO_2 and K_2O and meet the important chemical criteria of peridotitic or pyroxenitic komatiites, or both. Since Cr and TiO_2 remain relatively immobile during greenschist metamorphism and seawater metasomatism (*20*), it is unlikely that these two components were redistributed to any significant degree. Likewise, the MgO values of these samples should also be original since all of them show definitive ultramafic mineralogy of magmatic origin, all have high Ni and Cr contents that are compatible with their MgO values, and two of these samples come from a stratigraphic level that was probably too deep to have been penetrated by seawater. The CaO/Al_2O_3 ratio is above unity for two and only slightly less than unity for the remaining five samples from Betts Cove. In light of the similar low CaO/Al_2O_3 ratios in many komatiite samples from Ontario and Australia, it is now recognized that a CaO/Al_2O_3 ratio higher than unity can no longer be taken as a characteristic feature of this rock (*3*), since it is dependent on factors such as the depth of melting within the mantle (*21*) and the degree of metamorphism (*6*). The ratios of total FeO to total FeO + MgO for the Betts Cove samples are very low (from 0.26 to 0.36) that, if plotted against Al_2O_3, fall in the same general field as the Archean komatiites (*3*).

Most of these samples differ from Archean komatiites of similar MgO values in possessing slightly higher SiO_2 and lower total FeO. Although I do not discount metasomatism as a contributing factor, the available textural evidence on the five pillow lava samples indicates that the SiO_2 enrichment was most probably caused by the presence of primary silicic material in the matrix and inside the globules. Some of this silica, I believe, was subsequently remobilized to replace some of the olivine-clinopyroxene phenocrysts. Similar enhancement in SiO_2 contents has also been documented from the ocelli-bearing basaltic komatiites of Barberton (*22*). Studies on the Archean quench metabasalts showing replacement of olivine by quartz have indicated that the silica was derived internally from siliceous glass (*23*).

The presence of basaltic komatiite in Betts Cove (*24*) and in the Cambrian lavas of the nearby Rambler area (*25*) and this report of peridotitic-pyroxenitic komatiite suggests that this region of Newfoundland is analogous to some of the Archean terranes where such variants also occur in close association with one another. The mode of occurrence and the textures of the porphyritic dike samples 70S168 and 70S215 from Betts Cove are similar to some of the Archean komatiites, for example, porphyritic dikes in Barberton (*4*), chilled margins of sills in Ontario (*3*), and the porphyritic lavas in Rhodesia (*9*). The enormously thick sills that are capped by komatiites in certain Archean terranes (*3, 9*) are missing in Betts Cove, although almost identical relationships are exhibited on a smaller scale by very thin sills that show a gradation into pillowed komatiites toward the top. The quench skeletal blades are displayed almost exclusively by clinopyroxene in Betts Cove, which is similar to some peridotitic komatiites of Rhodesia (*9*) but in contrast to other Archean examples where such crystal forms are developed chiefly in olivine.

I have attempted to show that the Phanerozoic Betts Cove komatiites are similar to the low-Mg peridotitic and associated pyroxenitic komatiites of the Archean terranes in many respects, despite an age difference of over 2×10^9 years. The apparent confinement of this suite of rocks to the Archean has been attributed chiefly to the prevalence of steeper geotherms and a thinner lithosphere during this early part of the earth's history than in the Phanerozoic

(*10*). The heat required to generate such high-Mg melts in the Betts Cove area of Newfoundland could have been provided by an anomalously high concentration of radioactive minerals or some other viable processes operative in the mantle. The erratic occurrence of komatiites in post-Archean rocks may therefore be attributed to local irregularities (steepening) in the otherwise gently sloping smooth geotherms (*26*). These relatively young komatiites tend to diminish the supposed uniqueness of Archean magmatism.

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References and Notes

1. Komatiites are characterized (*3-5*) by the following: high MgO, Ni, and Cr and very low TiO_2 and K_2O contents; low Fe/Mg ratios; and a CaO/Al_2O_3 ratio generally above or close to unity. Occurrence in an extrusive-intrusive environment, the presence of pillow structures, polygonal jointing and brecciation near the flow tops, and, most importantly, the presence of quench ("spinifex" or skeletal) crystals are among their field and textural characteristics. Komatiites have been classified (*3, 6*) into peridotitic, pyroxenitic, and basaltic types that are identified by MgO contents in excess of 20, 12, and 9 percent, respectively; this classification and nomenclature have been adopted here.
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14. The primary silicic material in these and other pillowed samples from Betts Cove are here interpreted to have formed through liquid immiscibility. Microprobe work on the magnesian glass in the globules and the matrix reveals an average MgO content of 25 percent (30 percent in the glassy matrix of sample 70S168).
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Intracellular Calcium: Its Release from Granules During Bursting Activity in Snail Neurons

Abstract. *Pentylenetetrazole induces a bursting activity accompanied by intracellular movement of calcium toward the cell membrane in the snail neuron. The calcium appears to originate from the dense lysosome-like granules in the cytoplasm. Pentylenetetrazole markedly depletes the granules of calcium and alters them ultrastructurally from dense granules to lamella type granules.*

The D neuron in the subesophageal ganglion of the Japanese land snail, *Euhadra peliomphala*, manifests characteristic bursting activity after application of pentylenetetrazole (PTZ) (*1*). This bursting activity strongly resembles the firing pattern of neurons in the mammalian cerebral cortex during seizure discharge induced by PTZ (*2*). The calcium ion has become an important indicator of bursting activity and has been used in the interpretation of data from various electrophysiological experiments, especially voltage clamping (*3-6*). We have demonstrated that intracellular calcium, which is probably bound to a subcellular struc-

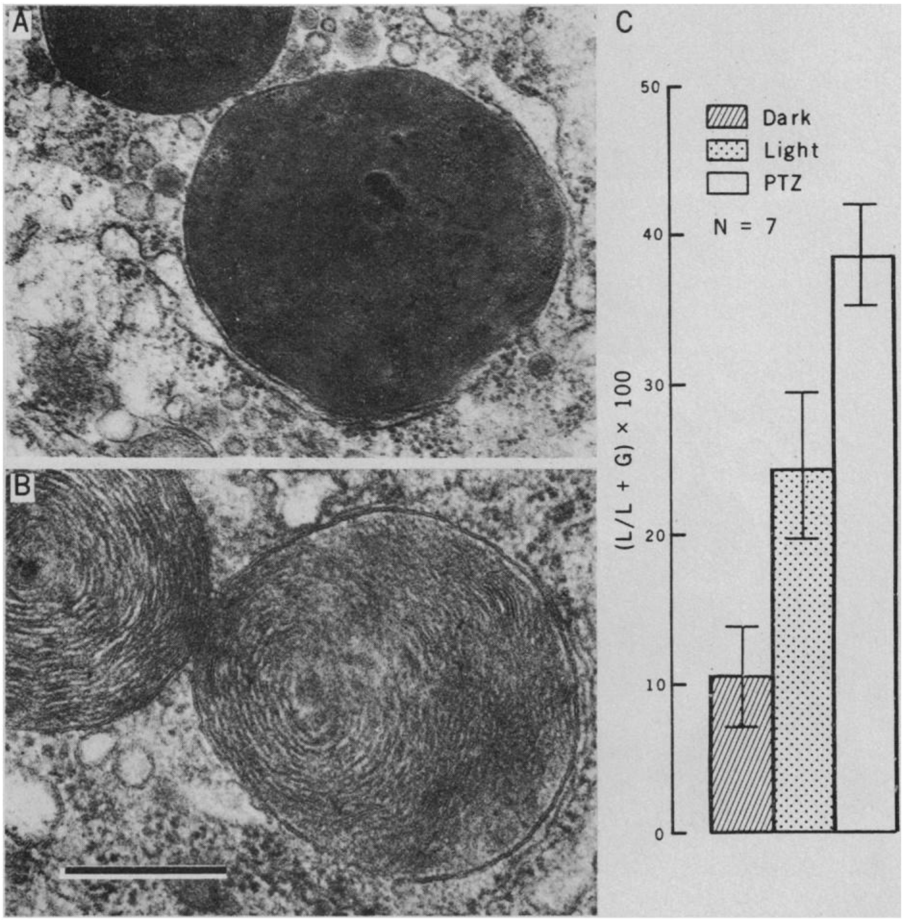

Fig. 1. Electron micrograph of intracellular granules in the snail neuron: (A) Normal neuron. (B) Neuron after 15 minutes of incubation in PTZ-containing Ringer (bar, 0.5 μm). (C) Percentage of lamella type granules (*L*) in dark normal, light normal, and dark, PTZ-incubated neurons; values are the mean ± the standard deviation of seven experiments on each type of neuron.

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