dropped by 40 m in the latest Miocene. Berggren and Haq (*38*) estimated a glacioeustatic sea-level lowering of about 70 to 100 m at approximately 5.5 million years. The shallowest water depths recorded at Blind River in the Kapitean occur at about 5.6 million years (Fig. 1). Thus, these antipodal regions record a drop in sea level of about 40 to 70 m at about 5.5 to 5.6 million years. A drop of this magnitude could have effectively isolated the Mediterranean Basin, perhaps in combination with some local tectonic activity (*38-41*). Evaporitic sequences were thus deposited during the youngest part of the Messinian stage during the well-known Messinian salinity crisis (*39*). A rise in sea level recorded in Spanish and New Zealand sequences (*11, 38*) near the Miocene-Pliocene boundary may have been responsible for the subsequent reconnection of the Mediterranean Basin with oceanic waters.

Major paleoenvironmental changes recorded in sedimentary sequences in the South Pacific during the late Miocene may have had an effect on certain events in the Mediterranean region. We support the suggestion of Adams *et al.* (*42*) that expansion of the Antarctic ice cap and related glacioeustatic sea-level changes were a major factor in the isolation of the Mediterranean Basin during the Messinian.

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Nautilus Movement and Distribution in Palau, Western Caroline Islands

Abstract. *Long-term movement of up to 150 kilometers in 332 days by tagged, living* Nautilus, *and postmortem shell drift of 1000 kilometers in 138 days, corroborate and explain the cosmopolitan distribution of many fossil shelled cephalopods.*

The well-known worldwide distribution of genera and species of fossil shelled cephalopods is relied on for precise correlation of fossiliferous marine strata. Understanding of the mechanism by which the dispersal of these organisms was achieved is minimal, largely because they are survived today by only a single genus, *Nautilus*. This relict animal is relatively rare and poorly known, and its inaccessible habitat has limited laboratory and field investigations. Re-

Table 1. *Nautilus* tagged, released, and recaught in 1977 and 1978 in Palau, Western Caroline Islands. "Distance moved" refers to minimum distance, measured roughly parallel to fringe reef. All animals tabulated were males except for Nos. 227 and 429.

Animal No.	Initial release		Recaptured		Elapsed time (days)	Distance moved (km)	Rate (km/day)
	Date	Site	Date	Site			
190	7-1-77	B	6-13-78	E	347	114	0.33
201	7-1-77	B	7-2-78	C	365	40	0.11
298	7-8-77	D	6-5-78	A	332	150	0.45
316	7-8-77	D	5-31-78	B	327	68	0.21
634	5-12-78	D	7-2-78	C	51	31	0.60
172	6-30-77	D	5-18-78	D	322	0	
198	7-1-77	B	5-26-78	B	329	0	
227	7-1-77	D	5-7-78	D	310	0	
323	7-8-77	D	6-17-78	D	344	0	
340	7-9-77	D	5-18-78	D	313	0	
005	5-27-77	D	1-20-78	D	239	0	
338	7-9-77	D	2-1-78	D	207	0	
429	7-24-77	D	2-1-78	D	192	0	

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cent discovery that *Nautilus* can be trapped, released, and recaught (*1*) establishes the feasibility of studying the animal in its natural habitat, through tag-release experiments. The results of such a study, carried out over a 14-month period in Palau, Western Caroline Islands, provide information on the distribution and long-term movement of *Nautilus* and on the postmortem drift of its buoyant shell, providing significant implications for distribution of fossil cephalopods.

During May to August 1977, 375 specimens of *Nautilus* cf. *N. pompilius* were trapped in baited, baffle-type fish traps set at a depth of approximately 90 to 215 m at two widely separated localities along the Palau fringe reef (Fig. 1, sites B and D). Each animal was measured, identified as to sex, weighed, and tagged with a numbered and addressed adhesive label (Fig. 2). These procedures (*2*) required handling each animal in air for up to 20 minutes, at temperatures often exceeding 30°C. After examination,

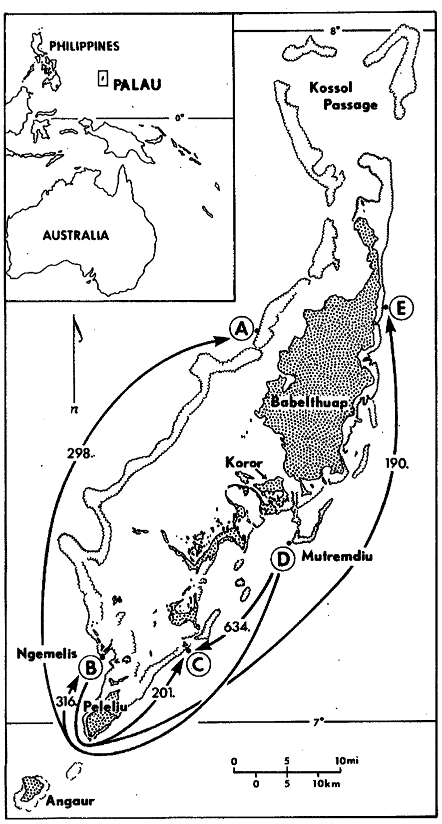

Fig. 1. Movement of tagged *Nautilus* during 1977 and 1978 along fringe reef in Palau, Western Caroline Islands. Of 247 animals tagged and released at sites B and D in May to July 1977, four were recaptured 10 to 12 months later, 40 to 150 km away (Table 1). In 1978, eight additional animals were recaptured at the same sites (B and D) where they had been released 5 to 11 months earlier. *Nautilus* lives in deeper, cooler water (> 90 m; < 24°C) peripheral to the fringe reef; warm temperatures (> 29°C) limit traverses across the shallow platform.

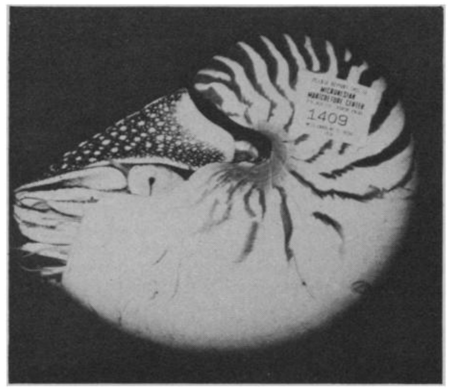

Fig. 2. Tagged and measured *Nautilus* returning to deep fore-reef habitat off Palau, Western Caroline Islands. The animal as shown is approximately one-fourth natural size.

247 tagged animals were released at the surface, near the point of capture. During the 3-month trapping period in 1977, 31 of these animals were recaptured once and three were recaught twice. At one site (Fig. 1, site D), 19 of the tagged animals had moved 1 to 2 km (the maximum distance between traps), while 11 animals were recaught at their original tagging sites within the 78-day trapping period.

During January to February 1978, 23 animals were trapped, tagged, and released (*3*) at site D (Fig. 1), including three animals that had been released at this site 6 months earlier (Table 1). In May 1978, trapping was again initiated at the 1977 sites (Fig. 1, sites B and D) and at three other, widely separated sites not trapped previously (Fig. 1, sites A, C, and E). Altogether 460 animals were trapped during the 1978 period, including nine animals that had originally been tagged in 1977. Four of these animals tagged in 1977 had moved 40 to 150 km along the Palau fringe reef in the 10- to 12-month period after their release. In contrast, three of 23 animals tagged during January and February 1978 (*3*) and five of those tagged in 1977 were recaptured at the same sites where they had been released 5 to 11 months earlier. Only eight of the 460 animals caught in 1978 were subsequently caught again during the same trapping period. However, one of these (No. 634), initially tagged 12 May 1978, at site D (Fig. 1), was recaptured 51 days later, 31 km to the south (Fig. 1, site C).

It is clear that *Nautilus* may travel for considerable distances in its natural environment; the data (Table 1) show up to 150 km of long-term movement along the reef front in 332 days, a minimum average rate of 0.45 km per day. Shorter term data (31 km in 51 days) indicate a similar rate of movement (0.60 km per day). Tagged animals moved both north and south along the fringe reef, indicating lack of current control. This record also shows that, while considerable movement is possible, *Nautilus* may remain at (or return to) a single site over an extended period of time. Furthermore, there is no correlation between sex and long-term movement; the high percentage of males recaught reflects the proportion of male *Nautilus* (approximately 75 percent) caught and tagged (*2*).

Water temperature appears to be an important limiting factor in *Nautilus* movement and distribution. In the Palau region, temperatures during May to July average 24°, 18°, and 14°C at depths of 100, 150, and 200 m, respectively (*4*). *Nautilus* was not encountered in traps set less than 90 m deep, and the majority of animals were caught at a depth of approximately 200 m (*1*). Palauan *Nautilus* placed in aquariums perished within several days in water warmer than 25°C, survived up to 10 months at 20° to 23°C and appeared to thrive at 17° to 21°C. Water on the Palau platform rarely exceeds 50 m in depth, and in most places is less than 20 m. At these depths, water temperature averages, and often exceeds, 29°C, restricting *Nautilus* to the deeper, cooler water peripheral to the Palau fringe reef, and limiting or excluding traverses into the shallow and warm platform areas.

Postmortem drift is regarded as an important factor in the distribution of *Nautilus* shells, which are positively buoyant (*5*). Our observations of moribund Palauan *Nautilus* showed that the shell separates from the body of the animal and floats within several hours after death (*1*). The shell of one tagged Palauan *Nautilus* (No. 532), released alive 27 January 1978, at site D (Fig. 1), was recovered 14

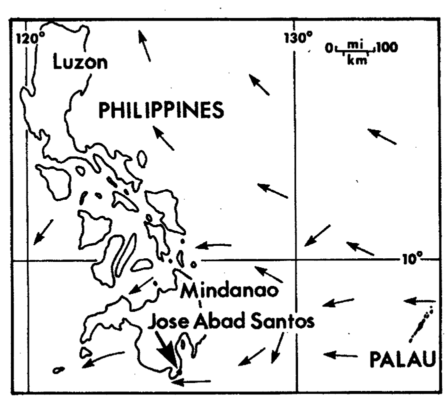

Fig. 3. The remarkably fresh, but empty shell of a *Nautilus* tagged and released alive in Palau (Fig. 1, site D) 27 January 1978 (*3*), was found 14 June 1978 at Jose Abad Santos, Mindanao. This apparent postmortem drift, approximately 1000 km in 138 days is compatible with known current directions (*6*).

June 1978, at Jose Abad Santos, Davao del Sur, Mindanao, Philippines. This occurrence, presumably the result of postmortem shell drift, is compatible with known current directions (Fig. 3) and indicates movement of more than 1000 km in a maximum of 138 days, or approximately 7 km per day.

The demonstrated ability of *Nautilus* for rapid, extended movement, combined with postmortem drift of the shell, give the animal and its remains unusual dispersal potential. This corroborates the extensive and often cosmopolitan distribution of Paleozoic and Mesozoic shelled cephalopods. However, final disposition of many *Nautilus* shells, in Palau and elsewhere, is beach stranding. This is unlike the occurrence of many of the fossil forms, particularly ammonoids, which are often preserved as complete shells in what are regarded as moderately deep open water deposits. This points to possible differences in the postmortem buoyancy of some fossil-shelled forms, or perhaps to physicochemical factors that may have inhibited postmortem decay of the body and separation of the shell.

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Allan Hills 77005: A New Meteorite Type Found in Antarctica

Abstract. *The unique achondrite ALHA 77005 appears to be related to shergottite meteorites through igneous differentiation and may have affinities with mafic rocks on the earth.*

Meteorite finds in Antarctica during the last several years have greatly increased the number of extraterrestrial samples accessible for scientific study. During the 1977–1978 field season, a joint American-Japanese Antarctic expedition recovered a large number of meteorites from the ice sheet in the vicinity of the Allan Hills, Victoria Land (*1*). One of these meteorites, designated ALHA 77005 (*2*), has proved to be a type of achondrite not previously known. Achondrites are igneous rocks, many of which have basaltic compositions, and thus their origins are understandable in terms of the processes (for example, partial melting and differentiation) which characterize the most abundant terrestrial and lunar igneous rocks. In fact, the generation of basaltic magmas appears to be one of the few characteristics shared by all of the terrestrial planets (*3*). Despite the petrogenetic similarities between achondrites and other igneous rocks, these meteorites commonly display mineralogical and chemical features unique to their respective (presumably asteroidal) parent bodies. However, one class of achondrites, the shergottites, have close similarities with basaltic rocks on the earth (*4*). The new achondrite ALHA 77005 may be related to this class of meteorites.

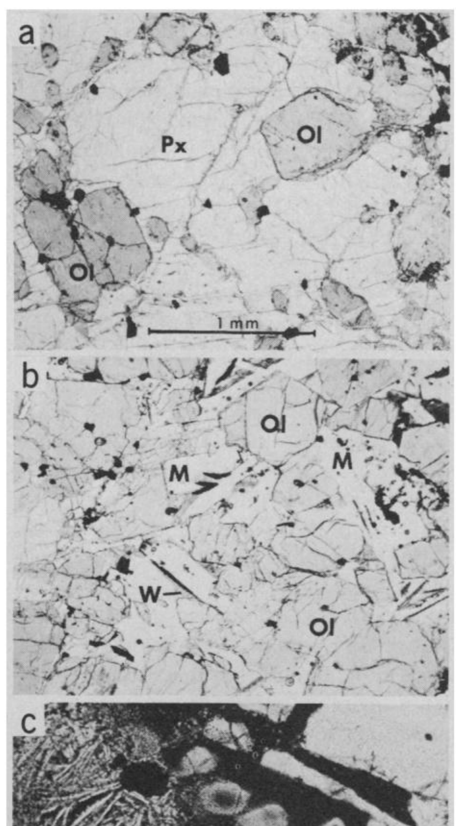

Fig. 1. Textural variations in ALHA 77005 (plane polarized light). (a) Cumulate olivine (*Ol*) and chromite (opaque) crystals poikilitically enclosed by pyroxene (*Px*) in sample 34. (b) Cumulate olivine (*Ol*) with interstitial maskelynite (*M*) and minor ilmenite (opaque) and whitlockite (*W*) in sample 31. Scale as in (a). (c) Patch of vitrophyre containing skeletal and hollow olivine crystals in dark glass.

This meteorite is a rounded stone, weighing 482.5 g, that is partially covered by dark fusion crust (*5*). It is texturally heterogeneous on a centimeter scale. In some areas of the meteorite, euhedral to subhedral olivine and chromite crystals are poikilitically enclosed by pyroxenes (Fig. 1a). The olivines are chemically homogeneous with average composition ~ Fo_{74} (74 mole percent forsterite) (Fig. 2) and have a distinctive brown color. Pyroxenes occur in both low-calcium and high-calcium varieties (Fig. 2). Some pyroxenes exhibit polysynthetic twinning, and all show undulatory extinction and deformation twinning with kink bands. Chromites enclosed by pyroxenes have rims that are slightly more aluminous than the core compositions (arrow *P* in Fig. 3). Minor troilite is associated with olivine. Other areas of the meteorite consist predominantly of subhedral olivine with interstitial maskelynite, titanium-rich chromite, ilmenite, troilite, whitlockite, and less abundant pyroxenes (Fig. 1b). The maskelynite (shocked plagioclase glass) grains are zoned with $An_{54}Ab_{45}Or_1$ (An is anorthite, Ab is albite, and Or is orthoclase) cores and $An_{54}Ab_{53}Or_2$ rims in extreme cases (Fig. 2). Small interstitial pyroxenes may subophitically enclose maskelynite laths; these interstitial grains are slightly more iron-rich than the larger pyroxene grains which enclose olivine and chromite (Fig. 2). Chromites in contact with maskelynite are zoned toward ulvöspinel compositions (arrow *M* in Fig. 3) or have reaction rims of ilmenite, or both. The ilmenite contains 5 to 6 percent MgO (by weight) with minor chromium and negligible Fe^{3+}. The meteorite is relatively

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