# 5. Shell Implosion Depth of Living *Nautilus*

by

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## Abstract

Three specimens of living *Nautilus pompilius* were pressure-tested. They imploded under the pressures approximately corresponding to the depths of 785, 827 and 830 m in seawater through the increasing pressure experiments under different compression rates. The depths mentioned above can be assigned the depth limit of this species.

Shell deformation generated on the two dead specimens of *N. pompilius* through the pressure test were measured by strain gauges. The last septum shows the greatest tensile deformation of $1432\times10^{-6}$ and the flank gives compressional deformation of 379 to $754\times10^{-6}$ at the implosion pressure of 567 m. The value of the safety factor of *N. pompilius* from Tañon Strait, the Philippines shows 1.6 and the lowest value of this factor is presumed to be 1.4. The living depth distribution of *Nautilus* species may not exceed 600 m.

## Introduction

The depth limit of *Nautilus* species can be assigned by the observation of physiological reaction of a living specimen against the increasing hydrostatic pressure in a hyperbaric chamber. The shell implosion depths of live *N. pompilius* have been known to be 785 m (KANIE *et al.*, 1980) and 827 m (KANIE *et al.*, 1981), and are considered to indicate the maximum depth of the vertical depth range in which *N. pompilius* is durable. Also this study gives similar impression value with two times of compression rate (0.1962 MPa/min).

KANIE *et al.* (1981) reported $13000\times10^{-6}$ of maximum strain-shortening when a live shell of *N. pompilius* was imploded, although the further examinations on dead shells show approximately 1/10 of tensile strain than previously obtained. These values support the measurements of SAUNDERS and WEHMAN (1977).

Based on these data, we discuss the safety factor (collapse pressure divided by designed pressure) of living *Nautilus* species.

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## Materials and Method

The specimen B-42 of *Nautilus pompilius* was trapped at the point LTR 021 on the 22 nd, September, 1981, at the depth of 135 m off Bindoy, Negros Oriental, the Philippines (HAYASAKA *et al.*, 1982), and was pressure-tested seven days later. The specimen was a female individual with a mature shell of 161.5 mm in maximum diameter being similar in size and sex to the specimens previously tested by the writers. The specimen was kept in 23 cm deep seawater tank of acrylic resin, thereafter it was placed in an "animal chamber" of the Japan Marine Science and Technology Center (JAMSTEC). The compression rate of ambient air was 0.1962 MPa per minute, which corresponds to the depth of 19.6 m in seawater.

The dead shells for strain-stress studies are as follows : specimen A, diameter 170 mm, Loc. Panglao, Bohol, the Philippines ; specimen B, diameter 70 mm, Loc. uncertain, the Philippines. The strain gauges (Kyowa Dengyo, KFC-5-C1-11) protected from water ; Chs 1-4 (Plates 1 & 2) were attached to the outer shells : Ch 4 to the last septum, Ch 3, Ch 2 and Ch 1 to the flanks of the phragmocones, Ch 0 to the living chambers for references. The specimens were placed in fresh water in a high pressure-test tank (diameter 45 cm, height 70 cm) of the JAMSTEC. The compression rate in fresh water was 0.6 MPa per minute, which corresponds to 58 m in depth of seawater. The strain was recorded by the pen-recorders of 6 channels (Yokogawa, type 2924).

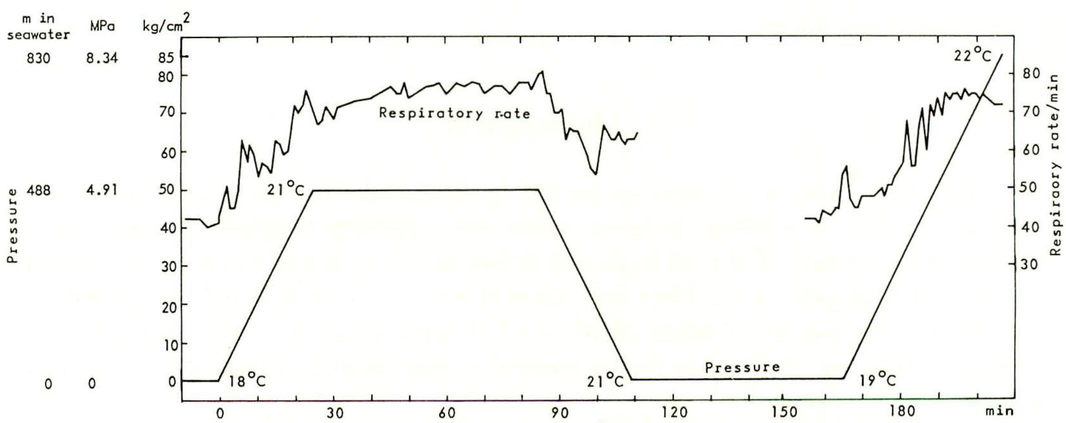


Fig. 1. Relationship between respiratory rate of *Nautilus pompilius* and ambient hydrostatic pressure. 18, 19, 21 and 22°C are seawater tempetature.

## Test Results and Discussion

The living specimen of *Nautilus pompilius* withstood a hydrostatic pressure up to 8.34 MPa corresponding to the seawater depth of 830 m, then it was killed by implosion of the phragmocone shell. The respiratory rate was greatly fluctuated between 55 and 76 (Fig. 1) in this compression rate (0.1962 MPa/min.).

The dead shells of *N. pompilius* imploded at 614 m and 567 m. In the specimen

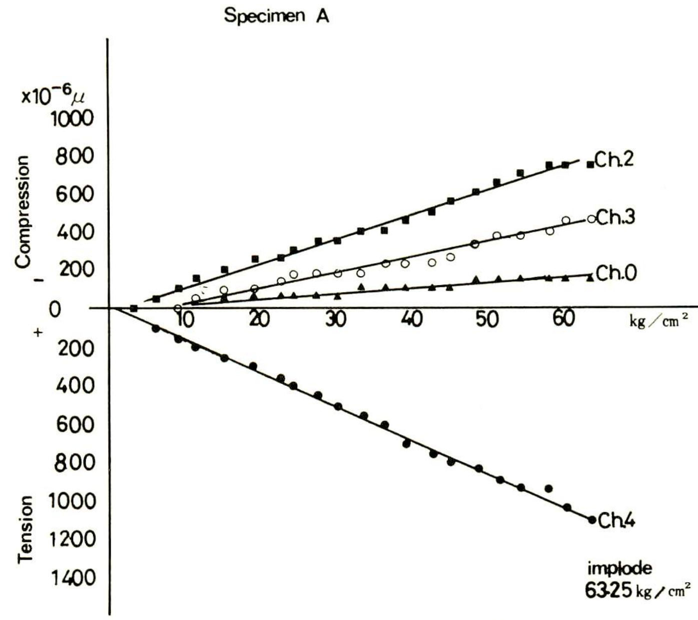


Fig. 2. Relationship between pressure and strain of specimen A.

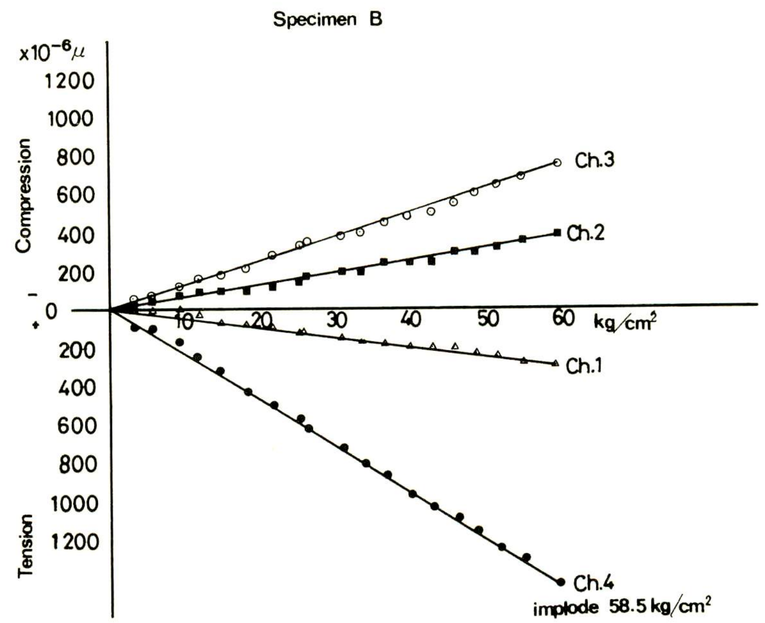


Fig. 3. Relationship between pressure and strain of specimen B.

A, Ch 4 (last septum) recorded +1089.0 micro (tensile) strain and Chs 2 and 3 at the flank recorded −750.0 and −450.5 micro (compression) strain, respectively (Fig. 2). Ch 4 of the specimen B gives +1432.1 micro (tensile) strain, and Chs 2 and 3 at the flank recorded −750.0 and −450.5 micro (compression) strain, respectively (Fig. 2). Ch 4 of the specimen B gives +1432.1 micro (tensile) strain, and Chs 2 and 3 give −378.8 and −753.8 micro (compressed) strains, respectively (Fig. 3).

Table 1. Imploded depth of living and dead specimens of *Nautilus pompilius*.

| Shell diameter (mm) | Shell implosion depth (MPa) | (kg/cm$^2$) | (m in seawater) | Shell maximum strain (×10$^{-6}$) | Compression rate (MPa/min) | References |
|---|---|---|---|---|---|---|
| 167.5♀(Live) | 7.89 | 80.5 | 785 | – | 0.0981 | KANIE *et al.*, 1980 |
| 165.5♀(Live) | 8.31 | 84.7 | 827 | −13000 | 0.0981 | KANIE, HATTORI *et al.*, 1981 |
| 161.5♀(Live) | 8.34 | 85.0 | 830 | – | 0.1962 | This report |
| 170 ?(Dead) | 6.20 | 63.25 | 614 | +1089 | 0.5886 | This report |
| 110 ?(Dead) | 5.74 | 58.5 | 567 | +1432 | 0.5886 | This report |

The implosion tests of living *Nautilus* gave the depth of about 800 m (785 to 830 m, Table 1) by the different compression rates (9.8 m to 19.6 m/min.). However, the dead shells imploded at the seawater depth less than 614 m, probably due to the weakening of the shells after death. The strain field resulted from this study is similar to the one reported by SAUNDERS and WEHMAN (1977). Namely, the tensile deformation was greater at the last septum, and the compressed deformation was observed at the flank.

Consequently, the shell implosion under pressure seems to have occurred at the surroundings of the last septum of the phragmocone. The determination of depth limits for living and fossil shelled cephalopods should be based on the precise calculations on shell morphology and thickness of the last septum.

## Safety Factor of Living *Nautilus* Shells

In the field of marine engineering, pressure case or pressure hull are usually used for protecting electronics or human body from ambient high pressure of the seawater. The safety factor (collapse pressure divided by designed pressure) is usually 1.5 to 1.65 and the value covers some inhomogenuity or flaw of pressure case. It means that if there are some flaw in the material or some incorrectness in the shape of machined pressure case, the pressure case could withstand designed pressure with high probability.

According to DENTON (1973), the safety factor of dead *Nautilus* is between 1.3 to 1.4 and 1.25 to 1.33 by WARD *et al.* (1980). The values seems to be rather low compared to the value of artificial pressure case. Several authors reported that captured depths of *Nautilus* were ranging from 40 to 650 meters and imploded depths of living *Nautilus* were 800 to 850 meters. Those values are shown in Table 2.

The safety factors were calculated from Table 2. *Nautilus pompilius* from Fiji showed 1. 2 and *Nautilus macromphalus* from New Caledonia showed 1. 3 (?).

The *Nautilus* from the above-mentioned localities were collected at open ocean and descriptions of captured depth and imploded depth were somewhat ambiguous.

The deepest *Nautilus pompilius* captured at Tañon Strait is said to be from 525 m (KANIE *et al.*, 1981), but the depth of the same locality is 495 meters by echo sounder, therefore we used a deepest living depth of 500 meter at the Tañon Strait.

According to the hydrographic chart No. 1612, the deepest part of Tañon Strait is 555 meters in depth. If this value is correct and if *Nautilus* is now living in the

Table 2. Captured and imploded depth of living *Nautilus*

| References | Locality | Species | Captured depth meters | Imploded depth meters |
|---|---|---|---|---|
| Challenger Note in DENTON & GILPIN-BROWN 1966 | | *N. pompilius* | 100–540 | |
| WARD *et al.* 1977 | Fiji | *N. pompilius* | 100–550 | |
| HAMADA & MIKAMI 1977 | New Caledonia | *N. macromphalus* | 40–350 | |
| WARD & MARTIN 1979 | Fiji | *N. pompilius*<br>*N. macromphalus* | 60–650<br>more than 300 | |
| KANIE, HAYASAKA & SAISHO 1981 | Tanon Strait | *N. pompilius* | 495 | |
| HAYASAKA & SHINOMIYA 1982 | Fiji | *N. pompilius* | 366–549 | |
| WARD *et al.* 1980 | New Caledonia | *N. macromphalus* | 600? | 800, 850 |
| WESTERMANN & WARD 1980 | Fiji | *N. pompilius* | | 800 (750–900) |

deepest part of the strait, the safety factors are 1.4 to 1.5.

If the depth of echo sounder is used, safety factor is about 1.6 (1.57 to 1.65, values of Table 1 were divided by 500).

It is concluded that the safety factor of living *Nautilus pompilius* is 1.6 in the case of closed basin such as Tañon Strait. If the safety factor of *Nautilus* which lives in the open ocean is slightly lower than that of Tañon Strait, and the safety factor is presumed to be 1.4, the living depth of *Nautilus* may not exceed 600 meter.

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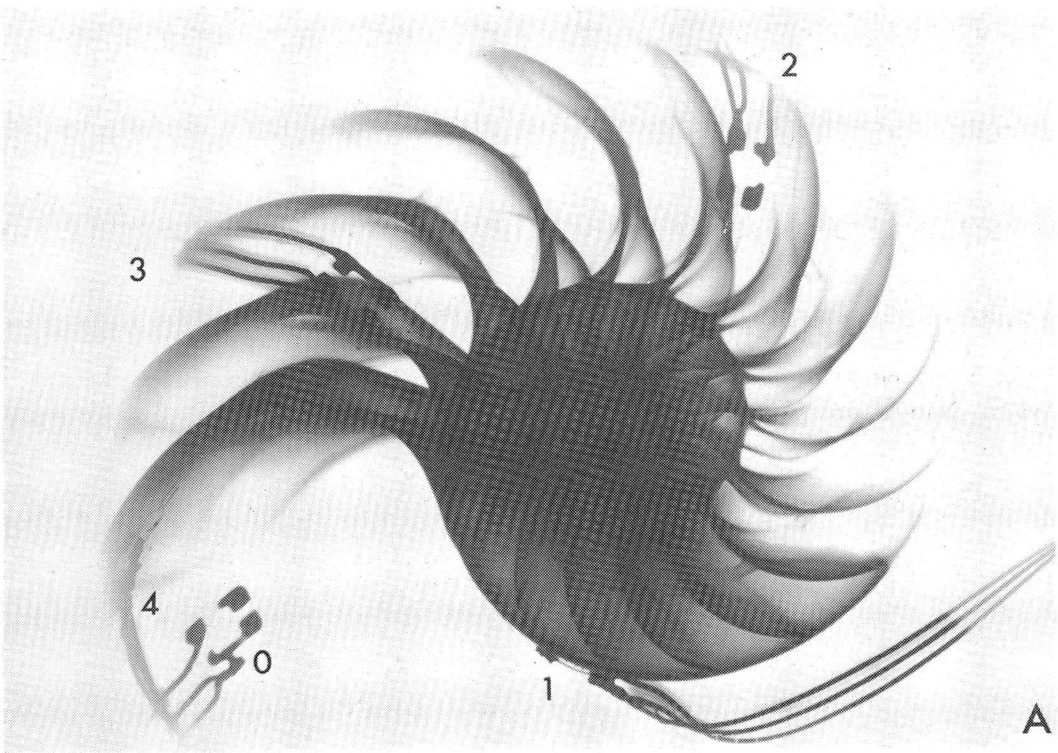
Plates 1-2

## Explanation of Plate 1

Soft X-ray photos of *Nautilus pompilius* specimen A for strain-stress studies. 0, 1, ....4: strain gauges. Lateral (A) and ventral (B) views. Natural size.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3
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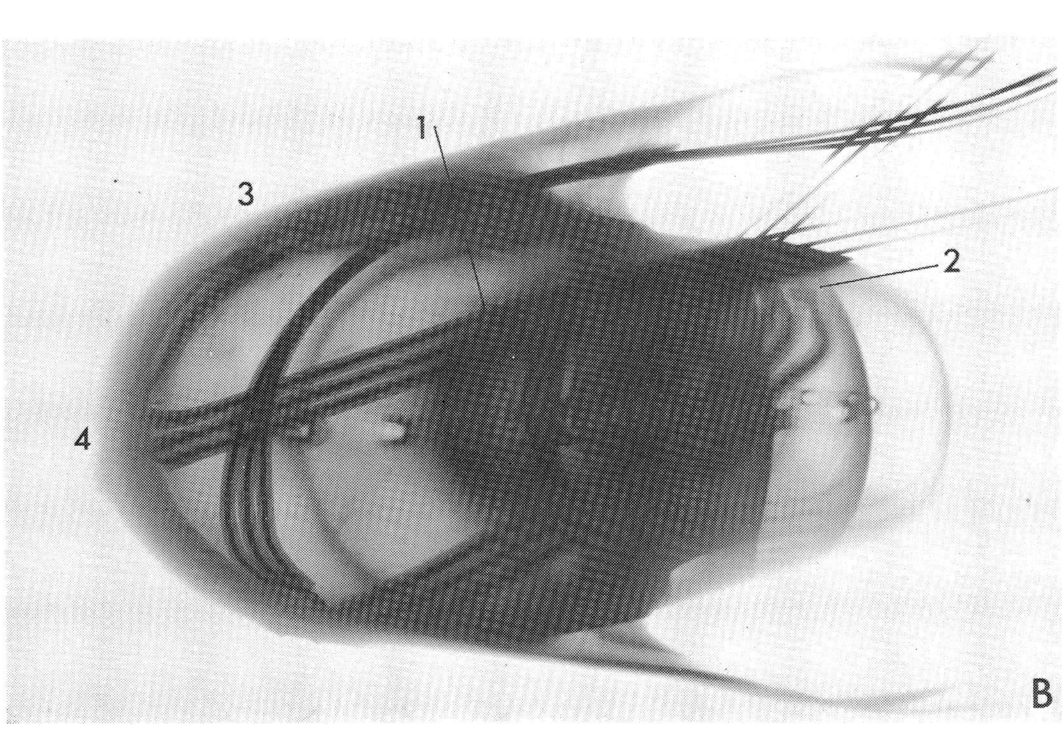
1
3
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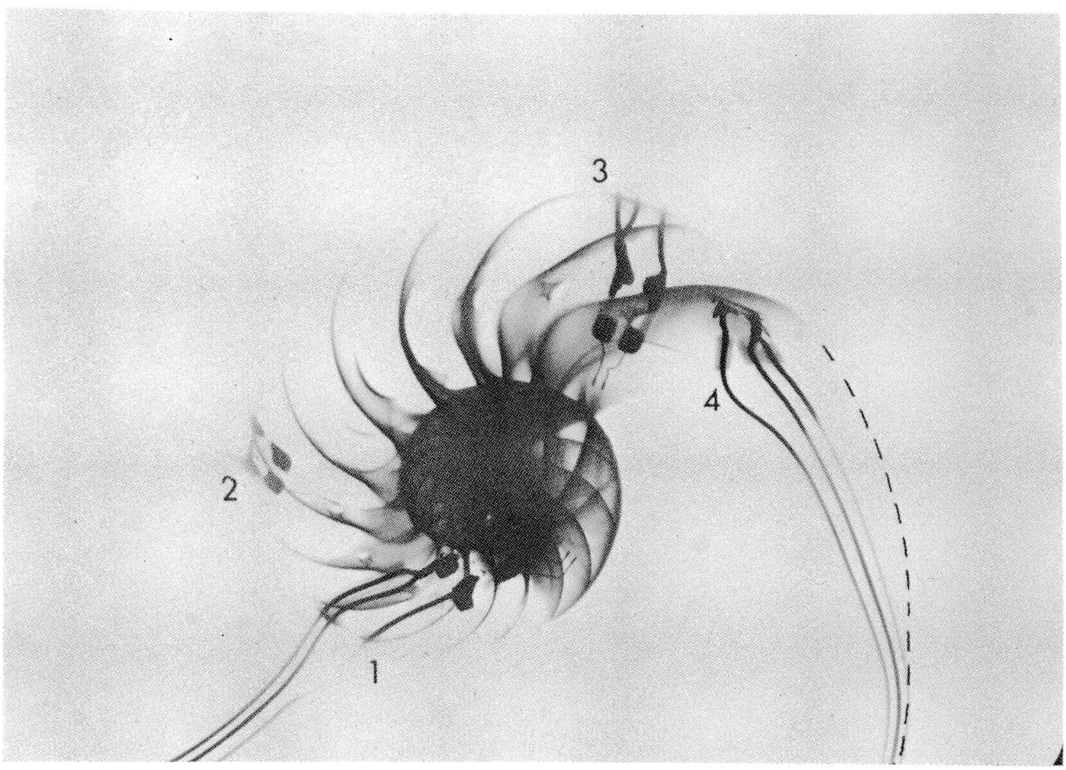
B

## Explanation of Plate 2

Soft X-ray photo of *Nautilus pompilius* specimen B. 1, 2, ....4 : strain gauges. Lateral view. Natural size.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