an angular distribution of crystallites of at least 5°. When mounted dry, the crystals appear to bend and this may contribute to the high degree of mosaicity.

The air-dried crystals of 1-γ-mercaptobutyric acid–oxytocin examined gave rather poor diffraction patterns. The reflections observed (*0kl*, *h0l*, *hk0*, *hk1*) are compatible with the space group *C2*. Because of the poverty of the diffraction pattern, marked pseudo face-centering with a space group $P2_1$ cannot be eliminated. The crystals have a density of 1.319 g/ml which leads to an asymmetric unit weight of 1062 ± 30. This corresponds to one molecule of 1-γ-mercaptobutyric acid–oxytocin ($C_{44}N_{11}O_{12}H_{67}S_2$, molecular weight: 1005) and 3 ± 2 molecules of water.

The remarkable similarity, not only in the cell dimensions but also in the intensity distribution in the principal planes, between the wet and dry forms of deamino-oxytocin (1-β-mercaptopropionic acid–oxytocin) and that of 1-γ-mercaptobutyric acid–oxytocin suggests that the insertion of a methylene unit into the ring structure may not grossly affect the overall molecular conformation.

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27 December 1965

Maximum Diving Capacities of the Weddell Seal, Leptonychotes weddelli

Abstract. *The probable maximum diving capacities of the Weddell seal were ascertained from observation of 959 dives and measurement of the depths of 381 dives. The deepest dive was 600 meters; the longest submergence was 43 minutes 20 seconds.*

Most information that biologists have obtained about marine mammals deals with their breeding behavior while on land or their habits while held captive in aquaria. The behavior of these mammals at sea—the depth of their dives, the duration of their submersion, and their feeding habits—has usually been observed fortuitously; measurement has been indirect and the samples small. For example, Collett reports a young gray seal being caught on hook and line at 146 m (*1*). There are similar reports for the harp seal at 275 m (*2*), the Alaskan fur seal and the Steller sea lion at 55 m and 183 m, respectively (*3*), and the northern elephant seal at 183 m (*4*). The only reports of experimental studies where seals had depth recorders attached are of a bladdernose seal pup which dove to 75 m (*5*) and of a Weddell seal which dove to 350 m (*6*). Field observations of lengthy submersions are scarce; they include reports of a 21-minute dive for the ringed seal (*7*) and a 16.5-minute dive for the Weddell seal (*8*). In the laboratory the bladdernose seal has endured forced submersion for 18 minutes, the gray seal for 18 minutes (*5*), and the harbor seal for 23 minutes (*9*), and none with ill effects. In comparison to whales these reported capabilities of seals seem rather modest. A sperm whale became entangled in a deep-sea cable at a depth of 1134 m (*10*), and bottle-nosed whales have been observed to remain submerged for 2 hours after harpooning (*11*).

During the austral summers of 1963–64 and 1964–65, we conducted a 2-year experimental investigation of the diving capacities and the behavior of the Weddell seal, *Leptonychotes weddelli*. The study area was near the U.S. Antarctic base at McMurdo Sound, which was particularly suitable for several reasons. Many seals are there during the summer months, they spend a great portion of their time diving under sea-ice which remains in good condition until late summer, a biological laboratory is established at the base, and U.S. Navy logistic support is readily available.

Four different types of instruments were used to monitor the seals' diving activities because each has certain advantages and disadvantages: (i) A Tsurumi-Seikikosaku (TSK) depth recorder, similar to the type used by DeVries and Wohlschlag (*6*), measures only the maximum depth of a dive. (ii) An ultrasonic (50-kcy/sec) depth transmitter indicates actual depth at any moment by a frequency transposed in the receiver into audible range by a reference oscillator and balanced modulator. This audible signal, in which frequency is proportional to the depth of the transmitter, was recorded on tape. The main disadvantages of this instrument are that it has a limited range for signal reception and that some of the seals seemed to be disturbed by the transmitter output signal. (iii) A manometer tube which records maximum depth only. (iv) A depth-time recorder which records depth against time on a smoked glass disc. The last two instruments are described in detail elsewhere (*12*). In addition to these recording devices, an under-ice observation chamber was used to observe the seals' behavior in some of the experiments during the second season of investigation.

The experiments were conducted at stations located on sea-ice in an area free from cracks and holes for a radius of approximately one mile and over water about 600 m in depth. Each station consisted of a heated hut placed over a hole cut in the ice, which was about 6 feet thick. For each experiment an adult seal was captured several miles away and brought to the station, where an instrument packet was attached to it. The animal was then released through the ice hole. When the seal returned to the hole for air, the instrument packet was removed and the data recorded. This experimental approach to obtaining information on the seals' maximum diving capacity had several advantages over that of observing the seals in their usual diving holes: (i) The seal was forced to return repeatedly to one particular breathing hole over several hours and, consequently, fewer instruments were lost during the measure-

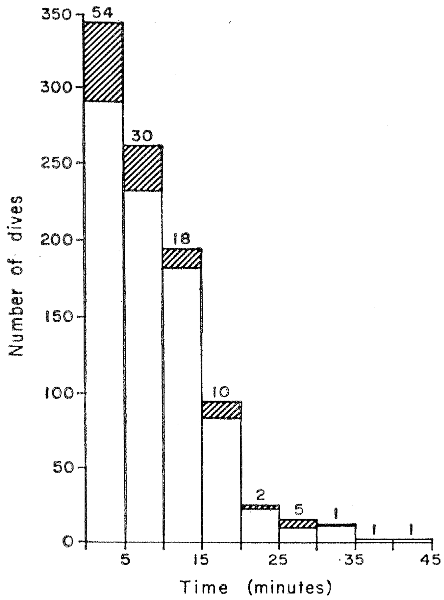

Fig. 1. Submersion time summary. The numbers above each column and the cross-hatchings indicate the number of dives observed with depth-time recorders attached to the seals. The total number of dives observed was 959, which represents the efforts of 31 adult and subadult seals.

ment of a large number of dives. (ii) The isolated nature of the diving stations often required the seals to make unusual diving efforts when seeking other breathing holes. (iii) The depth of the water in which the seals were diving could be controlled somewhat by shifting the station to an area over the desired depth.

When the seal was released at the diving station, its first dives were brief and shallow, but the later dives became long and deep. Some of the seals found other breathing holes after a few hours and never returned, but usually, even after finding another hole, they continued to return to the station for several days and use it for making dives in search of fish. One old bull, No. 377, was still at the station 4 weeks after he was brought there and after ice conditions had forced us to move our hut out of the area.

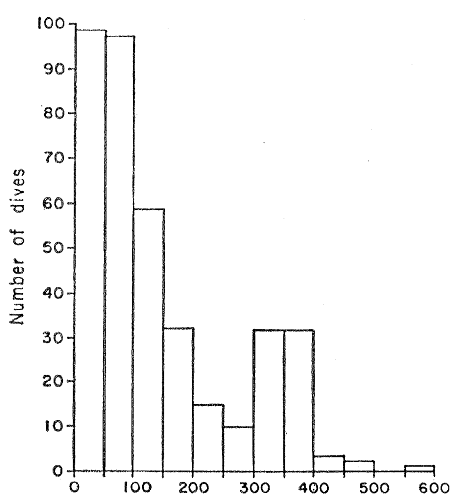

Fig. 2. Maximum diving depth summary. The total number of dives measured for 27 adult and subadult seals was 381.

The dives observed most frequently lasted from 0 to 5 minutes and were shallow dives near the hole (Fig. 1). Submersion times lasting from 6 to 15 minutes were usually correlated with dives in excess of 100 m and often greater than 300 m. The dives that lasted over 20 minutes seemed to be exploratory; the seals were probably searching for other breathing holes. The longest dive recorded was timed with a stopwatch; it lasted 43 minutes 20 seconds. This dive was made by an adult female carrying a depth-time recorder which stopped running after 33 minutes; however, the behavior of the seal, conditions of the experiment, and characteristics of the first 33 minutes of the dive leave no doubt that this was a single, uninterrupted dive.

The total number of diving depths recorded and their frequency within each grouping of 50-meter intervals are illustrated in Fig. 2. No attempt was made to measure the depth of all the shallow dives. The results illustrated in Fig. 2 show that Weddell seals make many dives to mid-water depths (300 to 400 m), but rarely dive deeper than 400 m. The deepest dive recorded in this investigation was made by an old bull, No. 377, carrying a TSK depth recorder. The instrument's calibrated range of 0 to 500 m was exceeded by many meters, but without damage to the instrument. A measured test drop using a TSK meter wheel was made with the same instrument in order to match the trace of the seal's dive, and the matching depth was found to be 600 m.

Any speculation on how marine mammals perform certain tasks requires some information about their maximum capabilities. Without a large number of observations, very little can be said about the maximum diving capacities or the significance of these diving capabilities in any particular marine mammal. Prior to this study, the only observation with a relatively large sample was that of DeVries and Wohlschlag (*6*). Although they have indicated little about the conditions under which the seals were diving, their deepest measured dive of 350 m corresponds in depth to the largest group of deep dives in this study (Fig. 2). In another report Littlepage (*8*), after observing one seal during 43 dives, suggested that the maximum duration of a dive for the Weddell seal is 16.5 minutes. The results shown in Fig. 1 clearly indicate that the Weddell seal frequently makes longer dives. Judging from the data in Figs. 1 and 2 showing the relative infrequency of dives deeper than 400 m and longer than 40 minutes, I suggest that the maximum measured diving depth of 600 m and submersion time of 43 minutes 20 seconds must be near the limits for the Weddell seal.

These findings raise the questions of how marine mammals endure such prolonged asphyxia and of what happens to the free air in their lungs, upper air passages, and intestine under such great pressures. Extensive experimental evidence is available to show how diving mammals respond to asphyxia. The explanation, however, of the ability of diving mammals to cope with great hydrostatic pressures, has been mainly in theoretical discussions (*5*, *13*); the experimental evidence is still to be advanced.

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