REMARKS CONCERNING THE PRESENT STATE OF THE DEEP SCATTERING LAYER PROBLEM

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Since 1942 numerous observations have shown that a layer exists in the oceans at a depth of 300-400 meters that scatters sonic and ultra-sonic sounds (1). This layer, called the « Deep Scattering Layer » (DSL), rises to the surface at sundown and sinks down again at sunrise.

So far it has not been possible to allege any physical discontinuity at present known in navigational circles as an explanation of the phenomenon. On the other hand, as numerous marine organisms show vertical variations of immersion in connection with light, most authorities agree that this scattering layer must be formed by concentrated groups of living organisms (Johnson, Lyman, Moore, Dietz, Boden, Tucker, Marshall).

In previous articles (Tchernia - a, b, c) we analyzed works on the subject that had appeared up to 1949, described our own observations in detail, and made certain reservations as to the hypothesis of the biological nature of the phenomenon.

Although we have not been able to undertake new observations since 1950 for financial reasons, American and British works that have appeared since 1949 have prompted us to reconsider certain aspects of the problem.

1. *A Few Criticisms of the Methods used in observing the Phenomenon.*

It should first be emphasized that the scattering layer is only known to us indirectly, through its effects on the transmission of *certain* sonic and ultra-sonic devices used as sounders.

The characteristics at present described are thus largely related to those of the instruments used.

This aspect does not seem so far to have sufficiently compelled the attention of some biologists, who in reporting their observations, not only do not discuss the physical conditions, but do not even supply the characteristics of the instruments used.

We pointed out previously (Tchernia - b) that all observations unquestionably referring to the DSL were carried out with special ultra-sonic devices with continuous long-wave transmission (1/20th to 1/10th of a second).

(1) According to information received verbally from Dr. Carruthers, the British Admiralty knew of the existence of the phenomenon prior to 1940, but the first scientific articles on the subject, so far as we are aware, are those of G.E. Duvall and R.J. Christensen (1946) and C.F. Eyring, R.J. Christensen and R.W. Raitt (1948) appearing in the Journal of the Acoustical Society of America.

Ordinary marine sounders are usually instruments with damped short-wave transmission (1/1 000th of a second). They do not enable observation of the phenomenon, although a number of them give excellent results on dense concentrations of plankton or fish encountered in shallow coastal waters.

We have also previously pointed out (Tchernia - c) that the intensity of the echo received definitely increased when changing from « short » (1/30th of a second) to « long » (1/10th of a second) transmission on our WEA. 1 U.S. Navy transmitter. This fact is in agreement with the theoretical considerations relating to the general phenomenon of what British authorities term « reverberation », and has been subjected to accurate measurement by Eyring *et al.*

According to information supplied verbally by F. Koczy, the DSL was occasionally observed from the *Albatross* during Professor Petterson's recent expedition, although the ship was equipped with a damped short wave sounding machine ; the latter was, however, specially built in Britain for the investigation of lower oceanic depths, and had a much higher transmitting power than ordinary marine sounders.

The acoustical phenomenon revealing the existence of a DSL therefore complies with one of the laws governing the phenomenon of reverberation : a law indicating that the intensity of scatter is in direct ratio to the sonic intensity at the source and to the length of the transmitted pulses.

It appears possible to deduce already from F. Koczy's observations and our own that the scattering power of the DSL is relatively small, and that for detection purposes the phenomenon requires the application of a relatively large amount of acoustic energy.

Although long waves facilitate detection of the phenomenon, they have the disadvantage of making observation impossible between the surface and an approximate depth of 100 meters, the depth varying according to certain instrumental characteristics and particularly with regard to the length of the transmitted pulse. This of course is detrimental to the investigation of a phenomenon apparently having one of its characteristic positions near the surface.

Moreover, these long, low-frequency impulses supply less clear-cut, less detailed and less accurate records than the short high-frequency impulses of ordinary sounders.

The fact should therefore be recognized that most of the observations with regard to the phenomenon (particularly those of Dietz, Moore, Boden and Tchernia, carried out with NMC echo sounders or WEA. 1 Sonar apparatus) are in some respects crude and grossly inaccurate. The characteristics that were thought to lend themselves to deduction are approximate if not erroneous.

It seems more necessary than ever, in order to remedy the state of confusion so far occasioned by observation of the DSL, to undertake a new physical analysis of the phenomenon by more appropriate methods, using the results already obtained by Eyring *et al.*, R. W. Raitt, Hersey *et al.*, and the suggestions made by us following our own observations (Tchernia - c, p. 56).

2. *Observational Facts*

In spite of the inadequate technical means at present utilized, a number of facts appear to emerge from the published work of the various observers.

(1) The existence of a deep layer scattering sonic and ultra-sonic waves is a universally recognized phenomenon in all ocean areas, as far as and inclusive of the Antarctic region (Tchernia - c, *versus* Dietz).

(2) This layer is located during daylight (1) at a mean depth usually found between 300 and 400 meters. Extreme observations occur between 180 and 900 meters. This latter figure is only reached when several (two or three) deep-sea layers are observed.

(3) The layer rises to the surface at sunset, descends again at sunrise, and remains at an approximately even depth during daylight.

Layers have been observed at a constant depth sporadically at night (Dietz, Tchernia).

(4) The speed of vertical variations of immersion is on the order of 1 to 6 meters per minute. The layer sinks faster than it rises (Moore, Tchernia, Ritchie *versus* Dietz).

(5) During daylight the layer is absolutely continuous and appreciably horizontal. Its thickness is on the order of 100 meters. Its density as estimated by its scattering power is variable. It is never, however, impervious to ultra-sonic waves and does not prevent detection of the ocean-bed.

(6) Variations in sea depth seem to have no effect on the DSL. Observable characteristics of the phenomenon remain identical when the bottom rises say from 3 000 meters to 1 000 meters.

If the bottom rises to the approximate level of the DSL, the latter disappears completely and reappears as soon as the bottom sinks to a minimum depth of approximately 500 meters (1).

(7) As it was possible to foresee in the case of a phenomenon existing in all the oceans, at an average given depth of immersion, conditions regarding temperature, salinity, oxygen and mineral salt content are extremely variable at the DSL level.

We personally have observed temperatures varying between — 1.3° (Antarctic) and + 21.6° (Red Sea), salinities between 34.37 gr. 0/00 and 40.61 gr. 0/00, and σ_t between 25.21 and 28.60.

(8) Observations carried out by us on hydrological stations have never revealed, at the DSL level, any discontinuity of temperature or salinity that might account for such an echo phenomenon.

(9) The appearance of the records taken by us as well as the oscillograms of Raitt, Hersey and Moore show that it must not be a reflecting surface that is involved but an area containing heterogeneous elements in so far as their scattering power is concerned.

To these arguments, on which the authorities seem to agree, we may add various data that are more open to question or less generally recognized.

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(1) Daylight being defined as the period between 1 hour after astronomical sunrise and 1 hour before sunset.

(1) This limit probably varies in accordance with certain characteristics of the ultra-sonic transmitters used.

(10) The DSL shows no seasonal variations (H. B. Moore).

(11) If the DSL is universal, its twenty-four hour variations of immersion are not. Personally we have never observed them between the subtropical convergence and the Antarctic continent (Tchernia - c).

This is important when we consider that the twenty-four hour variation is the most important argument in favour of the biological nature of the phenomenon.

(12) Very important observations by J. B. Hersey, H.R. Johnson and L.C. Davis (1952) show that at a given place and time, the oscillographic analysis of echoes on frequencies between 2 and 19 kc. reveals concentrated groups of scattering elements at various levels supplying echoes with different characteristics.

3. *Discussion*

We believe that it is extremely difficult at the present time to assemble all these data into a coherent whole from which a rational conclusion may be drawn.

Attempts have been made in the United States at cost of considerable effort to prove the biological theory directly, by comparing the qualitative and quantitative results obtained from samples taken simultaneously from the DSL and layers above and below it.

The uncertainty now prevailing as to the method of operation and efficiency of nets at greater depths leads to unreliable correlation of the results of a haul and ultra-sonic records obtained simultaneously, in spite of the care taken in controlling net operation (see Boden-Tucker).

Although numerous observations have seemed statistically to show that the area where the DSL was observed was more abundantly provided with planktonic organisms than areas above or below it, other observations show the correlation to be doubtful or non-existent.

In the most favourable cases the estimated degree of concentration from the haul seems to be very small (one organism or even less per cubic meter), and the question arises as to whether such a concentration can be considered sufficient to account for the echoes observed. In the absence of accurate measurements of the scattering power of the DSL on the one hand and of definite concentrations of planktonic organisms on the other, the question seems impossible of answer at the present time.

The only indication we have on the subject, due to P. F. Smith, is reported in the recent work of Hersey *et al.* (1952). Operating on shrimp (Palaemonetes vulgaris) from 2.5 to 3.5 cm. long, this author appears to have observed that a concentration of 25 shrimp per cubic meter is sufficient to account for echoes comparable to those observed in 1942 by Eyring *et al.*

As regards the qualitative aspect, the work of Moore and Boden has led these authorities to the assumption that crustacea of the Euphausiid family found at DSL level best fulfil the terms of the problem owing to their measurement and acoustical characteristics, and biological behaviour in relation to light.

Moore, particularly in a very important paper (1950), has exhaustively dealt with the physical and, above all, biological arguments that led him to this conclusion.

Tucker, on the other hand (1951), according to data obtained in the same areas (Northeast Pacific) and by the same methods as Boden's, recognizes the

possible rôle of Euphausids in the upper levels of the DSL, but attributes an essential rôle to small bathypelagic fishes of the Myctophidae family. As numerous species of this family are equipped with swimming bladders, individuals of the species, owing to the existence of this air badder, might possess acoustical properties, in spite of the sparse degree of concentration observed by capture (0.034 per cubic meter), capable of accounting for the echoes.

A British zoologist of the British Museum who specializes in bathypelagic fish, N. B. Marshall (1951), published at about the same time as Tucker an interesting article on the possibility of taking the presence of these fish as the cause for echoes observed at DSL level. He adds a certain number of other families (Gonostomatidae, Sternoptychidae, Astronestidae) to the Myctophidae mentioned by Tucker. By comparing observations published on the distribution and behaviour on the DSL and of these fish, Marshall makes several interesting analogies. Moreover, the existence of an air bladder in a large number of the species considered, which can be regarded as an important characteristic from an acoustical point of view, increases the possibility of a cause and effect relationship between the DSL and bathypelagic fish. It appears, however, that one of Marshall's main arguments is based on the fact that these fish, although abundant and present in large numbers in all the oceans, are rare in the Antarctic. But if the DSL was irregularly observed by Dietz in this ocean area, we observed it in 1949 as far as 62° S., and in 1950 at the continent's edge.

The absence of a DSL in the Antarctic is therefore an argument that has been refuted by our observations in 1950, of which Marshall had no knowledge.

The difference that can be noted between our 1949 and 1950 observations is probably due to the fact that in 1949 we were unable to go beyond the pack belt and that observations are difficult in ice for a great many reasons. In 1950 we did go beyond the pack ice and navigated in the open waters on the other side, when we observed the DSL approximately as far as 66° S. (See Tchernia - c, page 54).

It is nonetheless true that, added to Tucker's observations, Marshall's interesting paper confirms that the part played by bathypelagic fish must be included among plausible biological theories.

We have previously pointed out (Tchernia - a) that, basing their argument on principle, Chapman and Lyman had individually suggested the possible rôle of certain pelagic fishes and squid.

It can be seen that even the most convinced upholders of the biological theory are far from being in agreement.

It furthermore seems to us that if this theory were to be accepted, it would be logical to assume that in view of the permanent and universal aspect of the phenomenon, the formation of this scattering layer should not be attributed to such and such a species, order, class or even branch of marine organisms, but to concentrations whose acoustically active elements might differ from the zoölogical aspect according to the ocean area, and perhaps even in the same area depending upon the season. This idea would be consistent with the fact that many layers are frequently observed whose variations of immersion are not concurrent.

We shall not review here our previous objections to the biological theory as formulated by American authorities. We shall merely refer to the main one, based on the following argument:

Owing to the universality in space, stability in time, and the apparent uniformity of ultra-sonic echo records accounting for the phenomenon, the adoption of the biological theory is equivalent to the assumption that, under the influence of light, living organisms whose acoustic properties may account for the scattering of the waves used (18 to 24 kc.), are concentrated in the ocean by day between depths of 200 and 400 or 500 meters, whatever may be the variations in space of the physical and chemical conditions, in the ocean area concerned (1).

The recently published observations of Hersey *et al.* appreciably alter our previous conception of the phenomenon. For they show that the use of waves at various frequencies reveals layers of echoes whose appearance and immersion levels differ and vary in space and time. This variability of the phenomenon is no doubt closely related to the opinion we had formed regarding the distribution of living organisms in the ocean, but we must now assume that these organisms are grouped at certain levels, at least by day, according to their scattering capacity (acoustic size). This pre-established order of things seems most unlikely.

In 1951, some British oceanographers — Burd and Lee, followed by Parish and Craig — pointed out the existence in shallow waters located in the English Channel, the North Sea and the Barents Sea, of dense concentrations of living organisms that could be detected by means of short damped ultra-sonic waves from Kelvin Hughes MS XII and MS XX marine sounders. Records obtained showed some analogy with those observed by American authorities in connection with the DSL.

In particular, these concentrations reproduced the twenty-four hour variation in immersion, but they were located at shallow depths (between 10 and 80 meters) and were limited in space and time. Samples and observations taken by these authorities showed that concentrations of the larvae and young of fish were usually involved.

The research of numerous authorities (R. Balls, Tester, Renou and Tchernia, Hodgson, etc.) has long since shown that certain ultra-sonic sounding instruments currently used in navigation enabled the recognition in depth of dense concentrations of organisms in continental waters.

In order to investigate, we carried out numerous observations (1946-48) off the coasts of France and Morocco, and on the banks of Newfoundland and Nova Scotia, using various ultra-sonic devices. We had occasion to discover the existence of animal concentrations extending over several dozen miles, but we did not at any time observe echoes having the constant and uniform characteristics of the DSL.

Although it is difficult at present to supply any criteria characterizing the DSL, we nevertheless believe that this phenomenon of reverberation should not be confused with phenomena involving direct echoes obtained from dense although limited concentrations of fish or planktonic organisms that may be encountered in continental waters, generally at shallow depths. The DSL is an oceanic phenomenon, and it was an error on our part, on the basis of as yet incomplete information, to correlate Lee's observations in the Barents Sea (Tchernia - c, page 55.)

(1) We were able to ascertain that the crossing at a given period of a hydrological boundary as important as the Antarctic Convergence had no noticeable effect on the DSL characteristics as shown by our ultra-sonic echo records.

Very recently (October 26, 1952), according to information appearing in the press, an American, Otis Barton, while submerged in a bathysphere, observed the existence *de visu* of « a swarming, seething layer of strange creatures ». As early as 1949, following a similar diving operation, Barton announced that an approximate depth of 800 meters he had « entered into a dense layer, into a veritable barrier of crustacea », but no American works that have since been published on the DSL make any reference to Barton's observation. It may be remarked in this connection that the bathyspheric observations carried out by W. Beebe and O. Barton in the vicinity of Bermuda between 1930 and 1934 showed no particular concentration of organisms near the 450-meter level, which according to H.B. Moore is the DSL level in this area.

4. *Conclusion*

This paper is in no way claimed to be a complete appraisal of the DSL problem in its present stage. Readers who wish to become acquainted with all aspects of the problem may refer to our previous work published on the subject, to L. Walford's article and to various papers listed in the bibliography appended hereto.

We have merely attempted to classify and define certain aspects of the question, and to point out apparent contradictions between various observed facts and the explanation commonly given for the phenomenon.

As early as 1949 we wrote as follows: « The phenomenon exists, but we are aware of it only in terms of observational methods that we believe to be imperfect. It must continue to be investigated both from the physical and biological aspect ».

Attempts at biological analysis that have since occurred (Moore, Boden, Marshall, Tucker) have made the problem no clearer. It appears that neither our present knowledge of life in the oceans nor our standard methods of biological investigation can lead to any conclusive explanation of the facts observed.

The biological theory suggested by M. W. Johnson in 1945 caused the premature interruption of the physical analysis begun in 1942. The initial results of this analysis have moreover only partially been published in articles by Eyring *et al.*, Raitt, and Hersey *et al.* (1952) (1).

Hersey's recent work shows that our previous conception of the scattering phenomenon was based on an artificial aspect arising from the inadequacy of the observational devices used. It is not yet possible to supply a picture of what the actual aspect may turn out to be, but it appears necessary to abandon already the concept of a dense, uniform, continuous and universal concentration.

The real aspect of the phenomenon can be made evident by physical analysis. Before its cause can be investigated, it must be defined as accurately and as objectively as possible. Contradictions emerging from the examination of facts attributed to the DSL by various authorities are in all probability due to the imperfection of the observational method.

(1) A large part of these results appear in five anonymous military articles listed in Boden's or Hersey's published material, under : California, University of, Division of War Research.

It does not appear as if all elements had been extracted from the physical analysis of the phenomenon that might assist in the better presentation of the problem and its final solution, which is apt to change our present ideas regarding certain physical or biological characteristics of the oceans.

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