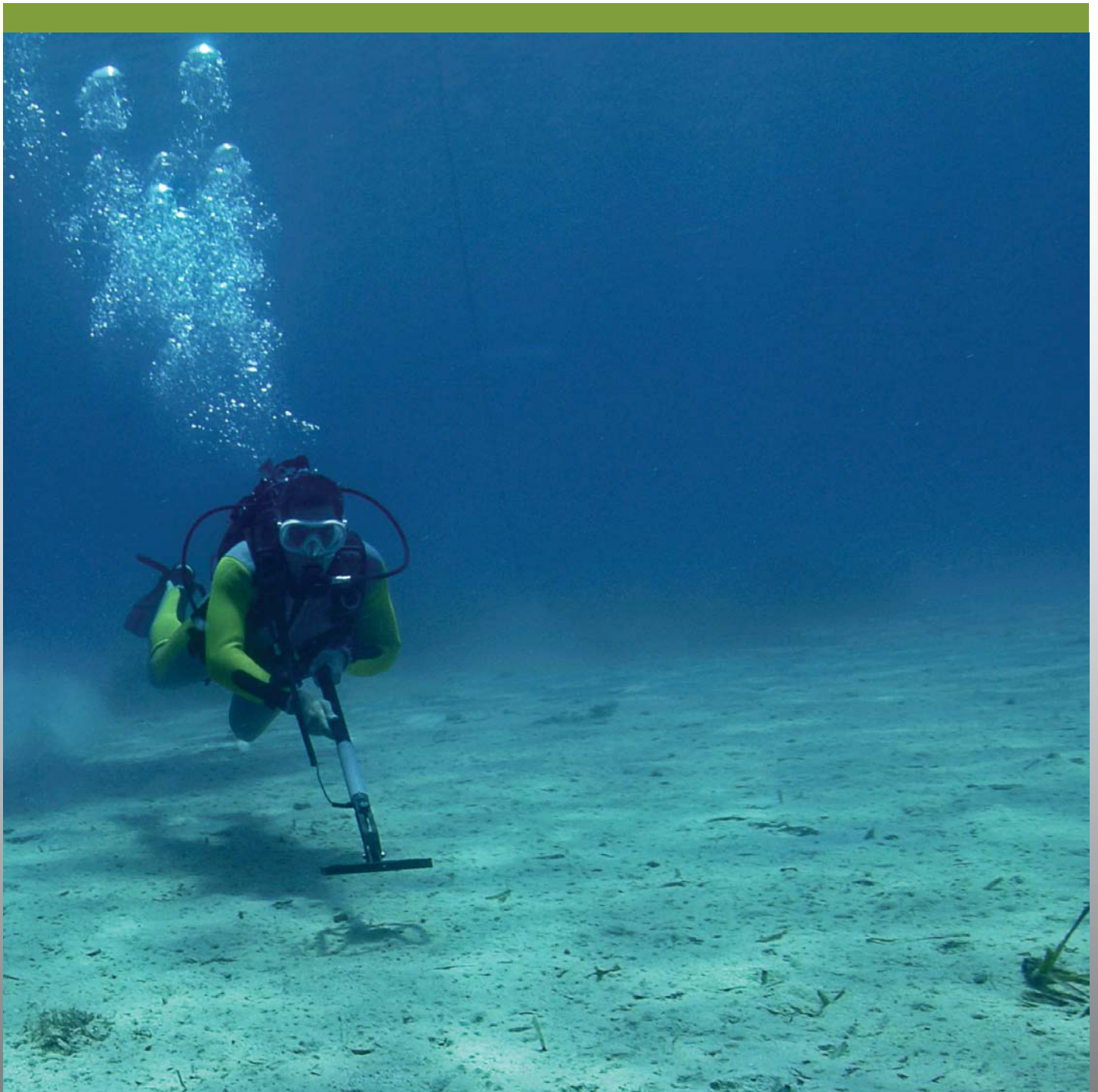


# The Challenge of Metal Detection at the Bottom of the Sea



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## 1. Introduction

To this day, ordnance in our waters remains an area of significant concern, and EBINGER is one of the leading worldwide companies that has taken on the difficult challenge of locating ordnance using underwater metal detectors. In this article the author, Klaus J. Ebinger, summarizes the development of this special technology from his unique perspective as one of the field's founders. This article is not to be taken as a scientific discussion of the technology, but rather it is intended to communicate how the author, who has had such a major influence on the development of underwater metal detectors, personally experienced the technology's evolution.

## 2. The first UW detector

To appreciate our active technology it is important to understand that the electrical conductivity of seawater causes "pseudo-signals" in metal detector circuits, which can interfere with the function of sensitive metal detectors. "Pseudo-signals" are really just false signals, which interfere with the system being able to detect metal. Underwater metal detectors used by my diving team in the early 1970s, were based on my invention of the "attenuation-sensitive search oscillator" - the "attenuation principle" for short. The attenuation principle came from an idea that occurred to me one night while transistorizing US mine detectors. The idea is that a search coil forms part of a resonant circuit; in the proximity of metal, eddy current effects cause an attenuated response in the search coil, which reduces the oscillator amplitude, which is related to the distance of the detector to the metal object. The device electronics converts the change in amplitude to an acoustic signal to guide the diver to the object. The invention revolutionized mine detector technology used in munitions clearance to such an extent that it was employed throughout the world.

The frequency at which a mine detector operates determines the size of the object that it can detect. Mine detectors that use attenuation-sensitive search oscillators operating at approximately 25 kHz detect small non-ferrous metal parts reliably. In forensics, these types of detector were the first effective underwater detectors for bullets and shell casings; they were also successfully employed for archaeology. Unfortunately, the metal detectors couldn't tolerate saltwater, which we discovered the hard way on a dive in the Baltic Sea, despite its relatively low salinity.

Our "frying pan" (Fig. 1 & 2), as the new UW detector came to be called, mutated into a mere conductivity meter, however it did produce interesting effects. It displayed a maximum reading just above the surface of the water. After diving below the surface, the display was adjusted to display zero. When tested on the diver's watch, the detector functioned almost normally. When the diver continued down to the seabed, the frying pan behaved erratically, requiring repeated setting correction! A dramatic effect occurred on the seabed, for which there was initially no explanation. As the detector was raised above the seabed slightly, it produced an anguished cry. But, it was not responding to the neutral sand - so what had happened?

So what had happened? The high operating frequency of the alternating field induced current paths that propagated in the conductive medium - the seawater - leading to a response similar to that which would be caused by metal pieces. Here too the eddy

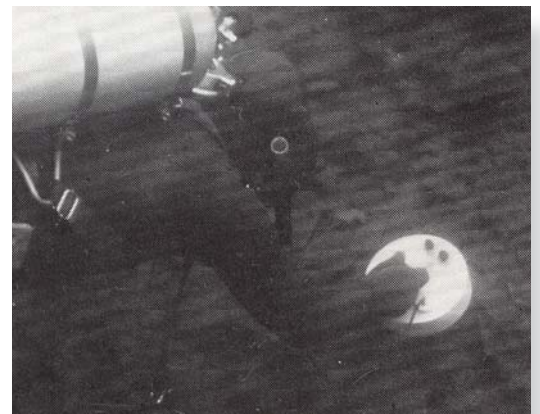


Fig. 1. and 2. „frying pan“ in operation



current effect was the cause of the pseudo-signals. Having a very sensitive metal detector, what would normally be an advantage, became a major disadvantage in seawater. Nonetheless, this was not the only cause of the spurious effect; another was that the conductivity dropped dramatically in the vicinity of the seabed. If the device was lifted off the seabed, it went from an environment of much lower conductivity to one of much higher conductivity, which also triggered a lift-off or a fault indication. At that time we were not yet familiar with the electromagnetic spatial response that I will explain in more detail below. Because of our disappointing experience in seawater we returned, humbly, to freshwater, where the frying pan functioned superbly. Occasionally we assisted the police, searching for stolen goods and weapons. During these searches, the number of munitions we found was unbelievable! We reported these finds to the police and to explosive ordnance disposal (EOD). Underwater munitions remains a serious problem.

### 3. Köln 661 mine detector

The only detector that functioned in saltwater was my first mine detector, the "Köln 661" - the so-called hockey stick (Fig. 3 & 4). The Köln 661 was marketed abroad as the METEX 4.100 by Dr. Förster of Reutlingen, Germany. The Köln 661 was based on an LF-TR (low-frequency transmitter-receiver system), which I had developed for surface clearance of munitions, supporting EOD.

Due to the Köln 661's low operating frequency of approximately 1 kHz, it detected parts made of iron and it was also capable of detecting larger objects made of non-ferrous metal. Because of the low operating frequency pseudo-signals were not created in the detection circuit when the system was used in seawater. Small coins could just barely excite the hockey stick in the true sense of the word. Even Roman clay fragments were detectable! There was no spatial effect or lift-off on the seabed. Only relatively large objects made of non-ferrous metal were unable to satisfy our underwater search appetite properly.



Fig. 3 Hockey probe in UW operation



Fig. 4. diving team N. Kaiser, K. Ebinger

## 4. New pulse induction method

As our technology progressed, new opportunities for improvement were found. In 1973, when I was still a young entrepreneur, I acquired the patent rights from a German engineer, Claus Colani of Munich for a trendsetting invention (Fig.5). Colani the engineer - not to be confused with Colani the designer - is quite rightly recognized as being the originator of the pulse-induction (PI) method. In simple terms, the PI method is based on the electromagnetic echo principle, in which a search loop, consisting of a few wire windings, is connected to a switch, which intermittently connects the loop to a battery. In this way, the high electrical current from the battery produces an extensive, pulsating magnetic field - the magnetic field induces eddy currents in metal objects (all metals). This eddy current induction leads to a secondary field, which after a short time-delay is received by the search loop and is electronically converted to a display signal or some sort of indicator. Important advantages of the method are: greater depth range, electronic selection of objects, and reduced conductivity effects from damp soil or saltwater.

The first-generation PI devices truly didn't respond in saltwater, as at that time measurements were still taken with large gate times - the time delay between the primary transmission from the loop and secondary reception by the loop. Colani described it as temporary cleaning of the surrounding, indeed spurious, medium. He was completely right, but this also imposed limits on the use of his technology. The large gate times required for operation in seawater to overcome attenuation effects compounded the problem of detecting small low-conductivity metal objects.

Though we were excited about PI technology it still needed a lot of development to meet our expectations of it. It also had an unacceptably large time constant in the display, which resulted in very slow searches. The "selectivity", as the munitions clearers called it - the ability to separate munitions from random metal fragments - was too poor in areas with lots of metal fragments and couldn't compete with my attenuation-based detectors. Battery consumption was also too high in comparison. We first needed more experience and understanding of the new technology in order to introduce our own new ideas. So, although the first PI detectors that we used in seawater were not able to fulfill our expectations regarding detection of small ferrous and non-ferrous objects, we could still use the technology to find larger metal objects with higher conductivity, even in deep mud or silt.



*Fig. 5. Colani PI system in archaeological use*

## 5. Development trend

As usual, the market was demanding metal detection equipment to help with increasingly extreme search tasks, for example, locating mines with low metal content. At the time only the attenuation technology could achieve this, at least in largely cooperative soils. My attenuation technology could also work where the magnetic effect of some soils, such as those caused by the volcanic rocks of the Eifel region of Germany, were sufficiently known to us to allow adequate compensation during munitions searching. At the time we still had no idea about laterite soils and soil-compensating PI systems. But that's another story! Anyway, the sensitivity of our pulse detectors got better and better, far beyond the standard performance of that time. Meanwhile, we encountered a familiar foe that we hadn't expected, which is introduced in the next section.

## 6. Conductivity effects on the seabed - the electromagnetic spatial response

In the area of the water's surface, that is the surface of saltwater, the new PI model proved to be very stable. Yet on immersion the acoustic signal rose to a certain level, and then continuously fell again near the seabed. After correcting the device settings we could search, but every time the probe was lifted above the subsurface an unknown fault indication occurred, which spoiled our joy of discovery. To cut a long story short: the conductive "full space", which surrounded us, changed its electrical character on the bed, and the PI detector responded to this change! And thus the so-called spatial response was born for "us." I used the plural form here, because I am including my old friend Gerhard Aretz, a colleague and former diving buddy, who still tests our underwater and land detectors expertly and uses them with a great deal of success (Fig. 6).



Fig. 6. Gerhard Aretz in action

## 7. Delay time and loop diameter

As things progressed we found that the loop diameter (search loop) and delay time are closely linked. In principle there is a logical connection between field propagation in the conductive medium and the electromagnetic response, which increases as the loop becomes larger. There follows a simple rule: small loop - short delays, large loop - long delays. Together with the operating frequency, this is the only way to keep the pseudo-signals of the surrounding space under control. I should also note that electronic compensators are available to suppress the spurious effect. However, they do so at the cost of the range. Once again to make it sufficiently clear: at intermediate depths the spurious effect in saltwater is relatively insignificant. However, the conditions change on approaching the sea bottom. There the operating point of the detector must be corrected if the delay and loop diameter are out of proportion. Gerhard Aretz is currently carrying out a new test campaign at his diving sites, the results of which I am eager to receive.

## 8. Explanation of the spatial response

A PI detector uses a search loop, which simultaneously serves as a transmitter and receiver (TX/RX). During the transmission phase the pulse current-carrying loop acts as a magnetic dipole whose dipole field penetrates all electrically conductive material and induces an electric current pulsating with the same frequency (Fig. 7). This induced current, like the current in the transmission loop, is linked to a so-called secondary magnetic field. The particular feature of this pulse method is the pulsation of the current in the transmission loop: between two pulses the loop is current-free and during this time it can operate as a receiver for the secondary magnetic field generated by the currents induced in the material. With their magnetic field, these more or less rapidly decaying currents induce a corresponding decaying voltage in the loop, which is registered as a measured variable at selectable times after pulse end (delays). This response depends on several different factors, which above all include the electric conductivity of the conducting body in which the currents were induced as well as

the geometry of the conducting body and the interaction of adjacent bodies that might be made of different materials.

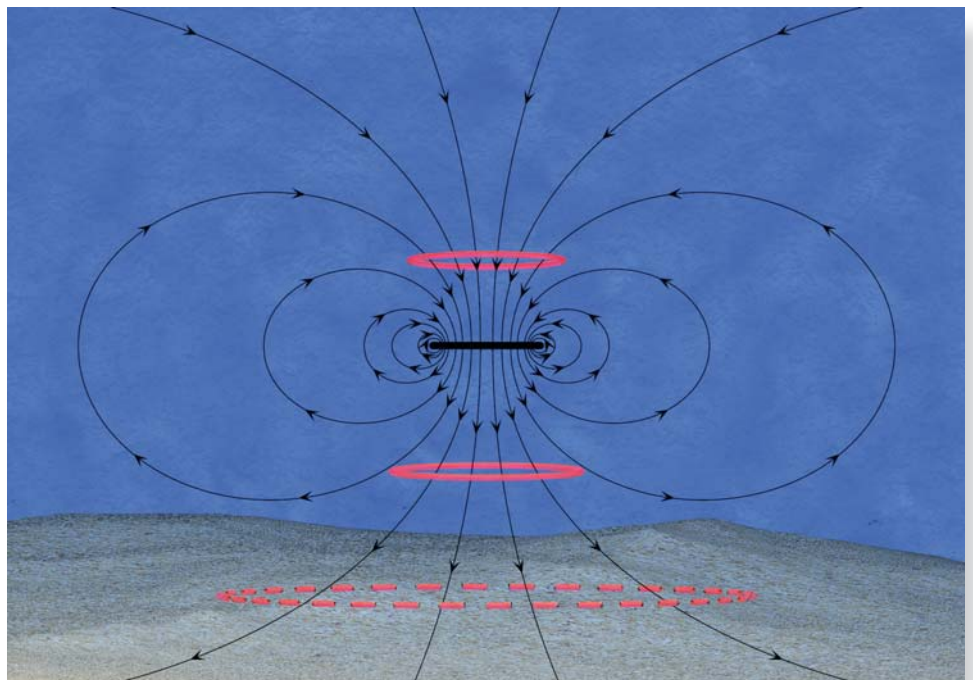
In the case of the detector deeply immersed in seawater the conditions are initially very simple. The transmission dipole generates a current field in the water with a linked secondary symmetrical magnetic field and a defined voltage drop in the loop in reception mode. The voltage can be compensated instrumentally to a zero display value. This compensation is maintained in homogeneous seawater when the detector loop is moved (i.e. shifted or rotated).

The situation can change considerably if one approaches the seafloor with the detector, which should become obvious looking at Fig. 7. As the detector approaches the seafloor the previous condition of symmetry is lost, because the material on the seafloor has lower conductivity than the seawater. This change in conductivity can easily be lower by a factor of 10 to 100. The display on the instrument therefore changes on approaching the seabed. This is not critical as long as the loop, for example, stays on the seabed, because the constant spurious excursion can then be compensated for again. But this is not the point of the measurement.

Detecting metallic objects on the seafloor (e.g. munitions, archaeological objects) necessarily requires moving the loop, which as a consequence, results in more or less severe fluctuations, even in the absence of metal objects, that depend on the distance from the seafloor and changes in soil conductivity. These spurious effects are naturally superimposed on the required useful signals of interesting metallic objects, so that nothing is gained from revised compensation.

Only adaptive technology can help here, if suitable loop diameters and delays are chosen for the respective detection situations. A very simple basic rule is that the induced magnetic fields in the seawater and

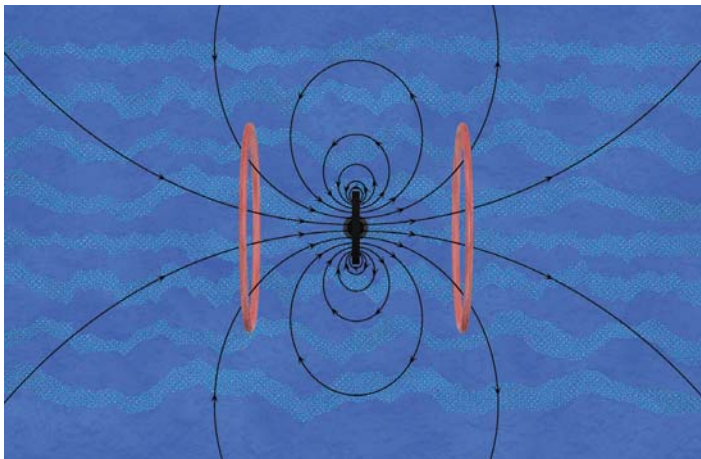
in the seafloor collapse far more rapidly than generally do the magnetic fields in metals; therefore, one can distinguish between the two types of signals with properly selected delay times. This does not always help with very small objects made of precious metals because the decay times are similar.



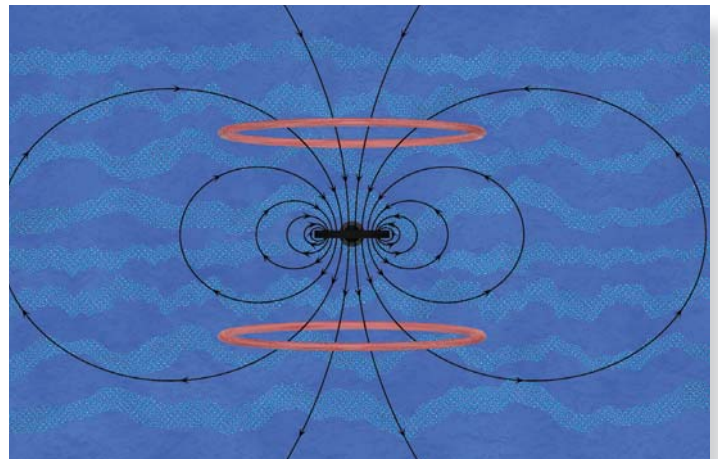
*Fig. 7. Detector loop in seawater: The loop flowed through by current pulses (black in the cross-section) generates a pulsating dipole magnetic field in the surrounding conductive space, which induces currents which propagate in the space (represented symbolically by red rings). The secondary magnetic fields of these currents (not drawn here) respond*

## 9. Vertical/Horizontal effect

Unlike the thought experiment above with the search loop in the middle of homogeneously conductive seawater, where movement of the loop does not cause any change in the display, practice has shown that an effect can indeed occur if sensitive underwater detectors are used to take measurements in the horizontal and vertical position. Systematically, greater conductivity appears to be displayed with a horizontal loop than with vertical orientation. This can be explained by the geometry of the inducing magnetic dipole field, if the preference of horizontal conductivity stratification in the seawater is assumed - controlled by the salt content (density stratification) and temperature, partially in conjunction with currents. From physics we know that the macroscopic conductivity of such anisotropic strata is greater parallel with the stratification than perpendicular to it. And with a horizontal loop as a vertical magnetic dipole the induced currents flow parallel to the loop surface, and consequently parallel to the stratification in the anisotropic seawater.



*Fig. 8. Vertical position of the search coil in the electrically conductive space with horizontal formation of the magnetic field produced the smallest conductivity effect*



*Fig. 9. Horizontal position of the search coil with vertical formation of the magnetic field produced the largest conductivity effect*

## 10. Modern UW detectors

Modern underwater detectors overcome the conductivity effects described when used in seawater; however the boundary conditions of the search must be noted. A small search coil, which preferably detects small metal objects, also allows a short delay in a conductive environment. If the aim is to detect larger metal objects, correspondingly larger search loops and larger delays are an advantage as has been described in Section 7 above.

Finally I would like to point out the modern underwater (UW) detectors in the EBINGER and SECON product ranges. UWEX detectors are intended for professional use. The UWM series is aimed more at the wider market.





## UWEX® 725

High-performance detector

- Large detection range
- Dynamic/static search mode
- Simple operation
- Easy to train
- Rugged design
- For long-term use
- Low operating costs
- Saltwater compatible



## UWEX® 725 K

for professional use

- Versatile UW detection system
- Modular design
- Various search heads
- Foldable large loop
- Detects ferrous and non ferrous metals
- Audio/visual indication

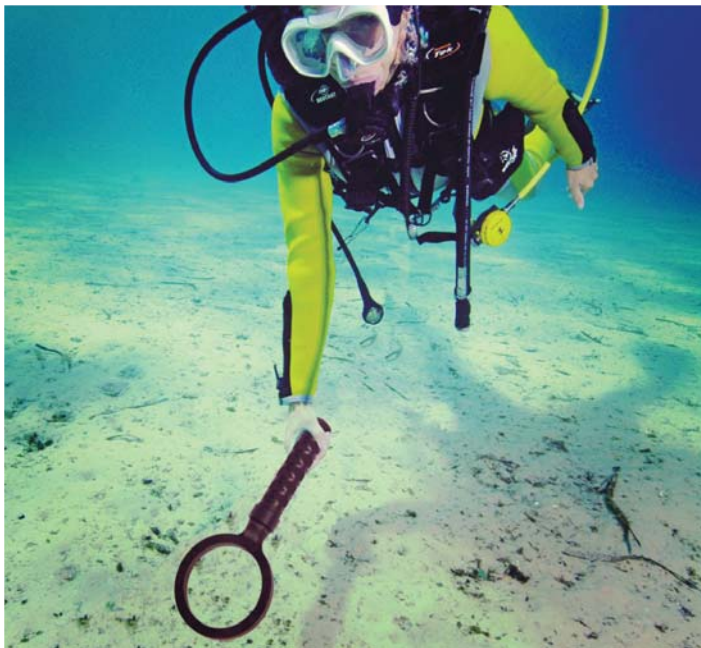
*in progress*



## UWM 10-2

UW rod probe

- Digital PI system
- High sensitivity
- Handy design
- Easy searching in sea grass
- Detects all metals
- Exact pinpointing
- Vibration alarm
- For fresh- and saltwater



## UWM 20

Ring-type probe for beginners

- Digital PI system
- Ring sensor with high detection
- Setting ring for sensitivity selection
- Detects all metals
- Easy to operate
- Vibration alarm
- Lightweight, robust
- For fresh- and saltwater



## UWM 30

for ambitious hunters

- Digital PI system
- High level of detection sensitivity
- Oval search head with large detection range
- External vibration alarm
- Detects all metals
- Easy to use
- Robust, compact
- Can be used in saltwater



## UWM 40

for professionals

- High detection range
- For land and underwater
- Detects all metals
- Audio object information
- Suppression of signals from small objects
- Clear audio signal
- Permits easy locating
- Can be used in saltwater



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