
# Tech Diving Mag

Research - Development - Exploration


DCAP

Mystical Wrecks of Truk

Fast & Super-fast Compartments

Wreck Exploration in the Gulf of Thailand

The Use of SCUBA & Surface Supply Diving Systems in Deep Scientific Work - Part II


Issue 30 - March 2018

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Front cover image courtesy of T. Timothy Smith.

# Editorial

Welcome to the 30th issue of ***Tech Diving Mag***.

A quick reminder: as an endeavor to share knowledge and experience, ***Tech Diving Mag*** finds it inevitable to bring up controversial issues. Information published by ***Tech Diving Mag*** are always obtained from sources believed to be reliable. However, ***Tech Diving Mag*** can not guarantee neither the accuracy nor the completeness of any information published in its issues.

I'm excited to announce that Ultimate Planner has been updated to accommodate for the M11F6 algorithm, in addition to the already-existing VPM-B and ZH-L16. Determined by late Dr. Bill Hamilton and colleagues during the development of decompression tables for the Swedish Navy, M11F6 has worked well for both nitrox and trimix diving. Download your free, Lite version and give it a play.

This is very much your magazine. If you want to share some views or decided you want to get an article you've authored published to an audience of thousands of technical -and wanna-be technical- divers, drop a line to asser@techdivingmag.com. And please subscribe to the newsletter at www.techdivingmag.com/communicate.html to receive a brief email reminder when new issues are available for download.

**Asser Salama**
**Editor, *Tech Diving Mag***

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# Decompression Computation & Analysis Program (DCAP)

## By Asser Salama

In the late 1960s physiologist Dr. Robert (Bill) Hamilton (1930-2011) and engineer and programmer David Kenyon worked in a laboratory dedicated to commercial diving. Their laboratory was charged with the task of developing tables for diving to a maximum depth of 200 meters (660 feet). The laboratory's efforts were successful. Afterward, Schreiner, the laboratory's chief decompression expert, moved to a management position, and both Hamilton and Kenyon eventually acted as independent decompression consultants.

Kenyon refined Schreiner's concepts into a decompression computation program. Hamilton and Kenyon used this program to furnish specially developed tables to navies and commercial diving companies. However, due to the lack of business communication tools such as faxes and emails at that time, they had trouble providing support to overseas clients. One of their customers, the Swedish Navy, proposed to install the table-generation software on their computer so that they could make whatever tables they would need without communicating with the decompression expert house. The table-generation software, called DCAP, incorporated several underlying decompression models. Afterward, DCAP was acquired by several key accounts, including navies, commercial diving firms and research laboratories. Scores of special sets of tables generated for specific projects were acquired by major customers, one of which was the NOAA-Hamilton Trimix Decompression Tables used by NOAA for diving on the American Civil War vessel *USS Monitor*.

Although DCAP uses various computational models, it is most famous as the Tonawanda IIa wrapper. Tonawanda IIa (frequently referred to as Hamilton-Kenyon) is described by its developers as a Haldane-Workman-Schreiner algorithm that accommodates multiple mixtures and can employ up to 20 compartments. It allows the user to control both the halftimes and the M-values. A well-known subset of Tonawanda IIa is the 11F6, which uses 11 halftime compartments ranging from 5 to 670 minutes (for nitrogen) along with the corresponding M-values. This matrix of M-values is referred to as either MM11F6 (when meters are used) or MF11F6 (when feet are used). Other models handled by DCAP include Kidd-Stubbs, VPM and USN E-L. Tonawanda IIa has also been folded over VPM to generate more conservative schedules.

**Do you know:** 11F6 with its matrix of M-values (M11F6 algorithm) is now implemented in Ultimate Planner. A free, Lite version is available for download.

The major advantage of DCAP is that it can apply constraints to decompression algorithms to guide the ascent. One of these constraints is a model called t-delta-P, which is folded over the algorithms DCAP incorporates. It uses the integral of supersaturation over time as an additional ascent limit. In other words, it adjusts the decompression to account for time spent under supersaturation, and it frequently recommends recalculating the ascent schedule at a slower rate. DCAP also affords a statistical estimate of the reliability of the schedules it generates, meaning that it can estimate the probability of occurrence of DCS of its generated schedules. For saturation (commercial) diving, DCAP employs a function that links the ascent rate to the oxygen level. Other capabilities include generating schedules for deep dives with neon and forecasting ICD.

Hamilton Research Ltd., the owner of DCAP, does not encourage small diving contractors to acquire or operate DCAP, mainly because of its cost and the necessary training and experience.

**Excerpted from *Deep Into Deco: The Diver's Decompression Textbook*. The title is available at:**

https://www.bestpub.com/books/scientific-diving/product/428-deep-into-deco-the-diver-s-decompression-textbook/category_pathway-42.html (print, electronic and combo versions)

https://www.amazon.com/Deep-Into-Deco-Decompression-Textbook/dp/1930536798 (print version only)

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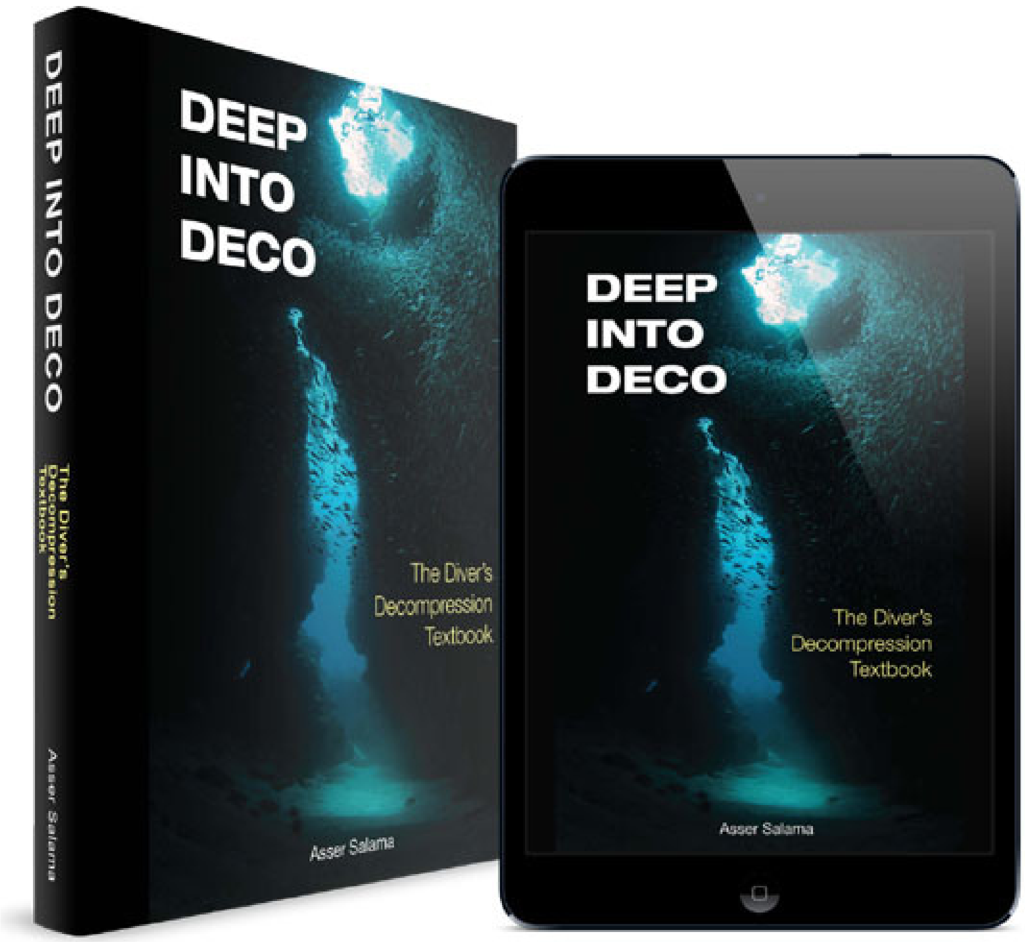


# Mystical Wrecks of Truk

## By Bret Gilliam

For pure unadulterated variety, sheer numbers and overall dive conditions, no place else on earth can rival Truk Lagoon, Micronesia. In February 1944 the Allied forces caught most of the Japanese merchant fleet and a few warships with their collective pants down in the atoll's anchorage and sent them to the bottom in a savage air attack. Yeah, pay-backs are hell.

My first trip to Truk was in 1974 and only a handful of divers had discovered this tiny paradise that had just begun peeking its head into tourism.

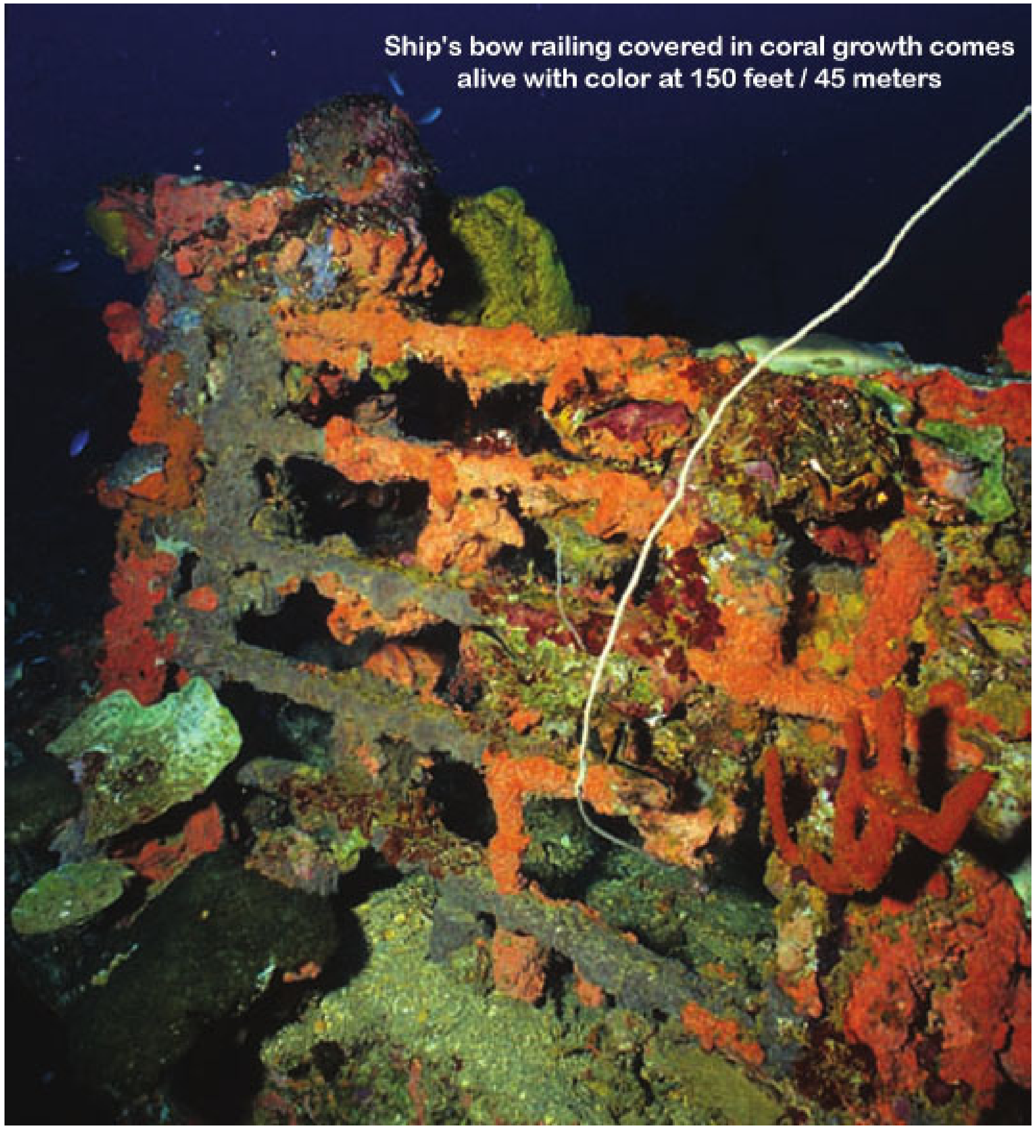
Back then only Kimiuo Aisek was seriously gearing up for visiting sport divers. Kimeo had witnessed the attack as a teenager and knew more or less where all the wrecks had settled. He was busy locating the hulks and guiding the occasional visitor with a dive bag to wreck Nirvana.

Outnumbering the divers then were a rather severe force of missionaries from the U.S. who had been called by a higher authority to save the Micronesians from their wicked ways. The Trukese were an affable sort who lived simply on the primary islands of the atoll and got by on fishing and copra crops all the while eschewing traditional western clothing and morality.

This, of course, did not sit well with no-nonsense decorum promulgated by the earnest Yankee Protestants with names like Caleb, Enoch and Mordecai. The vision of these determined stalwarts dressed in long trousers, long sleeved shirts and ties was a surreal contrast to men in loin cloths and their nubile ladies wearing mostly a smile and a flower... maybe. Sadly, at least from my perspective, the missionaries prevailed and the natives were converted to a more proper lifestyle. Now the uniform of the day showcases fashion statements ranging from billowing muumuu dresses to T-shirts and Nikes. Ah well, progress.


Skeletal remains of Japanese crew entombed deep inside wreck

But underwater the wrecks just continue to get better. There are over 50 regularly dived ships up to 600 feet / 180 meters in length. Depths vary from barely submerged superstructures on some vessels that sunk in the shallows to deeper sites at 165 feet / 50 meters or more. Aside from the obvious bomb or torpedo damage, these ships are intact and extremely well preserved. Now protected from artifact hunters and other looting, the sunken fleet has become a monument to another era.


Ship's bow railing covered in coral growth comes alive with color at 150 feet / 45 meters

Visibility ranges from 50 feet / 15 meters to nearly 200 feet / 60 meters and the water temperature averages a toasty 82 degrees F / 28 degrees C. Some sites are less than 20 minutes ride from the main island of Moen. And for live aboard divers, it's simply a matter of falling off the back of the platform. Festooned with 50 some years of colorful soft corals and other marine life, the ships are alive again with life in their slumber. And you'll probably have no more than 10-to-12 divers sharing the wreck with you at any time.

Topping the headliner list of popular sites are the freighters *Fujikawa* and *Nippo* who sit upright on the bottom and can be explored without venturing below 130 feet / 40 meters On the *Nippo*, towering crosstree masts reach toward the surface from main decks where troop trucks and tanks are still parked. A meandering swim through the wheel house reveals both the ship's wheel station and engine room telegraph still standing. The indicator is set to "one third ahead" as the captain desperately maneuvered to clear his anchor and steam to safety. The impressive bow and stern guns are aimed skyward in mute defiance. On the *Fujikawa*, the officer's tiled baths remain intact along with remnants of newspapers impossibly preserved after over half a century submerged.

On other ships huge caches of munitions and other ordnance still rest in cargo holds guarded by the skeletal remains of the crew. It's an awesome and sobering vista of a time long gone by. Delicate China tea settings with intricate floral patterns rest incongruously next to machine gun stations with bandoleers of ammunition. Life boats, never launched, hang suspended in davits overgrown with spectacular pink soft corals.

Artifacts including saki bottles, navigational lantern and China plates and bowls

Folks, it just doesn't get any better than this. If you're serious about wrecks, this is the place. And the scenery ain't bad either. I recommend a live aboard to maximize diving opportunities. So put away the dry suit, forget about a 10-hour boat ride in rough seas, and pamper yourself with wreck diving the way it should be. Laid back, easy and with enough high-voltage sites to enthrall the most jaded diver. Before you go, take the time to read up on the history of the battle and the accounts of the famed Micronesian star navigators who ventured all over the Pacific in their canoes without charts or compasses.

Inside the ship's hold

# Fast & Super-fast Compartments

By Albrecht Salm

The following is an **essay** on fast and super-fast compartments. So this is not a strict scientific paper, neither in form nor in contents but a couple of preliminary thoughts on the topic, intended to raise awareness or for further discussion.

If you are new to *Tech Diving Mag*, new to TEC diving or even new to diving, you may enjoy some basic information on deterministic decompression models and algorithms in chapter 2, the „Background". The seasoned diver may skip this safely. Readers not intending to go into the mathematical details may then proceed as well directly to „Take-home Messages" in chapter 12.

## Chapter 1: Rationale

During my first course on breath-hold diving some 20 years ago, I stumbled on the inability of standard decompression tables and algorithms to cope with breath-hold diving profiles. My then instructor on this topic, Andy Anlauf, who was at times an elite apnea diver, asked me if I could make a decompression table for the record profiles: for example in 2 min down to 130 m and then up to the surface. If you now look at a compartment, say with a halftime ($\tau_{½}$) of 12.5 min (compartment #3 in the standard ZH-L parlance), it will change its initial inertgas load from ca. 0.8 to only 1.1 bar after 1 min @ 90 m. The super-saturation of ca. 0.3 bar is not enough to yield any basic decompression; even on return to the surface it is still taking up inertgas and the super-saturation is raised to ca. 0.5 bar, still not sufficient for a substantial decompression time. The other compartments from # 8 on will not even take note on this pressure excursion.

Further on, there is a phenomenon called „Taravana": these are the many anecdotal reports on unexplained DCS cases during breath-hold dives, especially for commercial indigenious sea harvesters.

As well Paulev (cf. chapter 11) observed cases of DCS type II during breath-hold submarine escape training; Schaefer (cf. Chapter 4) observed $N_2$ bubbles in blood samples from breath-hold divers, quickly disappearing after 10 sec.

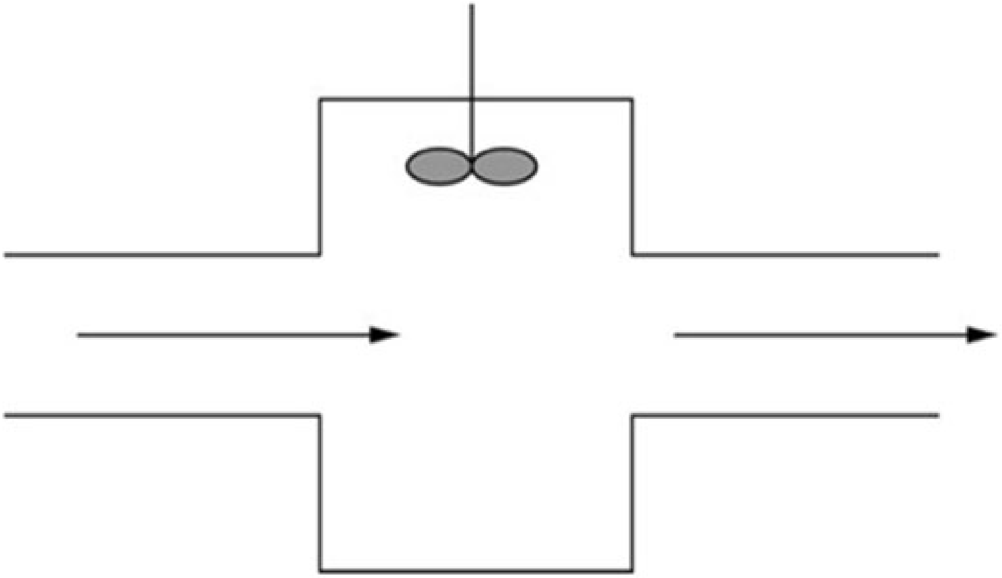
In the TEC community there is since long a sometimes overheated discussion around the effectiveness of short, 1 to 2 min, deep stops during decompression from mixed gas dives.

The time domain of all these phenomenon is in the sub-5 min region. Basically a phenomenological description needs thus an exponential halftime ($\tau_{½}$) in the order of a fraction of the maximal time-frame. Thus approximately 5 min divided by 6 halftimes would allow for a clean description to cope mathematically with the quick pressure changes: 6 halftimes being the rule-of-thumb for complete saturation or desaturation of any compartment (at constant pressure). We end up thus with $\tau_{½}$ of approx. 60 sec.

After a snappy introduction to decompression models and algorithms in the next chapter, there will be a short and limited literature overview which reveals if and how other selected researchers have been dealing with the spectrum of used halftimes.

## Chapter 2: Background: What is a compartment, anyway???

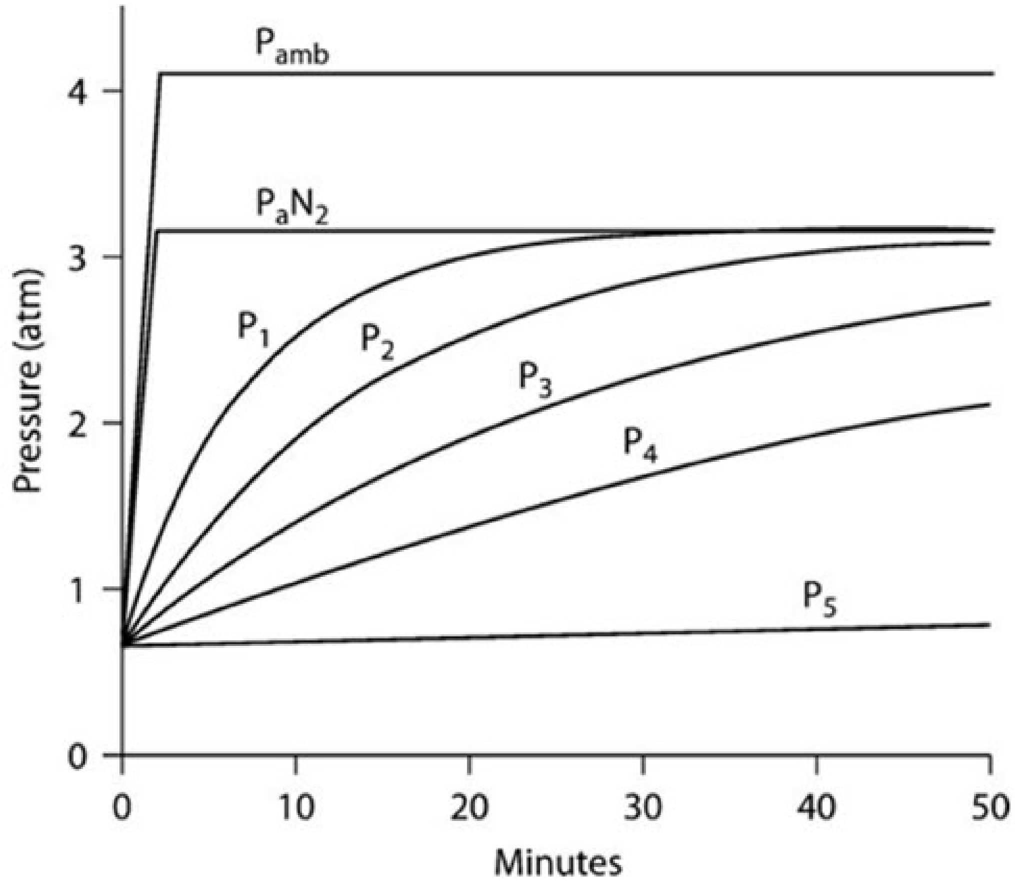
The following is a boldfaced copy from a book of Carl Edmonds, another chap of mine (Ref.: Edmonds, Carl. *Diving and Subaquatic Medicine, Fifth Edition*. CRC Press, 20150713. VitalBook file), the graphs used here have been drawed originally by Dr. David Doolette, working now for the Naval Experimental Diving Unit (NEDU) of the United States Navy (USN):



(with a friendly permission by Carl Edmonds and David Doolette)

The box depicted above is a model for the limited volume of some region in a mamalian body: one compartment is showed here. It is a model for a well-stirred tissue (thus the symbol with the little mixer) with a defined, perfusion-limited blood supply: the arrows from left, the arterial part to the right, the venous part.

Then we will look at a dive scenario with more compartments: we see the nitrogen uptake in five hypothetical perfusion-limited tissue compartments during a dive to 30 metres (4 ATA) using air. $P_{amb}$ is the ambient pressure in atmospheres (atm). The inspired pressure of nitrogen and the alveolar pressure of nitrogen rise to ~3.1 atm (not depicted in the figure), and the arterial pressure of nitrogen ($PaN_2$) immediately equilibrates. The tissue pressures of nitrogen are slower to equilibrate, due to the final capacities of the blood, lung and circulation carrying the inert gases. Only tissues 1 and 2 approaching saturation within the duration of the exposure depicted. From the lines in the graph and with the rule-of-thumb cited above you can derive the halftimes of the compartments. For example $P_1$ reaches its 50% saturation after 5 min, so after 6 * 5 = 30 min it is supposed to be saturated; $P_2$ after 6 * 10 min.

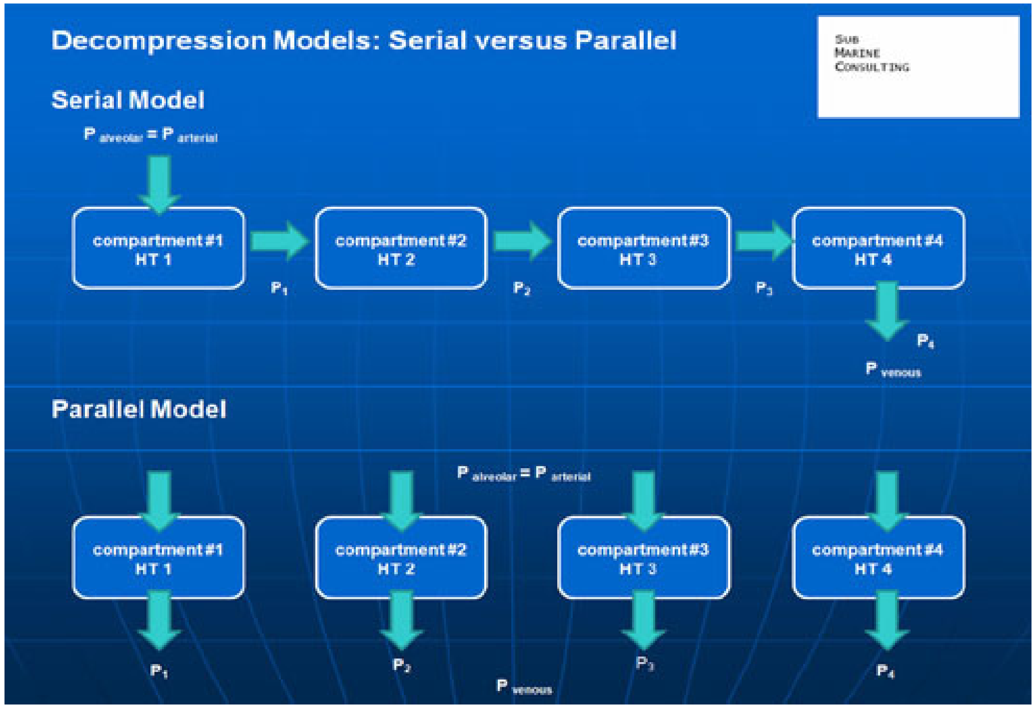



(with a friendly permission by David Doolette)

The lines of saturation follow an exponential curve, typical for many natural phenomena, the math behind a simple linear differential equation is already described elsewhere, for example here: https://www.divetable.info/theory.htm.

In this model we have $P_1$ to $P_5$ in a parallel circuit (cf. graph below, the lower part), other models with a serial circuit are possible as well. The most prominent decompression models like the ones from Haldane, Workman (USN tables), Schreiner and Bühlmann (ZH-L) are using the parallel perfused setup. The serial circuit showed below (upper part of the graph) is used by Kidd, Stubbs, Nishi et al for the DCIEM tables and Canadian military and commercial procedures. We see 4 compartments designated # 1 to # 4, with halftimes $\tau_{½}$ : HT 1 to HT 4. In the serial setup there need not to be different values.

### Serial versus parallel coupling of compartments




All these models are called „deterministic“: they try to predict a safe decompression, that is safe stop depths and stop times, based on the pressure/time profile and the inert gas content of the breathed gases.

A completely other game is a „statistical“ decompression model: there the outcome of thousands of dives is analysed after surfacing. The outcomes (DCS: YES or NO) being fitted to a model and then a decompression table with a defined probability of getting DCS is derived.

### Physiologic definition of the compartment halftime

As was described earlier, the halftimes ( $\tau_{½}$ ) are related to the change in the moved blood volume, i.e. the volume per time (ml per min) per ml of compartment volume; thus the physiologic definition looks like that:

$\tau_{½} = 0{,}693 * \alpha_{ti} / (\alpha_{bl} * dQ/dt)$ (0)

where:

$\alpha_{ti}$: solubility of the inert gas per compartment (tissue = ti), $ml_{(S)gas} * ml_{ti}^{-1} * (100\ kPa)^{-1}$

$\alpha_{bl}$: solubility of the inert gasin blood (blood = bl), $ml_{(S)gas} * ml_{blood}^{-1} * (100\ kPa)^{-1}$

dQ/dt:perfusion rate, $ml_{blood} * ml_{ti}^{-1} * min^{-1}$

The ratio of the solubilities blood / tissue ( $\alpha_{bl} / \alpha_{ti}$ ) has a well-known name: the „partition coefficient“; it could be looked up in tables (cf. the remarks on PBPK in chapter 8). If you do not have the partition coefficient of your compartment in question and you do not have a clue about its perfusion rate, you collapse everything into a single value. This approach leads directly to the pragmatic Schreiner matrix (cf. chapter 5).

### A compartment as a „low pass“!

The exponential functions to describe the on/off gasing of the compartments are nearly the same for an electronic circuit, consisting of a capacitor and a resistor. It is used for example to rectify the current from AC to DC: the high frequency parts of the AC are filtered, allowing only the lower frequencies to pass the electronic circuit; thus the name „low pass“.

Now, if you have a part of your dive profile with a „high frequency“ behavior, i.e. noticeable changes of the diving depth versus short times as in yo-yo diving, the decompression algorithm is „blind“ for it: the dive computer may log the depth changes over time but the slower compartments will never notice it. (Ref.: Hahn MH (1989): *Reponses of decompression computers, tables and models to „yo-yo“ diving*, Undersea Biomed Res 16 (Suppl.:): 26.)

## Chapter 3: Experiment with goats: Haldane

(Ref.: Boycott AE, Damant GCC, Haldane JS. *The prevention of compressed air illness*. J Hyg (London). Jun 1908; 8(3): 342–443.)

The set of halftimes for his 5 compartments was generated by just doubling the 5 min halftime 3 times, with the longest halftime being 75 min due to a hypothetical saturation of nitrogen uptake at around 5 to 7,5 h (pages 349 and 350) for the goats he used for his experiments: 5, 10, 20, 40 and 75 min. Then there could be as well a compartment with a halftime of 2.5 or 1.25 min. On page 348 he gave a hint to a faster saturation process within max. 10 min which would yield a halftime of: 10 min / 6 → ca. 1.6 min.

We could easily exploit this with his rule for safe ascent, the famous „2:1“ rule to generate a „new“ haldanian-type decompression table, but with **deep stops!** These stops being noticeably deeper than in the original tables, in the 1 min region and not altering the shallow stops by much [an easy procedure on how to do that and an appreciation of the work of Haldane and his colleagues you will find in this magazine, cf. *Tech Diving Mag*, Issue 25 (December 2016), on pages 13 – 20].

## Chapter 4: Submarine escape: Schaefer

In his 1955 contribution to the first Underwater Physiology Symposion, he presented his paper titled: *The role of carbon dioxide in the physiology of human diving*, Schaefer describes on page 135 that during breath-hold dives in the 90 feet submarine escape training tank there have been bubbles observed in alveolar and venous blood samples which have been attributed to $N_2$ and not to $CO_2$. The blood samples were drawn from the divers immediately on surfacing after a breath-hold dive. The foam due to these bubbles may have been disappearing 10 sec after surfacing or 40 sec after start of ascent, the duration of these dives being ca. 1 to max. 2 min. An allowable super-saturation ratio of 3:1 seems to be exceeded.

This in turn would imply a de-saturation with a halftime of approx. 10 + 40 / 6 (ca. 10 sec) and a saturation process with a halftime from 1/6 min up to 2/6 min.

## Chapter 5: The pragmatic Schreiner matrix

In this contribution to the fourth Symposion in 1971, Schreiner and Kelley presented their paper titled: *A pragmatic view of decompression*.

As we can see in the following page, the pragmatic 4 by 4 matrix of the 16 compartments, compartment # 0 is never used. That is: we (*) could easily extract a super-fast compartment with a halftime of 2.5 or 1.25 min by exploiting his scheme on page 210 with dQ/dt * R = 0.2772 $min^{-1}$ resp. 0.5544 (fat fraction X = 0.0)

| Specific rate of tissue perfusion ($\dot{Q}/R$) | Tissue fat fraction ($X$) | | | |
|---|---|---|---|---|
| min$^{-1}$ | 0 | 0.3 | 0.7 | 1.0 |
| 0.3 | 0 | 1 | 2 | 3 |
| 0.1 | 4 | 5 | 6 | 7 |
| 0.03 | 8 | 9 | 10 | 11 |
| 0.0085 | 12 | 13 | 14 | 15 |

FIG. 2. Derivation of inert gas exchange compartments by the arbitrary pairing of four specific rates of tissue perfusion and four levels of tissue fat fraction. The resulting compartments are numbered 0 to 15 as shown.

min$^{-1}$)* in solving Eq. (13), one obtains a total of 16 different values of $k$ representing 16 inert gas exchange *units* or *compartments*. These entities are not necessarily identifiable anatomical substructures of the body but rather represent assemblages of those regions within the human body that happen to be characterized by one and the same specific time constant of inert gas transport. These 16 inert gas exchange *compartments* (numbered 0 to 15 for ease of reference) are shown schematically in Fig. 2. It is immediately clear that any other arbitrary array of $\dot{Q}/R$ and $x$ may be employed to derive gas exchange *compartments* as long as representative and minimal rates of the specific rate of tissue perfusion and extreme values of fat fraction are included.

## Chapter 6: United States Navy method: Workman

(Ref.: Workman, Robert D. *Calculation of Decompression Tables for Nitrogen-Oxygen and Helium-Oxygen Dives*, Research Report 6-65, U.S. Navy Experimental Diving Unit, Washington, D.C. (26 May 1965))

Here we have compartment halftimes for $N_2$ from 5 to 240 min (p. 5) and the corresponding allowed inert gas super-saturations, called M-Values. The M-value follows a simple linear relationship, based on empirical dive data (Eq. 1):

$$M = M_0 + \Delta M * d \qquad (1)$$

where $M_0$ is the maximum inert gas partial pressure in the compartment for surfacing and ΔM is the change with the diving depth (in feet). By fitting separately the ΔM (Delta M) and $M_0$ over the halftimes we (*) could as well extract faster compartments and the corresponding allowed super-saturations.

### Fit for $M_0$

Our generator function yields with a correlation coefficient of nearly 1, for example for the halftimes 1.25, 2 and 2.5 min these values for $M_0$ are 156, 134 and 126 fsw respectively.

### Fit for ΔM

The above generator polynom gives here, as well with a very high correlation coefficient for the same choosen halftimes of 1.25, 2 and 2.5 min these ΔM values are 37.5, 8.4 and 4.5 respectively.

## Chapter 7: Swiss altitude diving: Bühlmann

(Ref.: *Tauchmedizin*, Albert A. Bühlmann, Ernst B. Völlm (Mitarbeiter), P. Nussberger; 5. edition in 2002, Springer, ISBN 3-540-42979-4)

Here we have already a simple relationship between the halftime $\tau_{½}$ of a compartment and the allowed super-saturation for $N_2$. If we combine the two empirical relationships for the coeffcients a & b from p. 129 (Eq. 2) with the linear equation for the tolerated ambient pressure (p. 117) (Eq. 3) into one:

(2)
$a = 2{,}0 \text{ bar} * (\tau_{½} N_2 [\text{min}])^{-1/3}$
$b = 1{,}005 - 1 * (\tau_{½} N_2 [\text{min}])^{-1/2}$

$P_{compartment} = (P_{ambient,tolerated} / b) + a$ (3)

This yields the following generator function (Eq. 4) by setting the tolerated ambient pressure to 1 bar (for a direct ascent to the surface for breath-hold diving or submarine escape training):

$P_{compartment} = (1 \text{ bar} / (1{,}005 - \tau^{-1/2})) + (2 \text{ bar} * \tau^{-1/3})$ (4)

Thus we could extract here as well faster compartments and the corresponding compartment overpressures. Here around a halftime of $\tau_{½} = 1.005$ min is a divergence in (Eq. 4) and thus this is the smallest allowed value.

Our choosen halftimes of 1.25, 2 and 2.5 min are yielding the compartment overpressures of ca. 11, 4.95 and 4.1 bar respectively. These we could compare directly with the $M_0$-values from the Workman set above, i.e. for d = 0 fsw in (Eq. 1): 4.8, 4 and 3.9 bar respectively.

## Chapter 8: PBPK: Mapleson, Nishi, Flook et al.

One of the first PBPK (**P**hysiologically **B**ased **P**harmaco-**K**inetic) models solved via a simulation with an electric analog circuit was the one from Mapleson, intended to simulate the uptake of inhaled narcotic gases like halothane in the human body:

Mapleson , W.W. *An electrical analogue for uptake and exchange of inert gases and other agents*. J. Appl. Physiol. 18: 197 – 204, 1963.

Others, like: Morales, M.F. and R.E. Smith, 1944, 1945 and1948 in: Bulletin of Mathematical Biophysics, have not been successfully solved at that time due to a lack of fast-enough hardware.

Since then the PBPKs are used to simulate as well drugs and other environmental influences on the human body: by the same token we could designate the Haldane model as one of the first PBPKs.

Mapleson‘s parameters have been used for operational diving by: Flook, V., R. Nishi, A. Khan. *Modelling and Validation of Treatment Tables for Severe Decompression Accidents*. In: Operational Medical Issues in Hypo-and Hyperbaric Conditions [les Questions medicales a caractere operationel liees aux conditions hypobares ou hyperbares] ADA395680, DCIEM, Oct. 2000.

Here we find as well super-fast compartments, i.e. # 1 and 2 in the following table:

**Characteristics of each compartment. Time constant in minutes.**

| Compartment | Tissues | Time constant |
|---|---|---|
| 1 | Adrenals, kidneys, thyroid | 0.86 |
| 2 | Heart, brain grey matter | 1.87 |
| 3 | Liver plus portal system, other small glands and organs | 3.07 |
| 4 | Brain white matter | 5.31 |
| 5 | Red marrow | 12.25 |
| 6 | Muscle and skin | 50.62 |
| 7 | Nonfat subcutaneous | 69.14 |
| 8 | Fatty marrow and fat nitrogen<br>helium | 211.3<br>78.3 |

*Reference values for resting blood flow to organs of man*: R Williams* and R W Leggett; Metabolism and Dosimetry Research Group, Health and Safety Research Division, Oak Ridge; National Laboratory, Oak Ridge, Tennessee 37831-6383, USA, 21 February 1989. On page 188 we have a compilation of the relevant perfusion values:

**Table 1.** Blood flow rates (ml per kg tissue per min) to tissues of resting man, as given in some reviews and physiology texts.

| Tissue | Mapleson 1963[a] | Bell *et al* 1968[b] | Cowles *et al* 1971[c] | Brobeck 1979[d] | Ganong 1979[e] | Guyton 1982[f] |
|---|---|---|---|---|---|---|
| Adipose tissue | 20 | – | 24 | – | – | – |
| Adrenals | 5000 | – | 5100 | – | – | 1800 |
| Bone | 0 | 120 | 0 | – | – | 50 |
| Brain | 510 | 650 | 530 | 540 | 540 | 500 |
| Lung tissue | – | – | – | 570 | – | 180 |
| Heart tissue | 800 | 1000 | 810 | 700 | 840 | 610 |
| Intestines | – | 700 | 390 | 540 | – | 700 |
| Kidneys | 4100 | 1500 | 4000 | 4300 | 4200 | 3600 |
| Liver (total) | 410 | 1500 | 840 | 540 | 580 | 750 |
| Red marrow | 90 | – | 400 | – | – | – |
| Skeletal muscle | 20-50 | 20 | 21 | 27 | 27 | 26 |
| Skin | 20-50 | 30 | 57 | – | 130 | 120 |
| Spleen | – | 400 | 390 | – | – | 700 |
| Thyroid | 4000 | 5600 | 5000 | – | – | 2500 |

The perfusion rates vary not only with a factor of 250 from ca. 20 (bones) to 5000, but as well over time course and authors. This variance should be reflected as well in the spectrum of used halftimes for a decompression algorithm. As well there are data for just 14 compartments, meaning that using a lot more, as some of dive computers do, would probably not give any further clues. The only argument of using more being philosophically, that „Nature does not make leaps“ (Gottfried Wilhelm Leibniz: La nature ne fait jamais de sauts).

## Chapter 9: Mixing two models: Egi & Gürmen

There is a nice method in this paper: Egi SM, Gürmen NM: *Computation of decompression tables using continous compartment half-lives*. Undersea Hyper Med 2000; 27(3): 143 – 153.

The authors were considering the Workman and as well the Bühlmann framework. But instead of fitting each set of M-values to the appropriate halftimes within the corresponding framework they fitted all M-values to all halftimes in a hybrid manner and such combining the Workman and Bühlmann values. The result is a smoothed M versus halftime function with high correlation coefficients. The plot of ln(M) versus ln(halftime) yields a straight line (Fig. 7 on page 149):

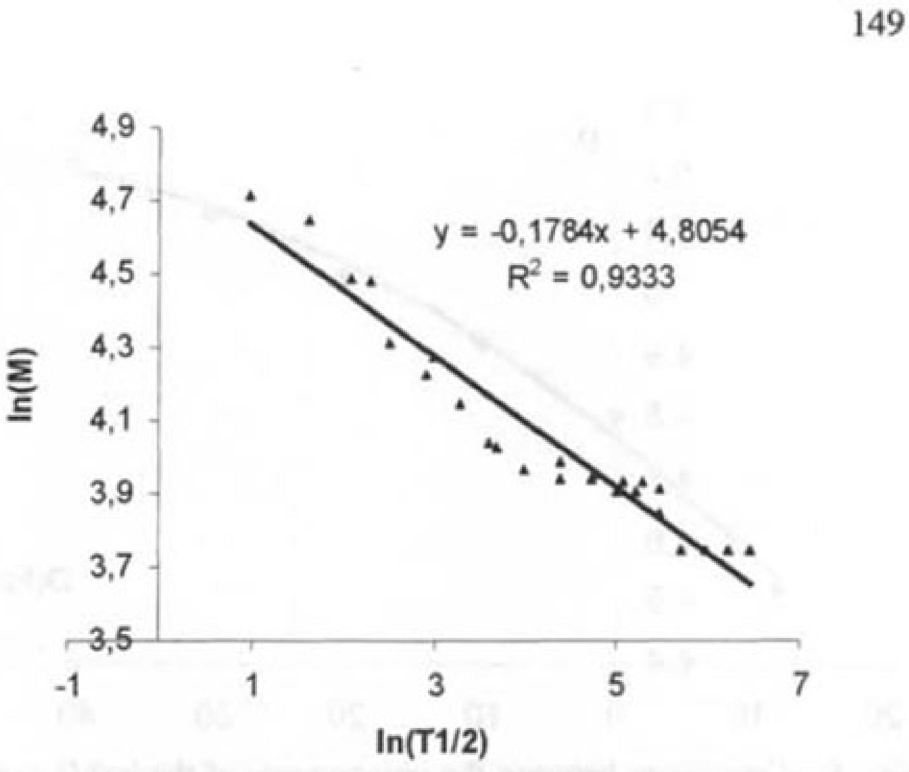



FIG. 7—Correlation between ln(M) and ln($T_{½}$) for the hybrid data set (Workman and Bühlmann) at sea level.. Table 4 lists the slope of the line and y-intercepts of different data set combinations.

If we exploit this function with x = 0.25 (i.e.: halftime = 1.28 min) the results are $M_0$ = 117 fsw; with x = 0.1 (halftime = 1.1 min) yields $M_0$ = 126 fsw.

**Chapter 10: Breath-hold and DCS Type II: Goldman et al.**

(Ref.: *Decompression sickness in breath-hold diving, and its probable connection to the growth and dissolution of small arterial gas emboli*; Saul Goldman, J.M.Solano-Altamirano, Mathematical Biosciences 262 (2015): 1–9.)

In this paper we find a super-fast compartment (brain) with the halftime of 72 sec.

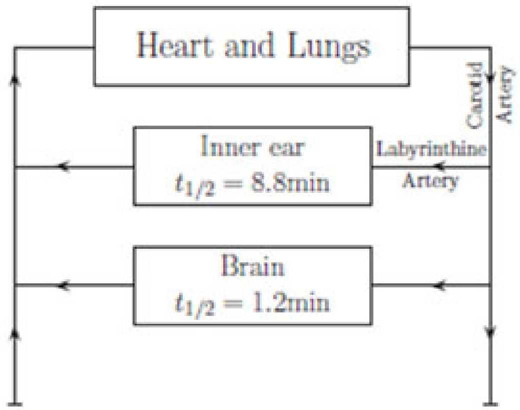



**Fig. 3.** Independent parallel compartmental model of the head showing the brain and inner ear, each represented as independent mono-exponential compartments, with their respective half-lives ($t_{1/2}$).

(Source: l.c., page 5)

**Chapter 11: A Fit to the Paulev data**

To be completely honest with my sources, I recieved the Paulev papers from Karl Huggins, with whom I started to discuss this topic around the turn of the millenium. Karl created his version of a USN deco table („HUGI table") as well he was fundamental for the ORCA EDGE dive computer in the 80s (The ORCA EDGE being one of the first diver carried computers not only interpolating stored table values but instead using a full-blown decompression model). Paulev, as described in the „Rationale", observed on himself a case of neurological DCS during submarine escape training (ref. 1) which has been treated successfully in a deco chamber. Subsequently he made measurements of exhaled gases during breath-hold diving (refs. 2 and 3):

Ref 1: PAULEV, P. *Decompression sickness following repeated breath-hold dives*. J. Appl. Physiol. 20(5) : 1028-1031. 1965.

Ref 2: PAULEV, POUL-ERIK, AND NOE NAERAA. *Hypoxia and carbon dioxide retention following breath-hold diving*. J. Appl. Physiol. 22(3) : 436-440. 1967.

Ref 3: PAULEV, POUL-ERIK. *Nitrogen tissue tensions following repeated breath-hold dives*. J. Appl. Physiol. 22(4): 714-718. 1967.

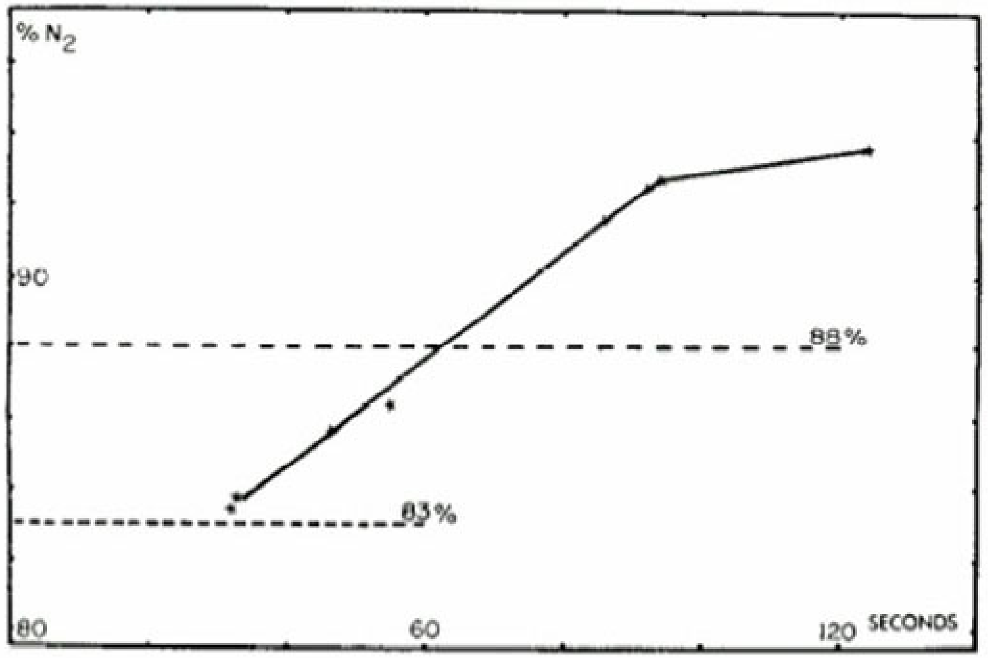



FIG. 1. $N_2$ percentages from alveolar samples obtained at the bottom of a 18.5 m deep submarine escape-training tank (7). The abscissa is the period from the start of the dive to the time of sampling. The mean durations for descent and ascent in such dives are in seconds [±SE (n = 14)]: 22.6 ± 0.3 and 13.3 ± 0.6, respectively.

From this published curve (Fig. 1 on page 715 in paper 3.; as well the Fig. 3 on page 438 in the paper 2), we (*) extracted graphically the raw data in order to simulate the $N_2$ uptake of one super-fast compartment. A fit to a mono-exponential saturation function like:

**Y = 1- a *EXP(- b *X) (5)**

Where Y = $N_2$ Saturation, alveolar [%] and X = dive time [seconds] yields the following:

**a= 0.24**
**b= 0.01**

with a relatively high correlation coefficient around 0.97; the mathematical details are too specific for an essay like this. But anyway there is:

**Error propagation**
We end at an error of approx. +/- 12 % of the fitted values due to uncertainities of the published graphical data, which is not available in digital form.

**Halftime of the super-fast compartment**
Thus the halftime is, by definition, $\tau_{½}$ **=ln 2 / b = ca. 70 sec +/- 12 to 15 %**, with a stunning coincidence with Saul's value (chapter 10). This one would give, in return to the a and b coefficients of Eq. (2), a maximal inert gas partial pressure (4) in this „fast compartment" of 8 up to ca. 20 bar within the Bühlmann framework. One could question the sheer size of this value derived from the model directly, but presently there are not enough data at hand. On the other hand, there are no arguments for not keeping the maximal tolerated overpressure from the fastest compartment as well for the super-fast compartments. Thus we could designate the ca. 3.5 bar overpressure from the traditional 2.5 to 5 min compartment to the faster ones.


**Chapter 12: Take-home messages**

A compartment is not a single physiological site in the body, instead, it is a group of various tissues, sharing some common properties, like the perfusion rate, which is basically the invers of the halftime used in the exponential curves.

If you use more compartments, say in your dive computer or a decompression model, you do not get closer to the truth, instead you just get closer to the data points at hand.

For fast processes, like yo-yo diving or breath-hold profiles, the usually used halftimes are by far too slow, i.e.: the dive computer (resp. the decompression model) acts like a „low pass“.

To simulate processes like that, you need faster and/or super-fast compartments, namely in the sub-min region, like a halftime $\tau_{1/2}$ from 30 sec to 1.5 min.

(*): SubMarineConsulting: www.SMC-de.com

# Wreck Exploration in the Gulf of Thailand

Text by Bruce Konefe

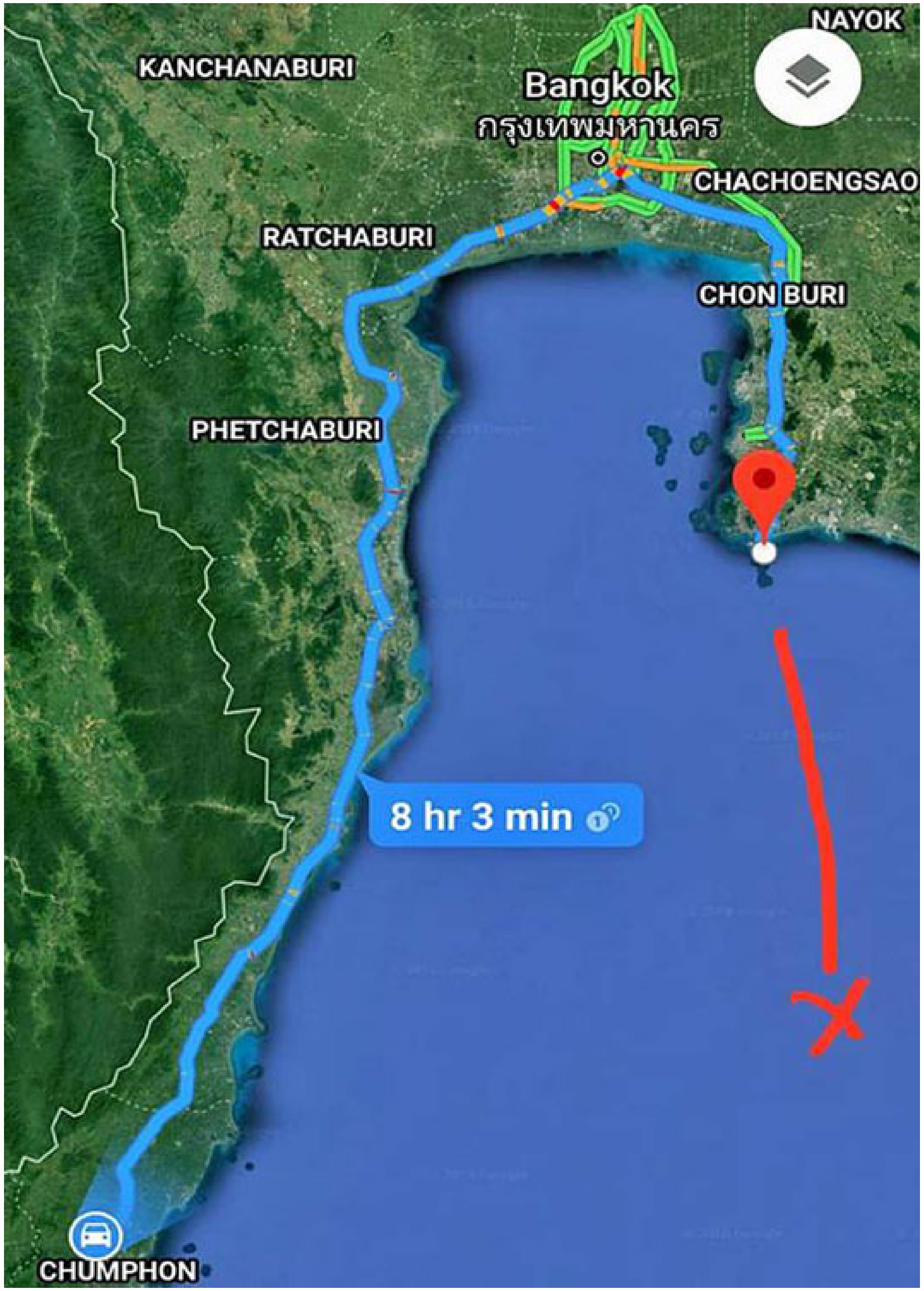
Photos by Mikko Paasi

After two months of planning and preparation, a group of mixed gas technical divers were getting ready to depart on a three-day deep wreck exploration trip. Some of the most experienced trimix open circuit (OC) and closed circuit rebreather (CCR) divers in Asia were carefully selected to join in on the trip. Some of the wrecks that we planned to explore were 15 hours out to sea and in a depth range of 65-70 meters. Because of the deeper depths all the divers would be using special equipment and breath a variety of trimix, nitrox and oxygen mixtures. The helium in the trimix would allow the divers to think much clearer because of the mitigation of nitrogen narcosis risk at those depths.

The group had received some GPS coordinates from some of the local fishermen. What we were led to believe was that these wrecks had been caught in storms and sunk to the bottom of the sea. The age and the type of the ships were unknown to any of the divers in the group. In past years there have been wrecks discovered that were up to 700 years old. Each dive would bring new information to all of us.

Days leading up to the trip many hours were spent filling tanks with the proper mixes and preparing the equipment. Each piece of equipment had to be carefully inspected. At this depth nothing could be overlooked. Some of the divers flew into Thailand while others drove up to 12 hours just to get to the pier where we would depart from.

All the divers were scheduled to meet up at 8 pm in the evening and the plan was to set sail one hour later. Everything had gone like clockwork. Everybody had found the pier and located the boat on time. It took about one hour to load up the 40 tanks, rebreathers and equipment onto the boat. Once everybody was on the boat they would find where their sleeping quarters would be. Most of the divers stayed up a while longer getting acquainted before calling it night.




As we were on the way to the first mark the boat captain wanted to stop off and check a new mark he was recently given. After going over the mark it turned out it was a large crane sitting on the bottom. The captain searched around but could not find the barge it would have been on.The large crane must have slid off the side of the barge into the water during a storm.

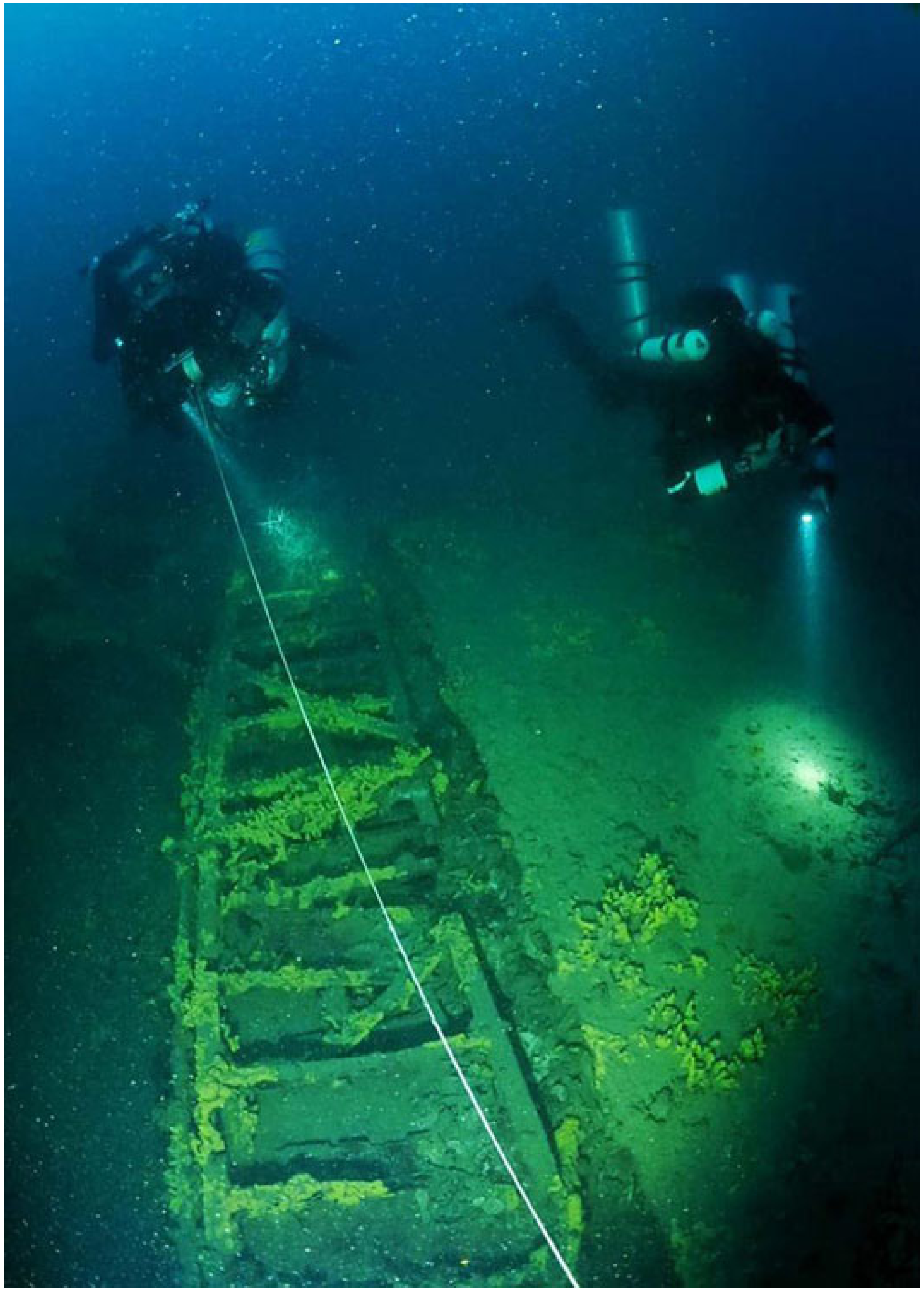
The divers had a quick meeting to decide if they wanted to dive the crane or move onto the primary target. It was an unanimous decision to head straight to the next mark. After 13 hours being on the boat we finally arrived at the mark. The boat captain had gone over the spot for a good hour before determining there was nothing there. From what we were told there was a large steel ship but there was nothing in the area. By this time it is starting to get late. The captain had a mark but it was 5 hours away. The team had to make a quick decision on what the next plan of action would be.We took the chance and hurried to the next spot. By the time we got there it was too dark to get into the water. The captain knew we were a bit discouraged but he also knew what would cheer everybody up. The captain normally charters out fishing trips and had everyone reeling in the fish that evening.

In the morning while everybody was eating breakfast the boat captain was searching for the wreck. The wreck was so large it did not take him very long to find.The captain and crew did an excellent job of dropping the anchor a couple meters away from the wreck. You could tell from there experience that they have done this many times. The bottom was 65 meters and the top of the wreck would be at 55 meters. The total length of the wreck we estimated to be about 120-130 meters.

Now that we had the actual depth of the wreck we could do our final dive planning. The divers had split up into two teams. The first team of divers in would be the OC divers. The CCR divers would start their dive 20 minutes later. This would give everybody a bit more room on the ascent/descent line. I was with the first group and we had started to descend down to the wreck. We had to stop momentarily on the way down since one of the team members was having trouble equalizing. We were lucky to have very good visibility. Even at depth we could see a good 20-30 meters. As we had descended it was very easy to see that the wreck was lying on its starboard. The captain had dropped the anchor a couple meters away from the keel. Once we reached the bottom I tied off onto the descent line. I would run the line out during the dive to help assist us back to the ascent line. Just as we finned over the top of the wreck we could see large cargo holes and also the mid center bridge. We did a quick search through the cargo holes as we worked our way towards the bow. Fortunately, we managed to reach the bow before reaching our turn pressure.

As we were returning back to the ascent line we had passed the CCR divers. The CCR divers would be able to gather much more information of the wreck. Mikko and Mario were able to take photos/videos which we could later examine. In some photos there are letters near the bow. There are only a couple of them but hopefully we will be able to identify this wreck in the near future.

Once all of the divers were back on boat we had a post dive briefing. Trying to figure out the age and where the wreck actually comes from can take months of research. We are getting the GPS coordinates from the captain… hopefully we can find a match on some of the wreck archives we have. The best that we could make out so far is the wreck is roughly a 120,000 ton mid center bridge post war with cargo forward and aft holds. Both of the bottom teams had laid out 100 meters plus of line. We believe the wreck to be between 120-130 meters long. At this time we are going through all of the videos and photos to see what clues we can come up with to help identify this monster.




The whole trip could not have gone any smoother than what it did. We were lucky to have calm waters and good visibility. As we gather more information and come up with more details we will try to keep you informed. Special thanks to Mikko Paasi for the hard work he did getting the excellent still photos and video footage.

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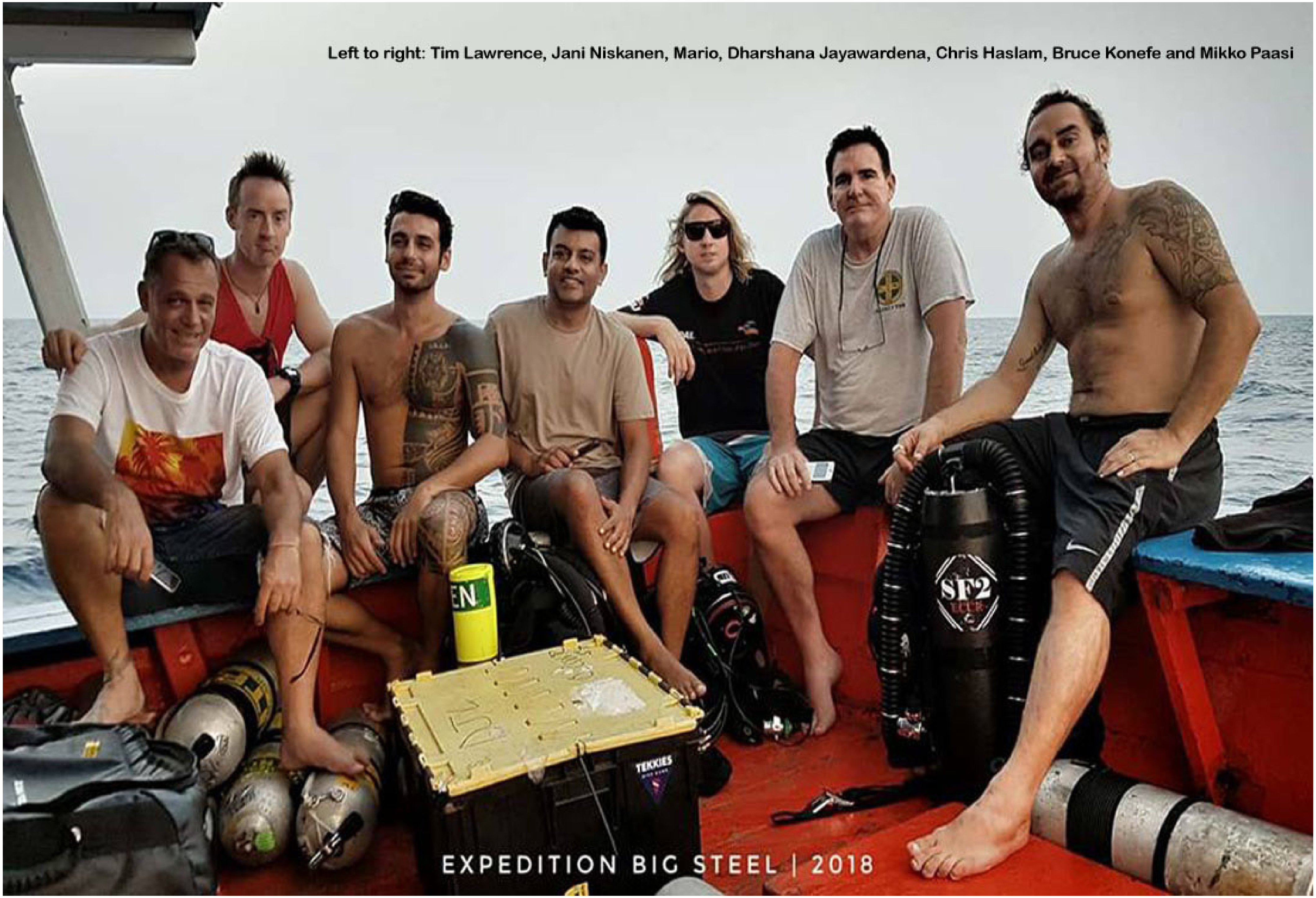
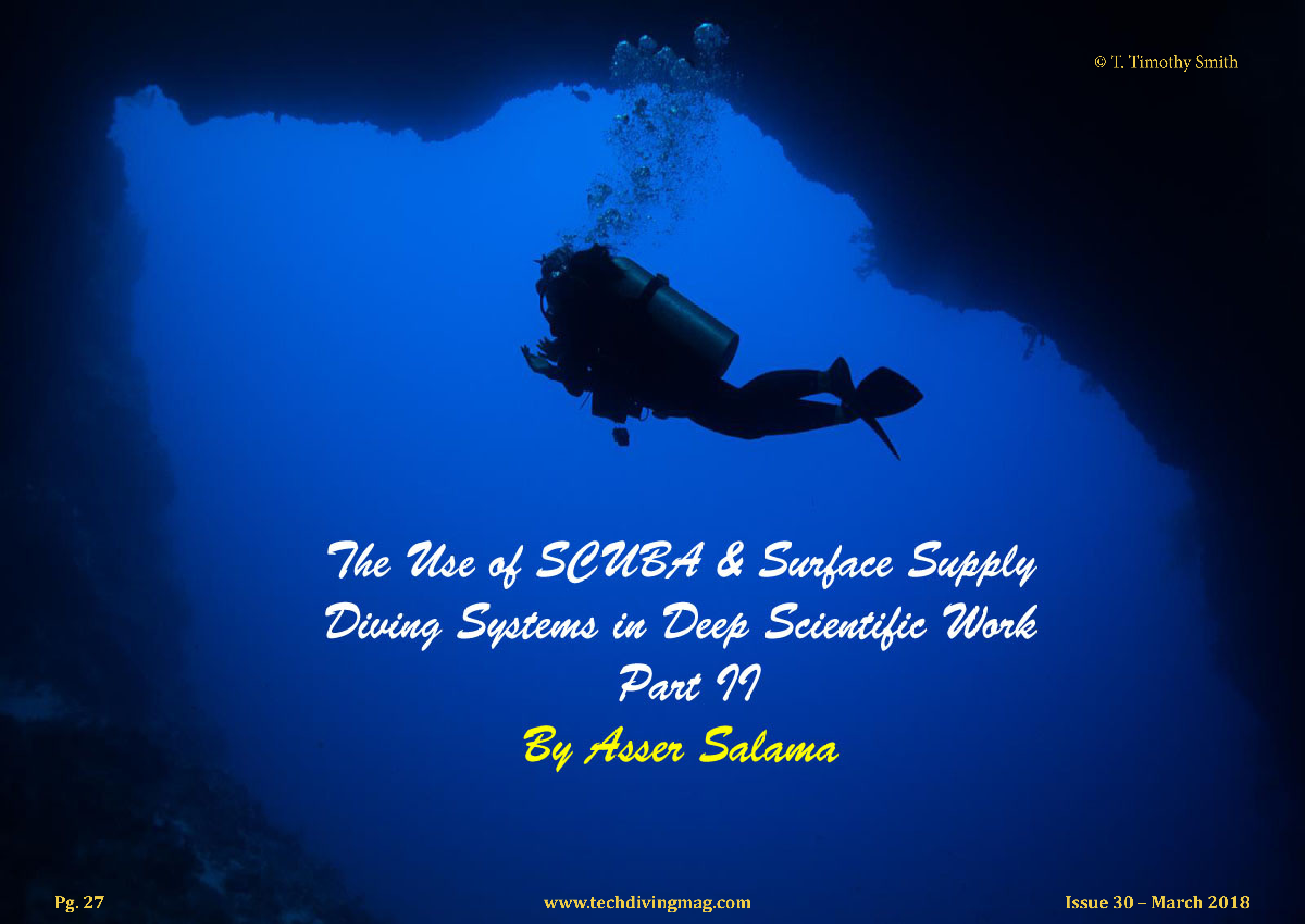


Left to right: Tim Lawrence, Jani Niskanen, Mario, Dharshana Jayawardena, Chris Haslam, Bruce Konefe and Mikko Paasi



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# The Use of SCUBA & Surface Supply Diving Systems in Deep Scientific Work
## Part II

By Asser Salama

In the first part of this series (published in issue 22 of *Tech Diving Mag*), author Konstantinos Alexiou illustrated the shift of the scientific diving community towards the use of closed circuit rebreathers (CCR) in order to conduct deep underwater scientific work. He stressed that the scientific diving community is yet to realize the potential of surface supply diving (SSD) systems for their deep applications. He argued this would take time, because an adequate operational and legislation framework in which this mode of diving would function is yet to be established. In this part, I will look further into the use of SSD systems in scientific work.

In an SSD setup, breathing gas is supplied to the diver via an umbilical. This umbilical typically consists of a breathing gas hose, a pneumofathometer (or simply pneumo) hose to monitor the diver's depth from the surface, along with a two-way communication line that usually serves as a strength member (for towing or lifting the diver if required) as well. The umbilical is either sinking or floating. The floating type is the default option for many scientific diving applications, as it is less likely to get entangled or stir up silt or contaminated sediments. Positively buoyant, it is more likely to be affected by high currents or get caught by a passing vessel though. Depending on the situation, the buoyancy of the umbilical can be modified on site by adding weights or floats. Throughout the dive, a dive tender maintains control of the umbilical, as it should have just enough length to allow the diver to work freely but not to get entangled. It is worth noting that, when it comes to deep diving, one constraint of the SSD setup is the length of the umbilical, which limits the range of the diver. Diving deeper means having less range.

On the surface, the dive is monitored and controlled via a control box or station. Breathing gas is supplied to the control box via tanks, compressors or a hybrid system. The control box operator is responsible for delivering suitable and sufficient breathing gas to the diver according to the dive plan and the diver's consumption rate. This setup provides the diver with virtually unlimited gas supply. The diver carries some gas for emergency situations only. The communication line connects the control box to the diver's microphone and earphones, which are integrated into the full-face mask or helmet. The control box operator is responsible for maintaining the communications with the diver.


A simple SSD operation requires a minimum crew of three: diver, tender and control box operator. Some SSD agencies require an additional member: stand-by diver (always ready to enter the water in case of emergency). If the scientific application requires two divers to be in the water at the same time, a minimum crew of six is required: two divers, one stand-by diver, two tenders and one control box operator, as the standard control box can cater for two sets of uniquely-colored umbilical lines.


Diver wearing full-face mask. Photo courtesy of Wikipedia. Public Domain.

Although SSD increases the complexity of the operation, it has several advantages. Being tethered, the diver could be hold in place and not get swept away in strong currents. Communications between the diver and the surface crew become more clear and efficient. On the other hand, it would be more difficult if not impossible to survey overhead locations like caves, caverns and grottoes.

Being on virtually unlimited gas supply makes the diver more safe, especially in situations when extensive time is needed to conclude the operation (long decompression or gear decontamination, to name a few). The help offered by the surface crew increases the possibility of operation success, especially when it comes to situations where the visibility is deteriorated to the extent that the diver can't read the gauges. As stated earlier, the control box operator will always monitor the diver's depth and ensure suitable and sufficient breathing gas is delivered.