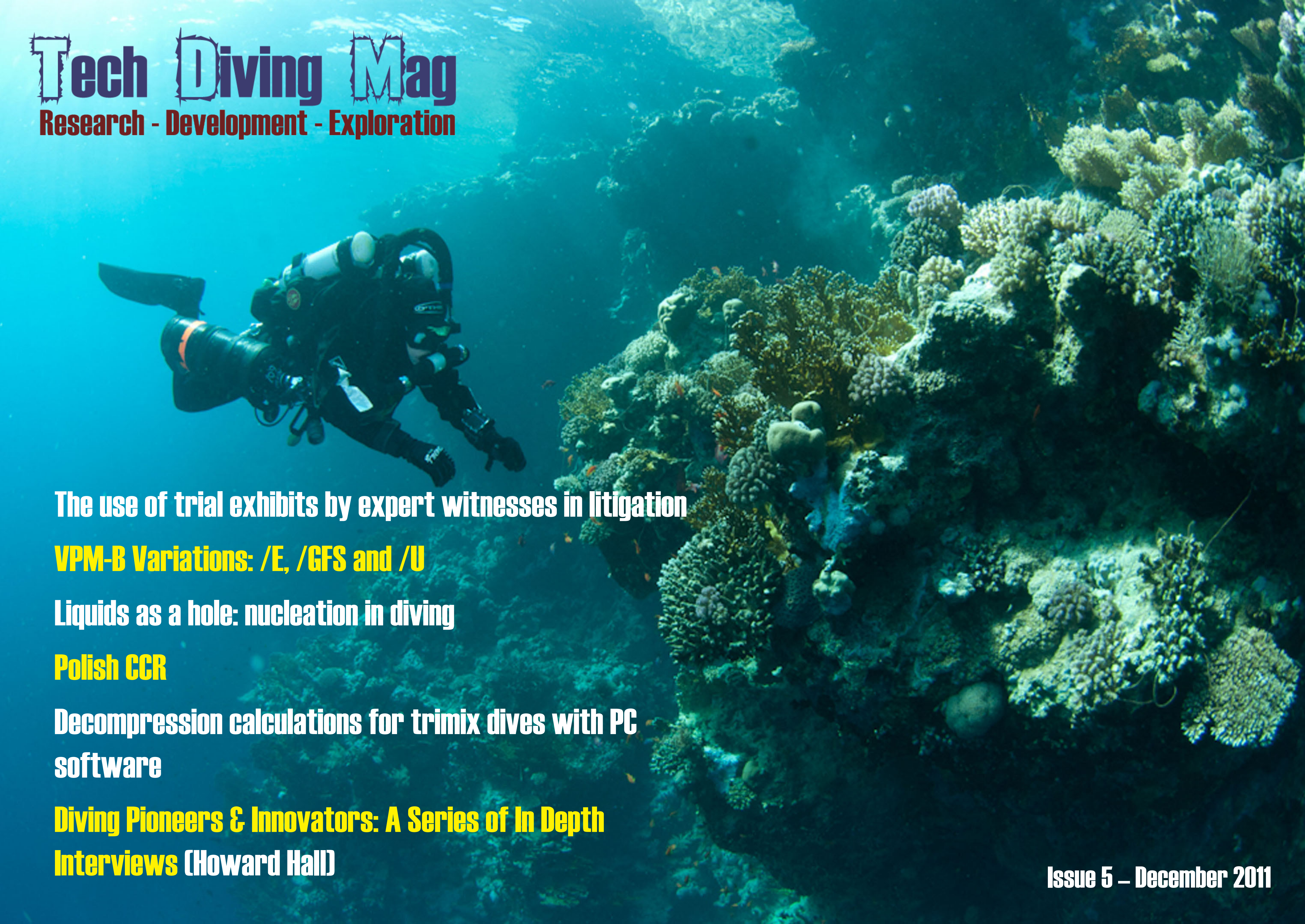


Tech Diving Mag

Research - Development - Exploration

The use of trial exhibits by expert witnesses in litigation

VPM-B Variations: /E, /GFS and /U

Liquids as a hole: nucleation in diving

Polish CCR

Decompression calculations for trimix dives with PC software

Diving Pioneers & Innovators: A Series of In Depth Interviews (Howard Hall)

Issue 5 – December 2011

Contents

Front cover image © Espen Indbjør.

Editorial

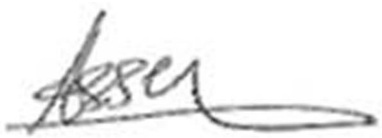
Welcome to the fifth issue of Tech Diving Mag.

It's Tech Diving Mag's first anniversary! And we'll celebrate it with a "deco-special". Read some in-depth decompression-related articles, in addition to other interesting topics.

In this issue, the contributors have, again, brought together a wealth of information and distinctive first hand experiences. The contributors for this issue are world renowned industry professional Bret Gilliam, retired NASA researcher Michael Powell (MS, PhD) and technical diving instructor Albrecht Salm (PhD). Read their bio at www.techdivingmag.com/contributors.html.

Tech Diving Mag is very much your magazine and I am keen to have your input. If you have any interesting articles, photos or just want to share your views, drop me a line at asser@techdivingmag.com.

Please visit www.techdivingmag.com/communicate.html to subscribe to the newsletter in order to be notified when new issues are available for download.



Asser Salama
Editor, Tech Diving Mag

The use of trial exhibits by expert witnesses in litigation

By Bret Gilliam

My article in the last issue dealt with the analysis of a specific single case and trial that I worked on as the defense maritime and diving expert. This involved the disappearance of two divers at Cocos Island, nearly 500 miles offshore of Costa Rica. A key thing at trial is being able to use exhibits during testimony to help the jury understand complicated facts, theories, and the geography on an area where an accident or fatality has occurred.

It's a complicated process and most trials end up being won by primary expert witnesses during their live testimony. Doing the "grunt" work on the files is fairly routine but takes time and a bit of careful strategy in coming up with a defense posture that can play effectively to a judge or jury. But there is nothing like the pressure of a live deposition or trial wherein the absolute necessity for extemporaneous and calculated quick thought plays such a vital role. As an expert witness, it is impossible to fully anticipate where the cross-examination will go, what ploys are attempted by opposing counsel, what tactic to deceive you about the actual evidence or prior testimony may be taken, etc. It is a very stressful role to play as you must not only protect the defendants' conduct with sometimes very extemporaneous responses, but also remember to maintain control and speak to the jury as a credible, likable, and professional witness in whom they should place their trust to explain the complicated facts and nuance so they choose to favor your opinion over that of the opposition. It is an arena that few people do well in and requires a tremendous degree of control and spontaneous thinking with no room for error. I've described it before as the equivalent of an "intellectual gladiator pit". That sums it up pretty accurately.

If given the proper tools and time for preparation, there are few trial lawyers who can cross-examine me without actually hurting themselves in the process. For years, I've been able to make more points sometimes during cross than in direct testimony and this is not lost on the jury when opposing counsel gets his ass clobbered when he least expects it. That ability to think quickly and respond effectively to gain the advantage is what wins cases.

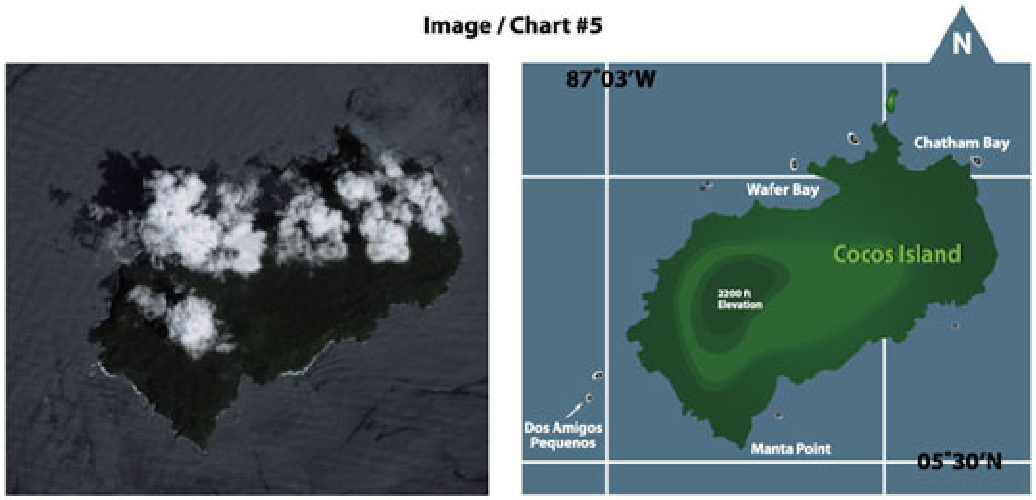
The pressure of depositions and trial work for an expert is difficult to fully articulate. But lawyers even occasionally ask themselves if they would like to place themselves on that line of fire. Even they don't experience that pressure since they are not cross-examined. It's a very surreal experience and only a handful of professionals are consistently successful at it. So far in my career (specializing exclusively in diving and maritime litigation), I've done 247 cases. I've yet to lose at trial. That's a pretty tough record to equal. There are many "experts" who also tend to taint their credibility by almost exclusively doing either defense or plaintiffs sides as their "specialty". You may have heard the term "plaintiff's whores" applied to some "experts" whose entire careers have been devoted to selling themselves to those who are prosecuting the case on behalf of those suing for damages. The same term gets applied to those who only do defense work. This is usually brought out at trial and tends to immediately damage their credibility. It doesn't help them that these types are also advertising in legal journals and running recruitment web sites.

In my career, my case load is nearly exactly evenly split between plaintiff and defense work. And I don't advertise or even have a web site. All my work comes from referrals or my reputation from other trials that can be researched by lawyers on such things as WestLaw or Lexis. If I don't absolutely believe in the conduct of a defendant or the facts that suggest that negligence did occur and a lawsuit is justified, I turn down the case. Because I am so extensively published on diving and maritime operations, medical and safety protocols, risk management, and all other issues involving these industries as well as having my expert opinion taken in hundreds of sworn depositions and trial testimony, I can never take a case that would be counter to prior opinions. That would give the other side cause to “impeach” my testimony and lessen its influence on the jury. So I sometimes end up turning down cases where I am actively solicited since my opinions and “moral compass” will not allow me to support their side. Like I said... it’s complicated. Especially if you believe in ethical behavior. That’s lacking a lot in litigation from my perspective.

Now to specifics and how trial exhibits have been practically, and successfully, applied to win cases.

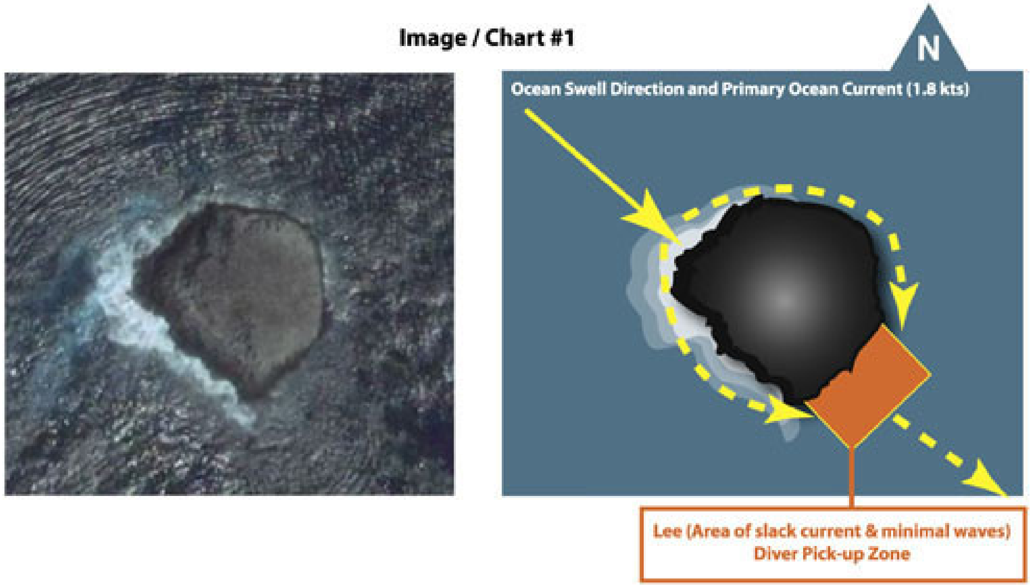
Double fatality at Cocos Island: defense maritime and diving expert

Image / Chart #5



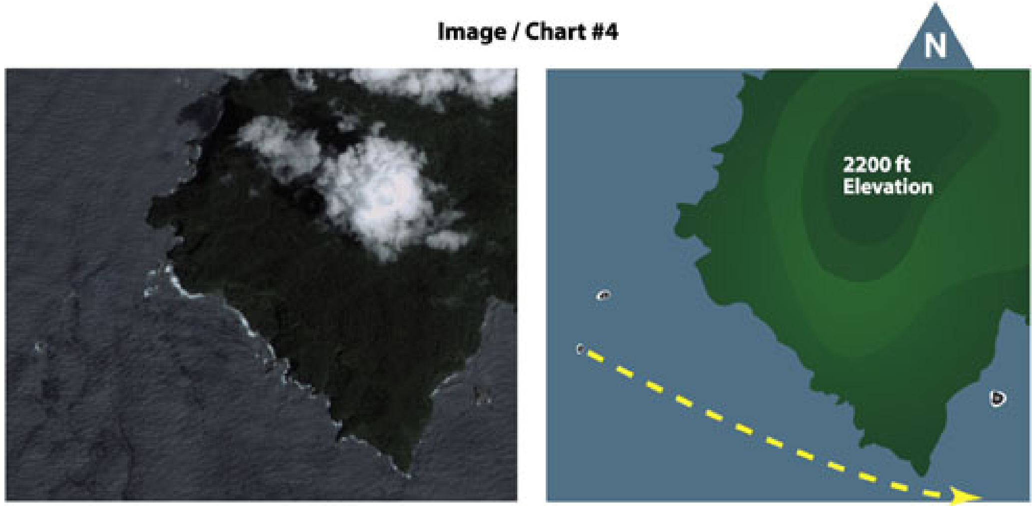
The above exhibit was derived from taking an actual satellite photo of Cocos Island and having a graphic artist produce a drawing that replicates it showing latitude and longitude as well as the island’s mountainous topography and the relative position of Dos Amigos Pequeno (the accident site) from the dive vessel’s anchorage in Chatham Bay, about eight miles away. The accident site was located off the main island’s west side and VHF radio communications to the dive boats was blocked by the high mountain. Since none of the jury had ever been there, these exhibits help them to understand the geography, currents, relative positions of the dive site to the support vessel, etc. during my live trial testimony. These are projected on large screens for their simultaneous viewing.

Image / Chart #1



This exhibit shows another satellite photo of the small pinnacle where the dive took place. You can clearly see the impact of the seas as they strike the face of the pinnacle and deflect to wrap around it. The graphic then shows the actual direction of sea swell and prevailing current. It also shows the area on the south side of the pinnacle where almost complete calm water and no current exists. This was the planned pick-up zone for divers as they completed their observations of schooling shark activity on the north side and then rode the current around to the protected lee for recovery by the dive launch. All divers, except the two who disappeared, completed the dive and were picked up immediately upon surfacing in the lee zone. The two who disappeared were not see at all by the others and their disappearance remains a mystery. But the facts suggest that they died underwater and never surfaced. Since they were diving independently and not being guided or involved in supervised instruction, they were responsible for their own conduct underwater.

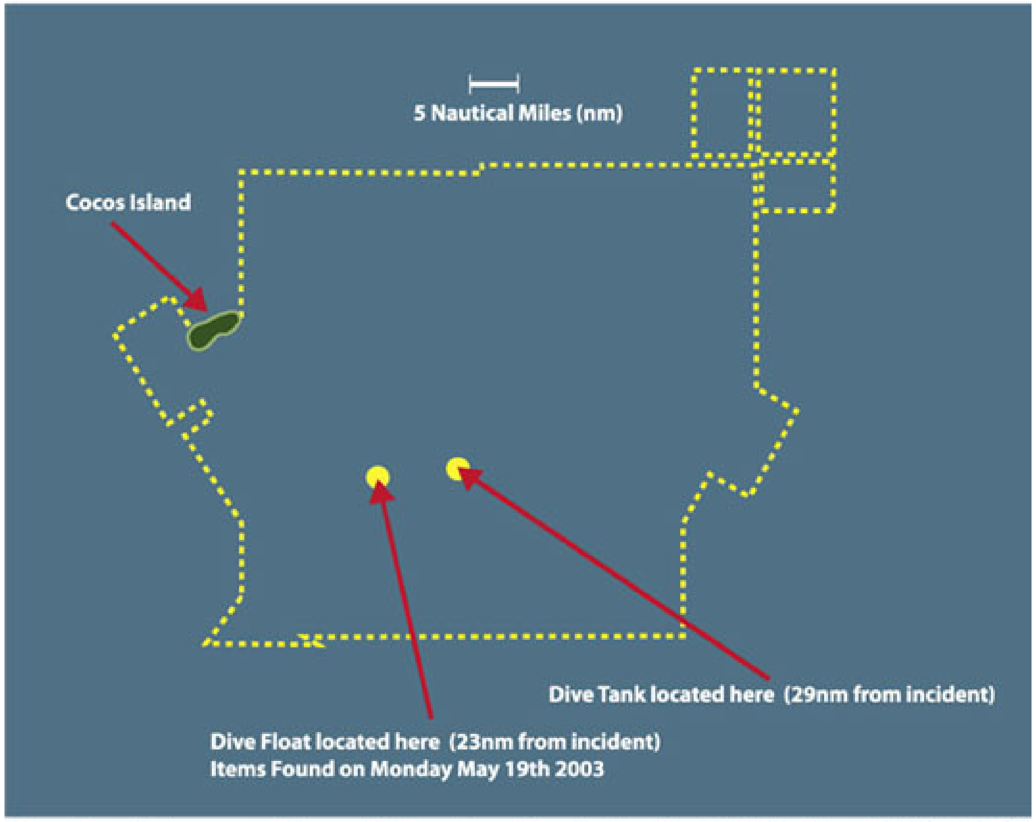
Image / Chart #4



Ocean Current Drift Path

This exhibit shows the ocean current set and drift and what would happen to a diver or object on the surface if they came up and simply drifted. The current would have tended to push them within easy reach by swimming (less than 100 yards) of the southwest corner of the island. The current then wraps around the island and moves to the east making it even more likely that divers would simply have been brought to the south beach area unharmed. Since no trace of them or their bodies were found underwater or on the island, my argument convinced the jury that their deaths occurred underwater at the Dos Amigos Pequeno site. This shut down any arguments that the defendants (the divemaster, the vessel, the captain, etc.) failed to do a proper search & rescue in the aftermath. You can't fail to do such an operation if no one comes up to find.

USCG Search Area



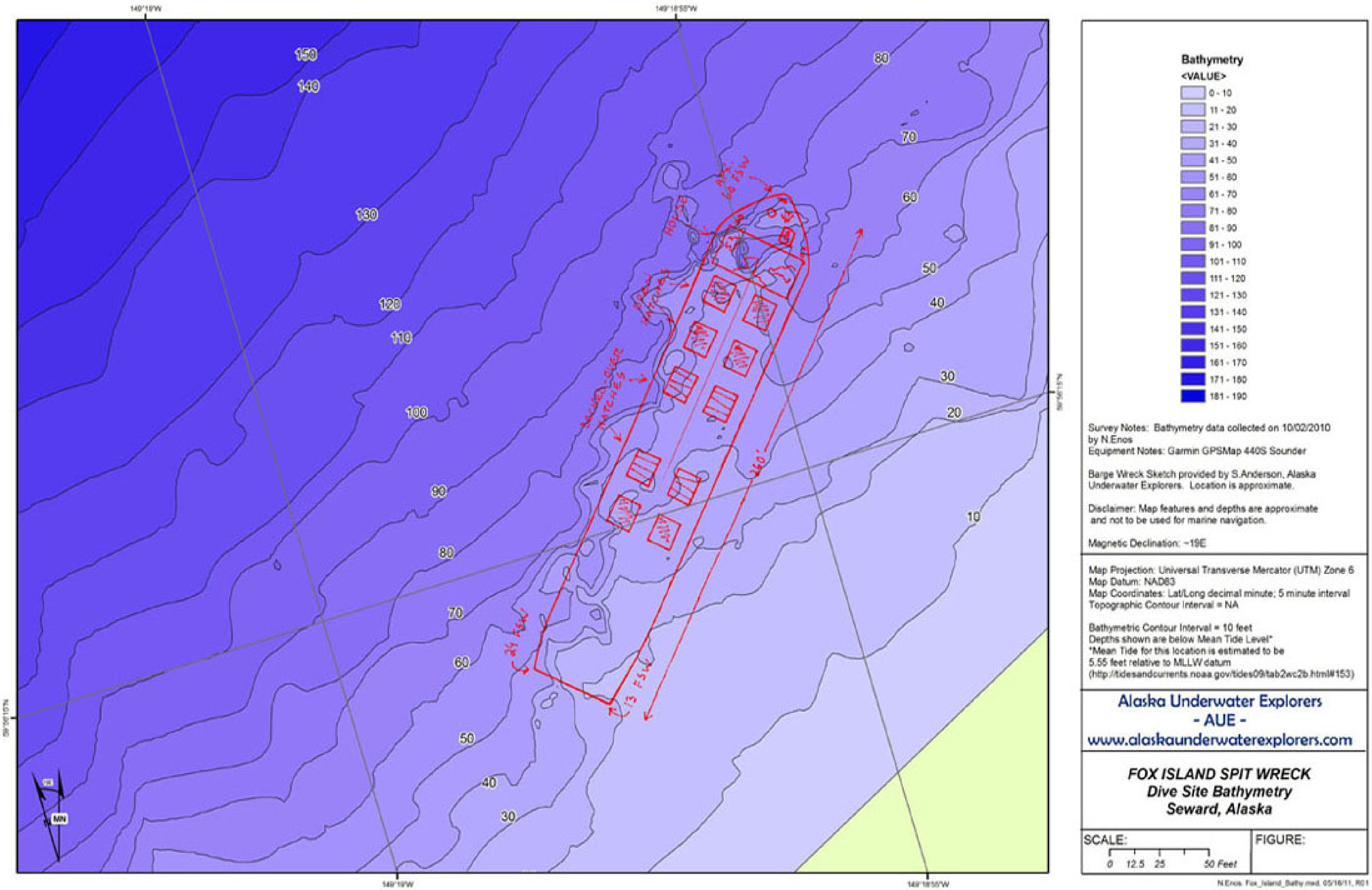
Graphical Representation of Searches Conducted by USCG May 16-22 2003

This graphic was produced from the exhaustive reports of the U.S. Coast Guard in their own search operations that lasted seven days and involved surface vessels, aircraft, helicopters, and manned high speed boats to canvas nearly 2000 square miles of ocean. The only trace ever found of the divers was a dive tank and a surface sausage float that had not been inflated. My testimony was that it was beyond any credible belief that such items would have been jettisoned by divers if they were drifting on the ocean surface and hoping to be found. A tank provides both positive buoyancy, low pressure air for Dive Alert whistles, and the ability to inflate a BC. The tank had over 500 psi remaining and therefore was a valuable safety tool for a diver. No other traces of the divers were ever found. It is more likely that one diver had an out-of-air emergency and they suffered the typical double fatality that has been statistically the case in so many scenarios. More likely than not, the tank and safety sausage either came apart during the underwater struggle and floated to the surface while the two divers sank to the deep bottom... over 1000 depths near the pinnacle.

The trial lasted two weeks. I was the last to testify and I was on the stand all day... nearly eight hours for both direct testimony and cross-examination. The jury believed my expert opinions and returned a complete defense verdict with no award for damages. It was a remarkable victory for the defense in a highly publicized and emotional case.

Right: Prof. Rick Grigg, Ph.D. and Capt. Bret Gilliam following testimony in a Hawaii trial in Federal court. Grigg and Gilliam are frequently teamed as experts to cover oceanographic conditions and maritime/diving issues respectively. In addition to being a world renowned oceanographer, Grigg is a pioneer surfing legend who led the way in the late 1950s with first to surf the giant waves of Hawaii's North Shore. Both men do civil and criminal trial work as well as consulting to government agencies.

Diver death during training in Alaska: plaintiffs' diving expert



The above graphic is a dramatic illustration of the site where this fatality occurred in Alaska. An instructor and one student were to dive this wreck to a maximum depth of 110 feet for 20 minutes. This shows the exact bathymetry of ocean bottom contours and topography along with the outline of wreck laid over the ocean bed. The wreck is in close proximity to shore and only submerged about five feet deep at its stern. The bow is in nearly 120 foot depths. This gives the jury a very clear overview of the site, its location near the shore, and the various depths involved.

This case had multiple issues of negligence directed at the supervising instructor who allowed his student to run completely out of air during a training dive. This was even worse for the instructor's conduct since it was just him and one student... no issues of trying to look after more than a single diver. After the diver ran out of air and made a panicked ascent, the instructor failed to share air or establish the student's buoyancy on the surface by inflating his BC. More negligence was evident since the instructor insisted the student wear his weight belt under his BC waist and crotch strap so it could not be dropped. Although they were only a short distance from shore, the instructor decided to let the student sink beneath him and desperately try to cling to the instructor's extra regulator second stage... only by his teeth... while being towed by the instructor on the surface. When the student became exhausted from such an ordeal, he finally lost his bite grip on the mouth piece and sank in less than ten feet of water. He was totally helpless since he was grossly overweighted by the weight belt that could not be dropped and completely out of air. Instead of diving down to rescue his student, the instructor (who had plenty of air remaining in his own tank) swam to shore. He then removed his own equipment, walked up the beach, and swam back out to the dive boat. He then called the Coast Guard and sat there for nearly two hours before rescue teams arrived. His excuse was that he couldn't see the helpless student on the bottom... less than ten feet below him. At that point, he would have been easy to recover and bring to the surface. Instead, the instructor abandoned him to certain death by drowning.

When the rescue team arrived and the instructor directed them to the position where he had last seen his student, they went there and immediately could clearly see the body from the boat. They didn't even have to get in the water. So the issue of vertical visibility was a huge factor in determining negligence and liability... not to mention the issues of the instructor's overall truthfulness in a series of statements and testimony wherein he contradicted himself repeatedly.

I decided the best way to show the jury what the instructor had really seen was to return to the exact site under the exact same tidal and visibility conditions and place a mannequin (equipped exactly as the deceased diver) on the bottom in the same depth of water. I then photographed that "body" from the perspective that the instructor would have had from the surface of the water. The above photo shows the life sized mannequin ready to be deployed from my support boat into the ocean and placed on the bottom.

Since the exact location of the body recovery was in the USCG reports and rescue team records, I knew the exact location to place the "body" to re-create the scene. Before putting the "body" in the water, I photographed the support boat's chart plotter and GPS as evidence that I was in the exact same location.

I then placed a surface buoy marking the exact location and showing how close to shore the helpless student was when the instructor abandoned him. The distance was less than 50 feet to the rocky beach.

This other photograph shows more perspective on the body location by providing scale with a person standing on the beach and showing another vessel in the background. The body was in nine feet of water when the instructor abandoned his student. The depths rapidly decreased to less than four feet deep in only 20 feet of linear distance to the shore. In my opinion, even a neophyte diver could have effected this rescue. The instructor involved had over 40 years of experience.

This view shows the "body" clearly visible in ten feet of water. I then had an assistant diver move the "body" progressively deeper in ten foot depth increments to clearly show that the student would have been easily visible and able to be swiftly recovered in far deeper depths.

This photo (taken from the just beneath the surface where the instructor's point of view would have been) shows the "body" clearly visible at 50 foot depth.

These photos completely impeached the instructor's credibility and testimony that he could not see the student in less than ten feet of water. I testified over the course of two and half days as the plaintiffs' expert. The case settled (to the satisfaction of the widow and children) a day after I testified. The trial was halted at that point before the plaintiffs' case was even completed.

The following press release came out in the trial's aftermath:

Alaska Wrongful Death Suit Against PADI Instructor Settles Mid-Trial

Plaintiffs Reject Million Dollar Settlement Offer Prior To Jury Selection

Released on: 8/30/2011

A lawsuit filed in Kenai, Alaska has been settled on a confidential basis during the third week of a jury trial against PADI instructor Robert Hicks and his employer Alaska SeaLife Center.

The suit alleged that Matthew Myers, a student training in Hicks' self-created Scientific Diving Course@ at the SeaLife Center died when he ran out of air during a deep dive, and was later abandoned by Hicks in nine feet of water approximately 30 feet from shore. Myers had been seriously overweighted and was being towed with Hicks' regulator second stage mouthpiece in his mouth while underwater, with Hicks swimming above him on the surface until Myers dropped off. Hicks proceeded on to shore, then returned to their dive vessel anchored a short distance away and called for help, which arrived over one hour later, but remained on the vessel.

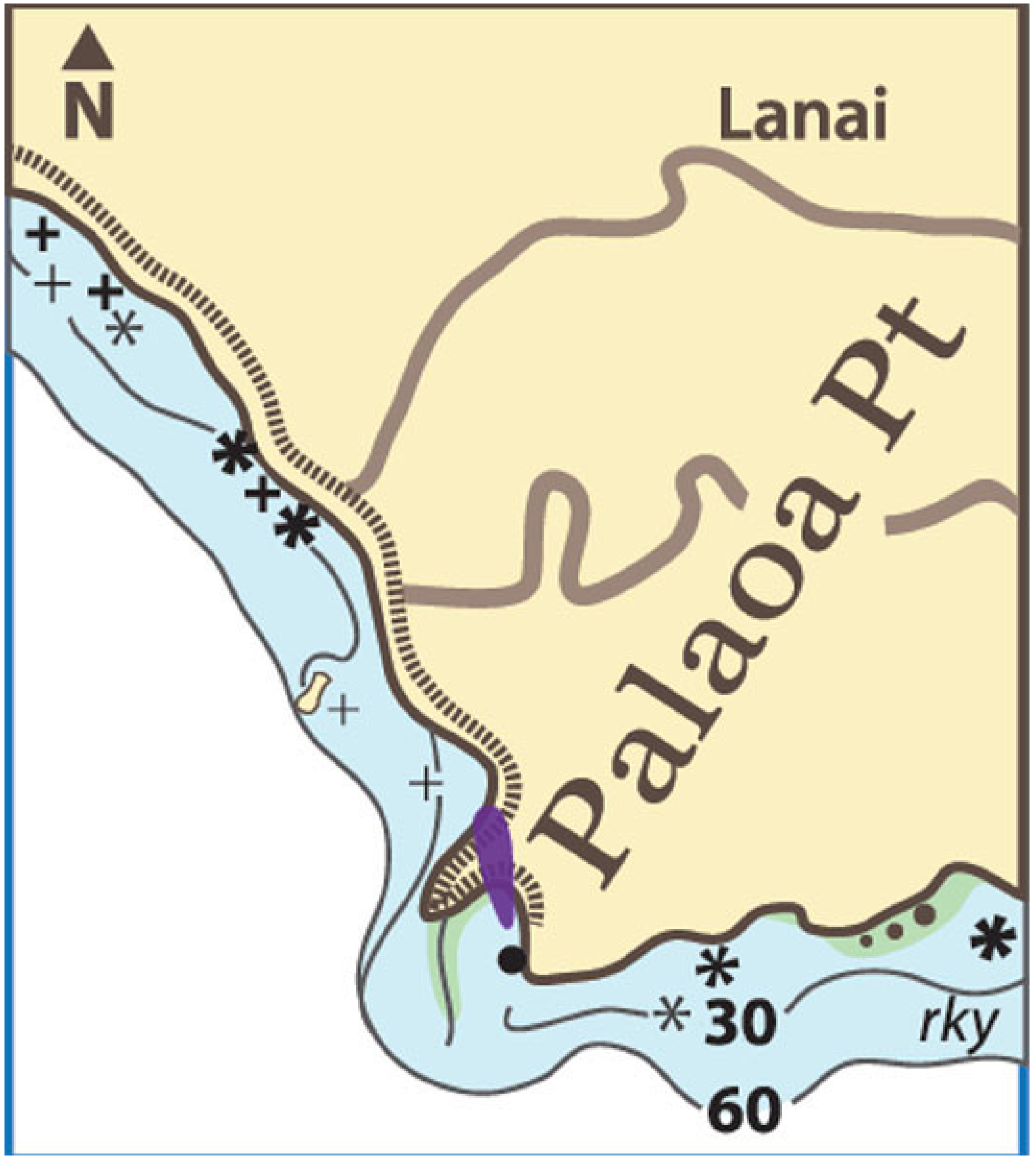
Myers left a widow and two small children, who were represented in trial by Anchorage attorneys of Phillip Weidner and Cristina Weidner Tafs, together with noted Divelaw attorneys, Michele Nelson Bass and Rick Lesser.

Freediver death during school cruise in Hawaii: plaintiffs' diving and maritime expert

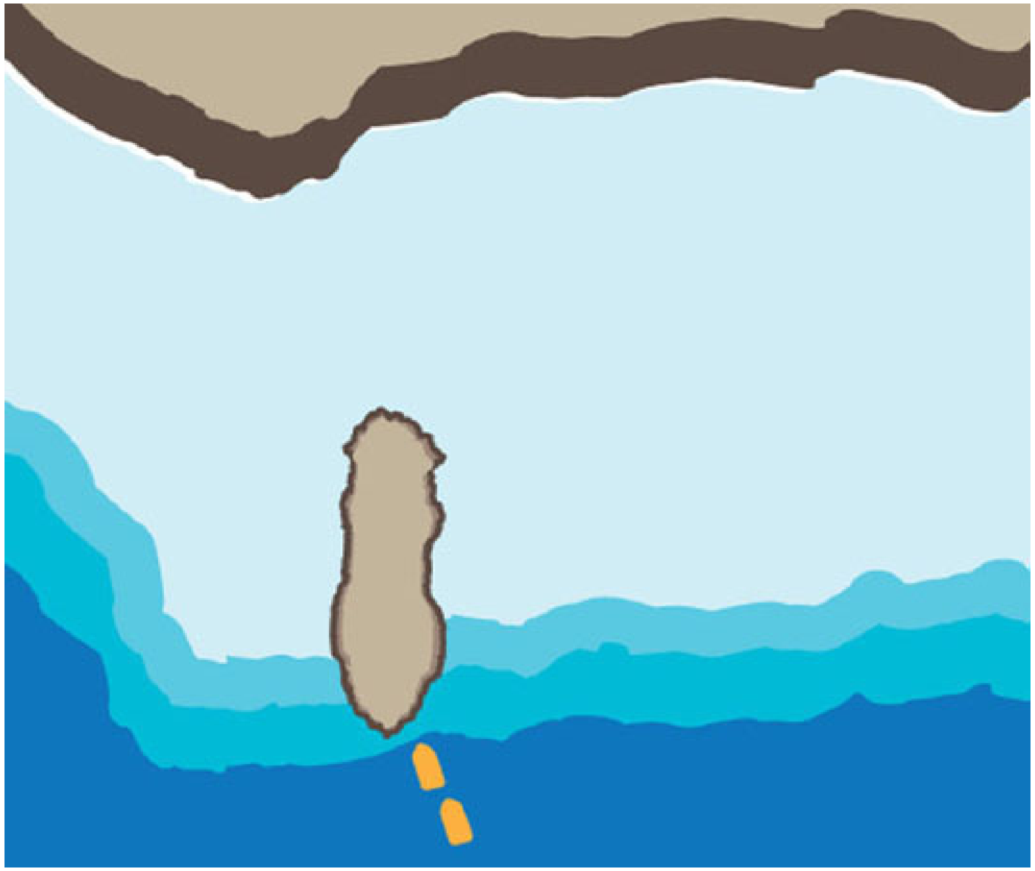
This case involved a high school teacher who accompanied his students on a small expedition-style vessel (145 ft. long) for a trip around the islands of Hawaii. He engaged in freediving at an area off Lanai Island (west of Maui) adjacent to a rock formation known as Shark Fin Rock. In this area, the east side of the rock features shallow depths (15-25 feet) and is protected from current. However, the ship had their crew place their large inflatable launches to a mooring site on Shark Fin Rock's west side where the area had an immediate precipitous drop-off and a strong current. The liability issues included whether this was an appropriate site, the fact that no staff accompanied the deceased, and then the boat crew failed to respond adequately when he passed out underwater. It was necessary to scramble other crew from the main ship since no scuba gear or oxygen units were aboard the launches. The deceased may not have been aware of the deep depths proximately to his entry point and that he would not have any crew support.

This first photo shows the bay on the west side of Lanai with Shark Fin Rock clearly shown. The orange inflatable is provided for scale.

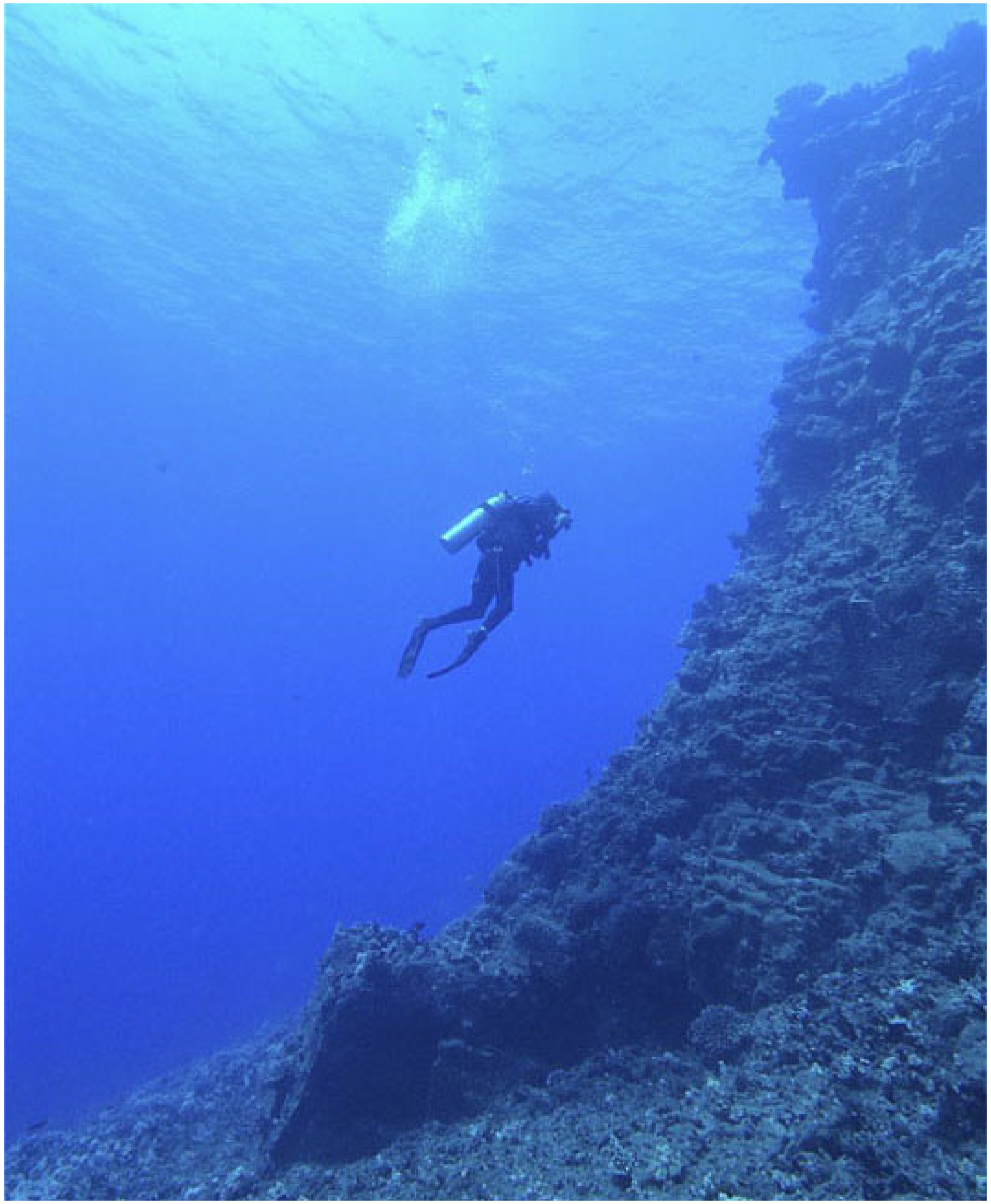
Another view of Shark Fin Rock showing an inflatable boat taking tourists snorkeling in the correct area.



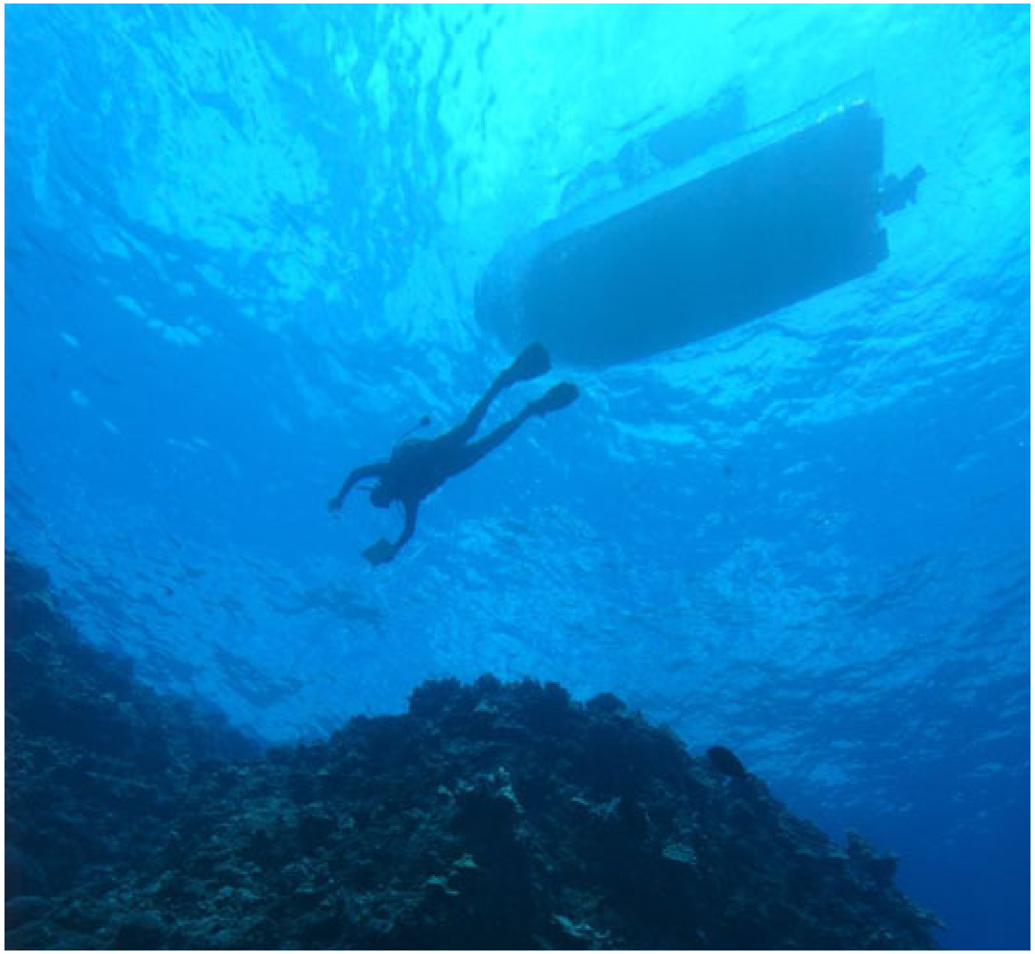
This re-creation of a NOAA nautical chart had to be completely redrawn to show accurate scale of the area. Shark Fin Rock appears as the small "island" to the left (west) of bay north of Palaoa Pt. This also shows the depth contours clearly and how close the ten fathom (60-ft. depth) line runs right to the edge of Shark Fin Rock.



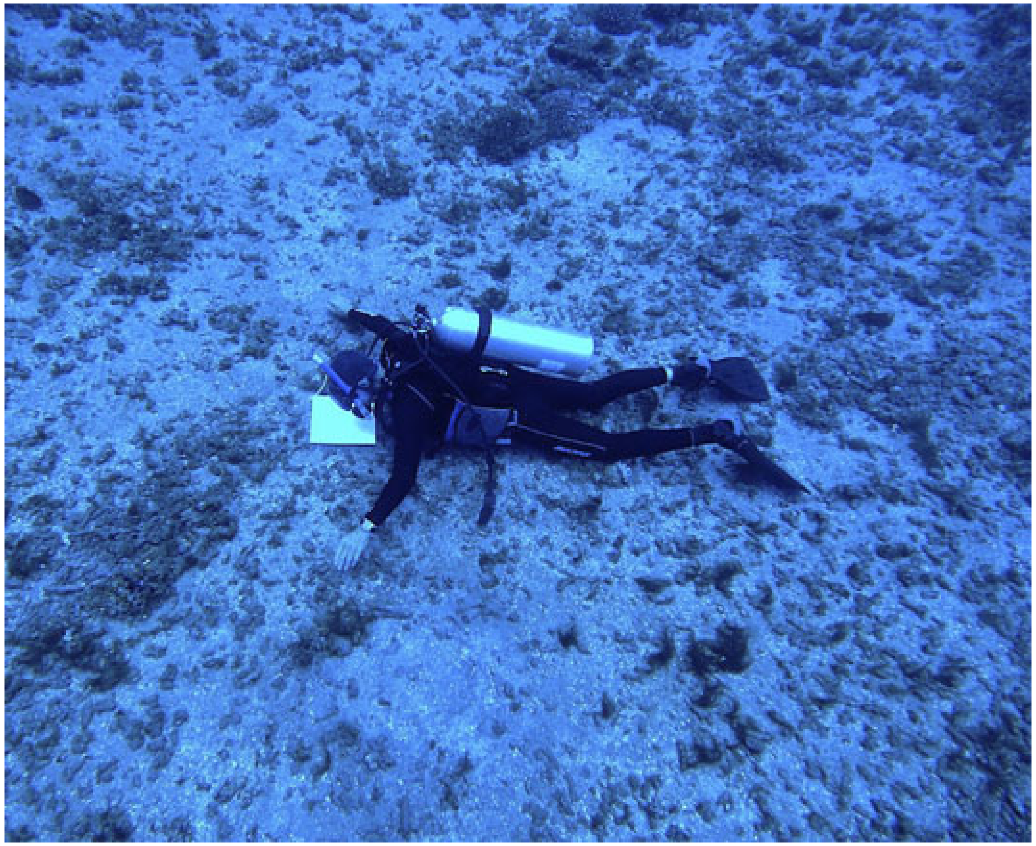
This graphic reproduces a "look down" image in more detail of Shark Fin Rock and how the two inflatable launches were moored. The first boat was moored with its bow barely over a tie-in point in about 30 foot depths. However, the bottom then swiftly dropped off so that snorkelers entering the water were actually in 60-70 foot depths with a drop-off falling away sharply.



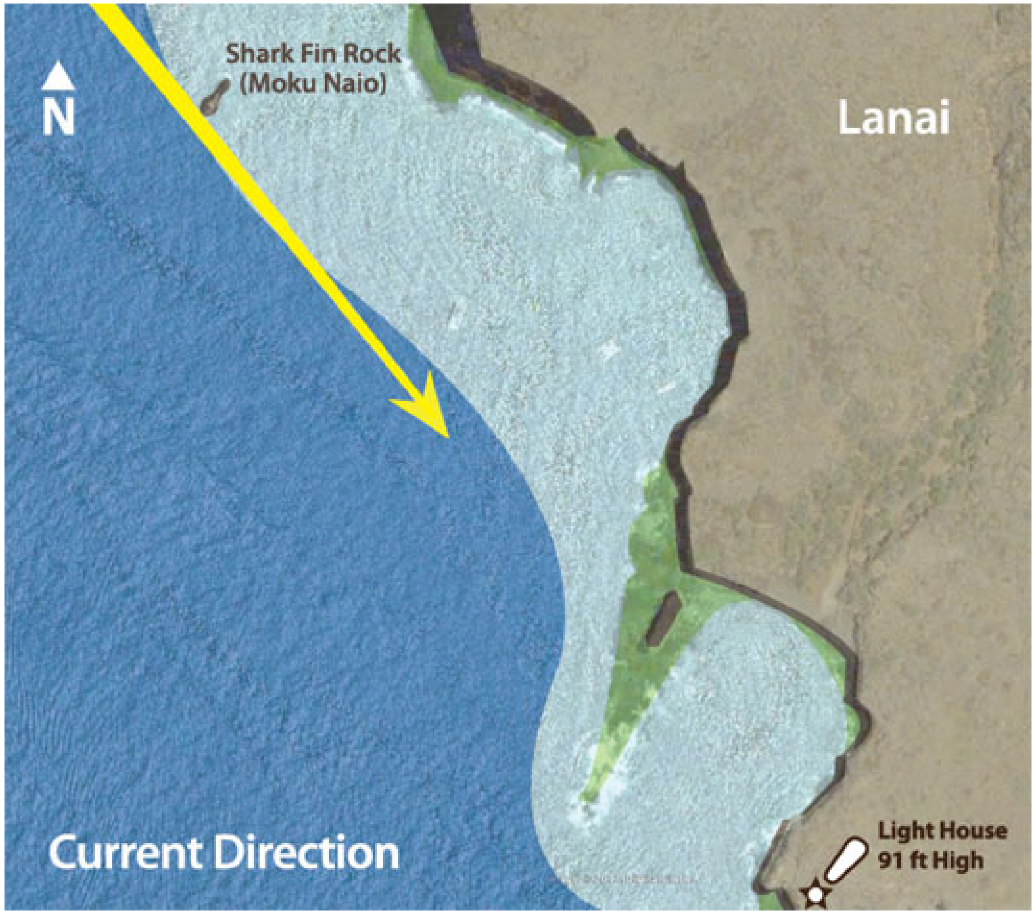
This photo shows the underwater topography and its steep drop-off with a diver included for scale. The deceased entered the water in this area and began freediving. He apparently was not advised of the deep depths, drop-off contour, and current that tended to sweep him into deeper water. He suffered an episode of latent hypoxia (sometimes called "shallow water blackout") during his ascent from his breath hold dive. He passed out only 10 feet below the surface but no crew responded in time before he sank to a depth of nearly 100 feet and drowned.



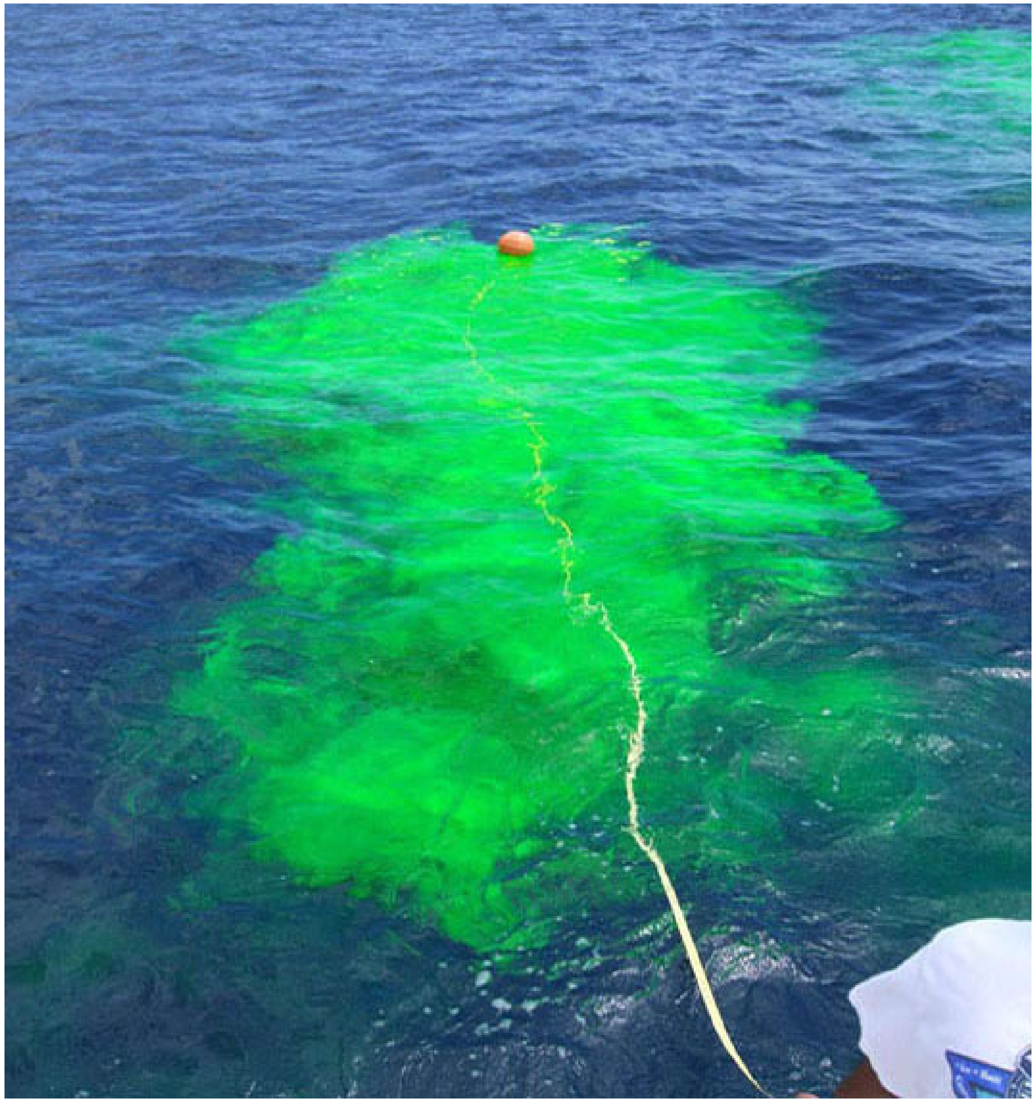
This photo shows the position of another launch on the same mooring. The boat's bow is over the pinnacle top in about 20 foot depths with its stern in over 70 foot depths and the drop-off falling away.

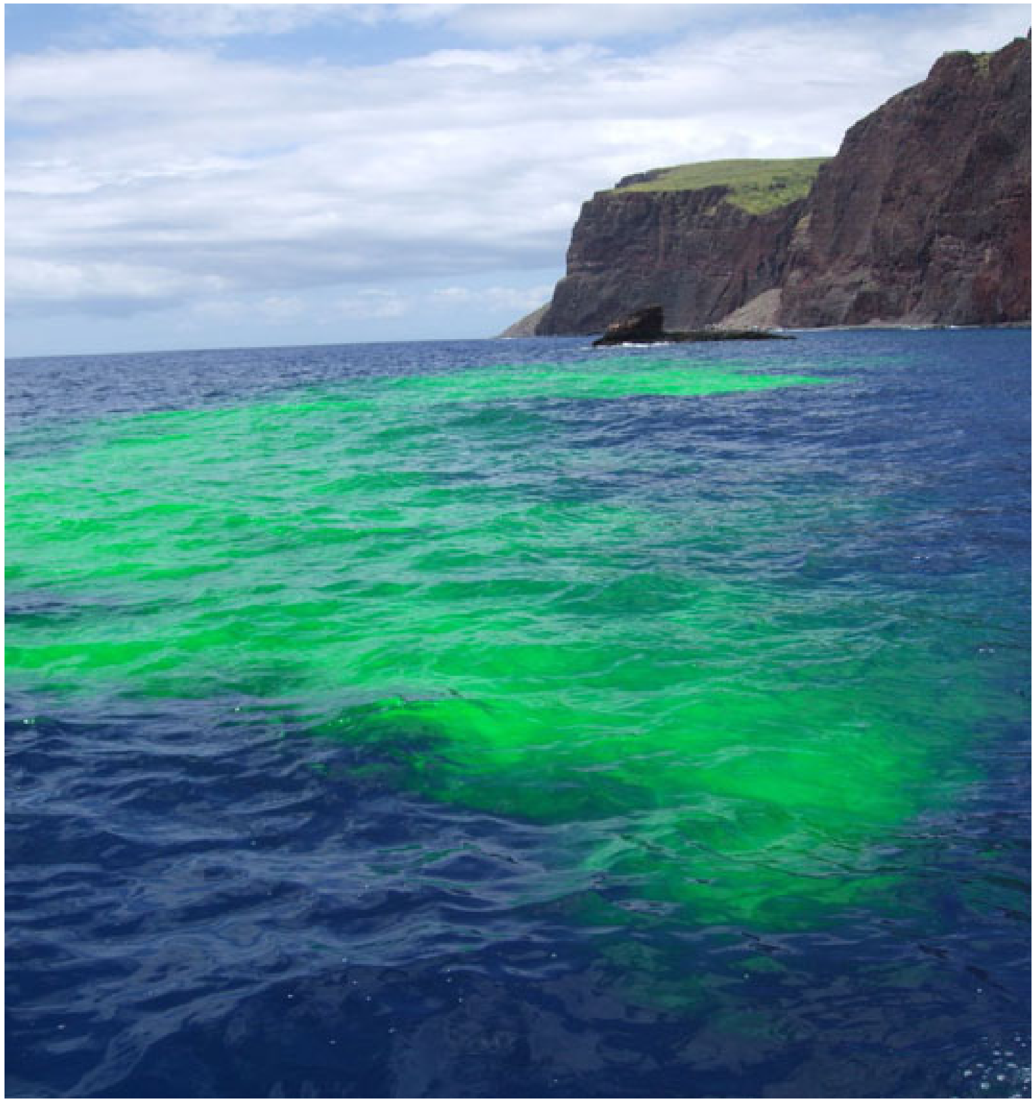


I used another diver to assume the same position of the deceased's body in 100 foot depths where it landed on the bottom after being carried away from the mooring point by the current.



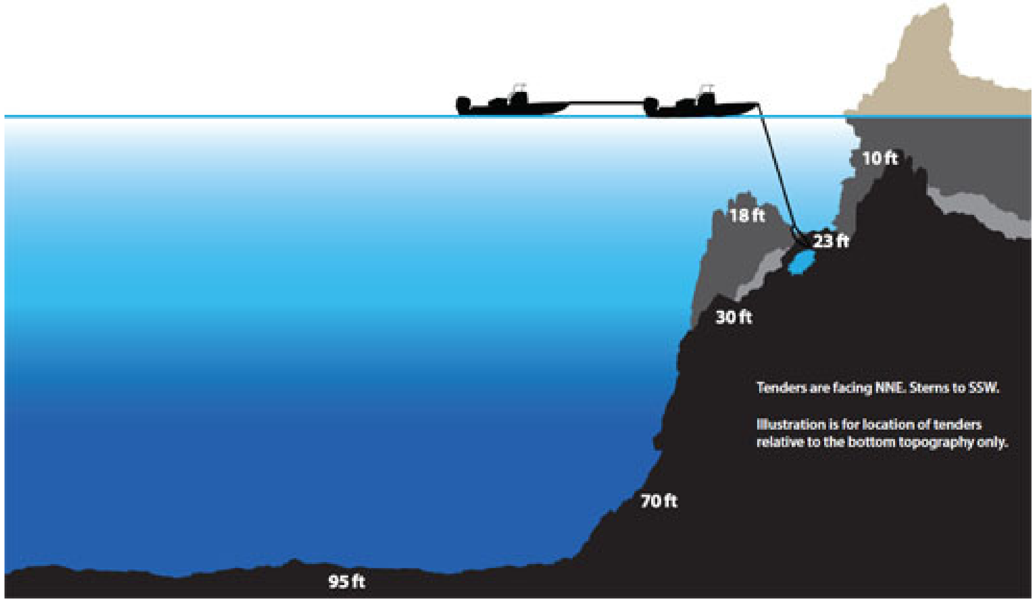
This graphic takes elements of the NOAA chart and lays in the current direction of drift showing that a freediver who entered the water would have been swept away from the rock and into deeper depths immediately.

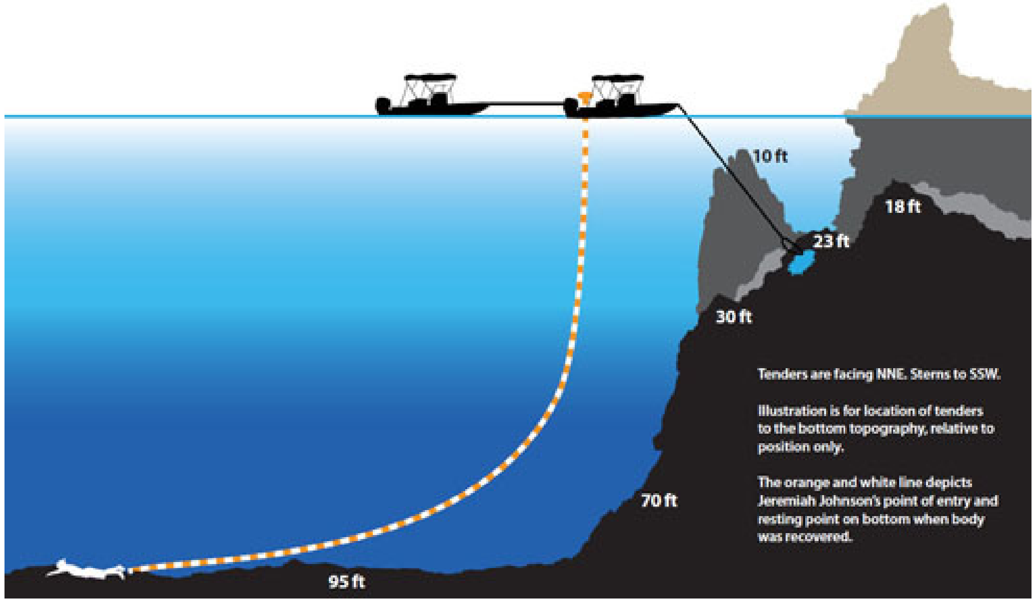




We had another expert in the case who was a professor of Oceanography who could establish the current force and direction. He accompanied me to the site and participated in all my inspections, photography, and subsequent re-creations. In this photo, he has deployed a green dye from the launch at the mooring site to show the direction of current drift. We then timed the drift and distance traveled to get the current's velocity.

I shot this photo looking back to Shark Fin Rock after ten minutes of the dye forming a trail that illustrates the current direction. It clearly shows that a person would be carried south-southwest into deeper water if they entered the water from that mooring at the Rock.





This excellent graphic shows the jury the “side view” that a diver could observe underwater. This illustrates the position of the launches and the immediate deep depths. The deceased entered the water from the stern of the first launch and was already in water over 70 feet deep when he apparently thought he would be in only very shallow snorkeling depths of perhaps 15-20 feet.

This last graphic shows the trajectory and final resting place of the deceased freediver’s body as it plunged from the launch and finally settled on the bottom after he passed out and the crew failed to rescue him in a timely manner. The time of his entering the water and being observed passed out beneath the surface to when rescuers got to him was estimated by various accounts to be from 8-15 minutes. Brain death from lack of oxygen occurs generally within six minutes of unconsciousness underwater with nothing to breathe.

This trial went all the way and last nearly four weeks. I was on the plaintiffs’ side representing the widow and children of the dead freediver. The jury deliberated and came back with a sizable award for them.

Conclusion

I hope that these three actual case examples show how important trial exhibits are to letting the jury get the feel of what it's like underwater and on the surface of accident sites. Remember: the average juror is not a diver or a mariner so they need all the help they can get to grasp the facts and opinions of experts. Such exhibits are invaluable in giving them perspective.

I currently have 13 open case files... again nearly evenly divided between defense and plaintiffs work. My job is made far easier by using my own photography and the skills of a graphics artist to prepare trial exhibits and do the best we can to help a jury assess the facts and render their verdict.

In the end, it's the jury who decides a case. Their job is the hardest of all.

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VPM-B Variations: /E, /GFS and /U

By Asser Salama

First introduced in 1986, the Varying Permeability Model (VPM; also known at that time as Yount and Hoffman) is a dual phase decompression model that considers both dissolved gas and bubbles. In the year 2000 the model was completed and in 2002 a revision was introduced. The 2002 revision compensates for bubble expansion and contraction using Boyle's law and is known as VPM-B.

In 2005, Ross Hemingway introduced a new model variation called VPM-B/E. This year, Shearwater introduced their VPM-B/GFS and I introduced the VPM-B/U. /E stands for Extreme, /GFS stands for Gradient Factor Surfacing and /U stands for Ultimate. The three variations aim at generating more conservative schedules.

To understand the logic behind each of them, I interviewed Ross Hemingway, the developer of VPM-B/E.

Ross, what can you tell us about your /E model variation?

"My method is propriety. All I will say is that it looks at the internals of VPM and extends them in a manner when the dives conditions within VPM become significant. The resulting extension time is in proportion to the underlying VPM-B model. The /E variation only starts to take effect when the decompression loading becomes large, usually affecting dives with 90 or 100 minutes total time or more.

"Interesting to note, most OC dives cannot experience any real change from VPM-B/E, because 100 minutes dive time is about the max for tank gas volume with reserves. Only at this point do the extended methods begin to outgrow the underlying VPM-B. For most divers, VPM-B and VPM-B/E is the same thing, simply because their dive isn't big enough to trigger the extra time from a /E plan.

"Also note that up to about 80 minutes, VPM-B is LONGER than ZHL!"

So why did you create it at the first place?

"I created VPM-B/E for Dave Shaw and his second 270 meter (886 foot) dive in the Boesmansgat cave. His first dive in that cave at 270 meters (886 feet) was with VPM-B and lots of padded extra time. For the second dive he wanted something in VPM-B but longer, to plan the dive with. VPM-B/E was created and the second dive was planned with VPM-B/E. But he never did use it because he died on that next dive in January 2005 from a CO2 hit while at 270 meters (886 feet)."

What about the /GFS? Is it all about comparing the VPM-B generated profile to ZHL with GFs 90/90 and using the more conservative?

"The new /GFS idea of Shearwater, is a combined method. They look at two plans concurrently, and then take the longer time frame from each. For the 100 to 200 minute dive time frame, it's about the same as the /E plan. But after 200 minutes or so, /GFS keeps growing and growing, out of proportion and into silly numbers. This of course reflects the underlying problems of ZHL. The failure of this two model approach is that it only works by coincidence. It gives meaningful info in a certain region only, and goes out of proportion beyond that."

And what do you think about the /U?

"Your /U method theory - dissimilar gas rates, is already accounted for in the standard Haldane and Schriener equations. So fiddling the off gas rates is a fudge – and a baseless one too, with no calibrations to back it up. Furthermore, it interferes with the base calibrations for the model."

Ross, here's, for instance, Haldane's equation:
Haldane Equation = Initial Gas Pressure + (Inspired Gas Pressure – Initial Gas Pressure) * (1.0 – EXP(–Gas Time Constant * Interval Time)). Can you explain how it accounts for dissimilar gas rates?

"The equation has bearing of the gas direction (+/–). The result is relative to the inspired and existing pressures. That's all it needs. To try to force it to a bias based on direction, is a fudge. A silly fudge."

I don't force it based on direction. As you said, that would be silly. And I think would probably create more problems when Schriener equation is involved.

However, the fact that it has a bearing and that the result is relative to both the inspired and existing pressures do not mean, in my opinion, that it accounts for asymmetric gas kinetics.

"There is some testing in hot / cold changes in the dive. Getting cold slows down off gas rates – that's established. And the US Navy Experimental Diving Unit (NEDU) uses this fact in its own dive stress testing, by making the diver cold on the bottom to enhance the DCS rate.

"So I think your /U data is really just the hot / cold problem."

Do you want to add anything, Ross?

"I don't think any of them are necessary. 96% of all dives are less than 100 minutes, which means they were all diving base VPM-B plans, regardless of the model choice they make. Only 0.5% of the dives are over 200 minutes long, where real time differences can be seen in plan times. For these divers, how can you tell the difference between extra time added for safety, and required extra deco time? You can't tell the difference. Adding extra time with a successful result, does not imply it was needed time. And of course common sense says add more safety to big dives.

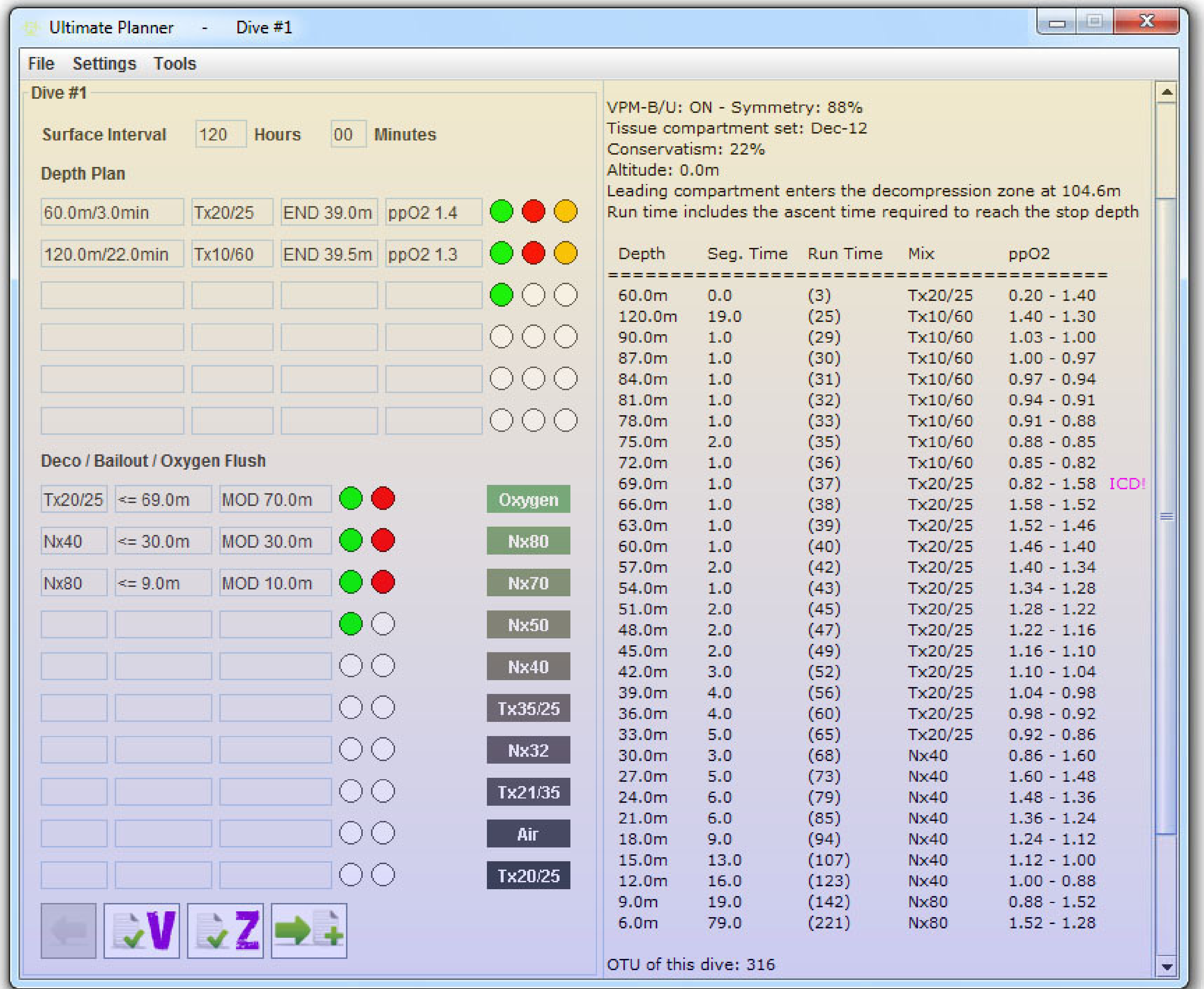
"The problem is that the frequency of 200 minute + dives is pretty rare. Consider that if we all did 200 minutes every weekend, we would all get a better feel for the situation. I believe then divers would then trim off all the excess deco time that these extended methods present, and we would be back to the base line times that regular VPM-B presents. But until then, extra safety is a good measure for success.

"So in conclusion, I don't think any of these add on methods are really needed. All of them only take effect on really long dives. They are added mostly for extra safety reasons on big dives, where extra safety is the right thing to do."

/U and the other decompression algorithms

As the /U simulates asymmetric gas kinetics, its use is not restricted to VPM-B. It can be implemented into virtually any decompression algorithm for extra safety. One of the most common applications is to use it with raw Buhlmann ZHL model (with GFs 100/100; i.e. without Gradient Factors) for planning CCR bailout.

In a bailout situation, if the CCR diver is to use the diluent on OC, there's always an urge to end up this phase as soon as possible, as the diluent's gas volume is pretty limited. That's why a lot of CCR divers prefer to use Buhlmann's ZHL rather than VPM-B in this situation, since it produces shallower stops. For adding a safety margin to this approach, asymmetric gas kinetics could be used to add time to the existing stops without adding deeper ones.



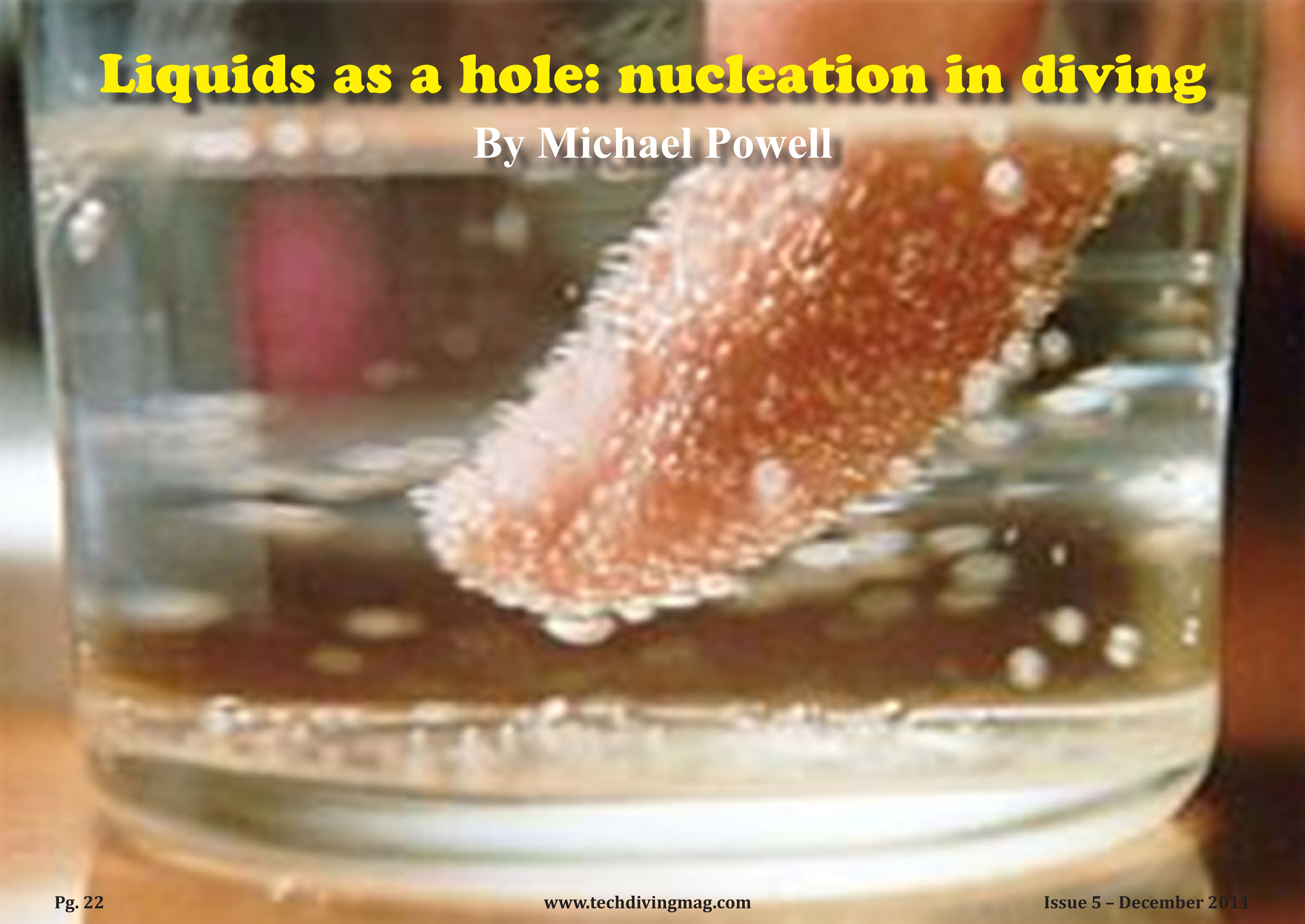
VPM-B variations are usually useful for bigger and/or longer dives like the one illustrated to the left (120 meters - 394 feet for 25 minutes).

For more info about Ultimate Planner with /U variation and other distinctive features visit

www.techdivingmag.com/ultimateplanner.html

Liquids as a hole: nucleation in diving

By Michael Powell



"Double, double toil and trouble; Fire burn, and cauldron bubble"

William Shakespeare, *Macbeth.*

We are all familiar with the formation of bubbles in boiling water and in soda water. In carbonated beverages, bubbles first appear when the can is popped opened and then again when the liquid is quickly poured into a glass. Depending on how fast the can is opened and the liquid is poured, you can to some extent control the formation of bubbles. Were this fine control also possible in the diver, the formation of decompression bubbles might be reduced, and thus we would experience a reduction in decompression sickness (DCS). Currently, decompression bubbles are controlled by reducing the level of supersaturated dissolved nitrogen (or helium) that is present in the diver's tissues.

We are taught in basic scuba class that bubbles *form* when the pressure is reduced on the diver's body; the object of decompression tables is to reduce that *formation* by reducing the sum of the gas partial pressures in "compartments/tissues." In truth, tiny "microbubbles" are already present and excess gas pressure causes these to *grow, not to form*. There is a fascinating story about these "seed bubbles" that is of practical use to divers, and it is that story that we will now examine in this article.

"No bubbles, no troubles"

When I worked at the German *Institute of Aerospace Medicine* in Bonn, the scientists in the barophysiology section thought that the phase "No bubbles, no troubles" in English was quite funny. In German, it had not nearly the same lyrical resonance and whimsy since *auf Deutsch* it was, *"Keine Blasen, keine Schwierigkeiten."* You get the picture, *"Ach, Du Lieber."*

In industrial processes, controlling the number and size of bubbles in glass, plastics, or even in bread and pastries, is essential. As youngsters, we controlled nuclei when we made rock candy with sugar solution. We hung a string on which the crystals could grow and it provided a *nucleating site*. When desperate, people try to nucleate the clouds for rain drops to form. You can really get a knockout by dropping a *Mentos* into *Coca Cola* and setting off a virtual eruption. [You can see this by a Google search for "Mentos eruption."]

Decompression bubbles actually arise from tiny microbubble "seeds" present in all liquids - including the liquids in our tissues. Surprisingly, if there were no microbubbles in our tissues, we could ascend from several thousand feet to the surface. Now that is a decompression table! Since tissue micronuclei are always present, we should spend some time discussing this. It can give an insight into one cause of DCS, and it can lead to safer diving. Now that is something in which everyone would be interested.

We encounter nucleation in many events in daily life. Not all of these are readily apparent. Certainly crystallization to make rock candy is one of them. Supersaturation of the sugar solution is the driving force for this form of nucleation. Reduced temperature is the driving force for the freezing of water. The supersaturation of nitrogen is the driving force for formation [growth, actually] of decompression bubbles.

I am not ambitious to appear a man of letters; I would be content the world should think I had scarce looked upon any other book than that of nature.
Robert Boyle [1627 – 1691]

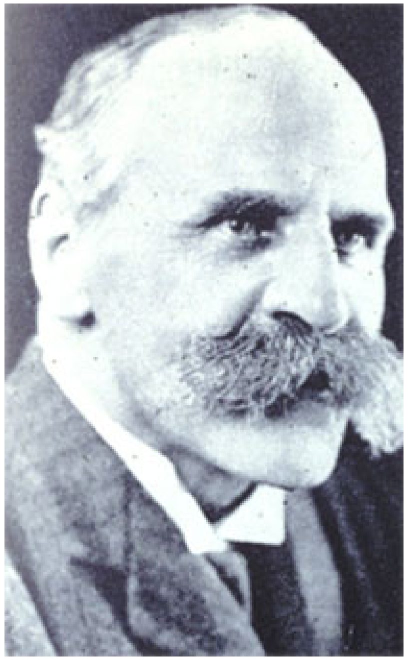
Bubbles in living organisms were first discovered by Robert Boyle in 1660. In addition to discovering "decompression bubbles," Boyle was a polymath. He excelled at alchemy [writing *The Sceptical Chymist*], physics, philosophy, and theology. Divers are familiar with that name as it relates to Boyle's Law that relates pressure and volume of gasses. It is this law that can kill you if you ascend with your breath held. Serious business.

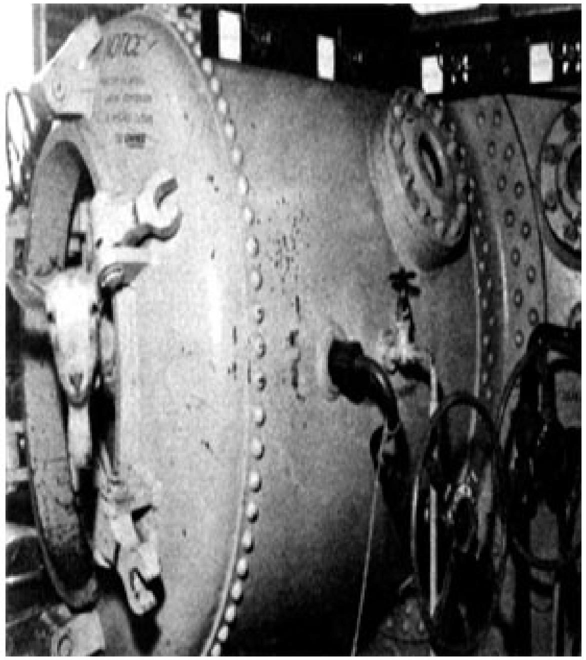
Using an air pump invented by his young assistant Robert Hooke, Boyle observed the effects of rarified air pressure on live plants and animals. He wrote, "I once observed a viper furiously tortured in our exhausted receiver… that had manifestly a conspicuous bubble moving to and for in the waterish humour of one of its eyes." Thus, the first bubbles in living creatures were actually in altitude depressurization. The picture is a painting ["*An Experiment on a Bird in the Air Pmp"* by William Wright of Darby, 1768] showing a bird expiring in the "exhausted receiver." The young woman in the forground shields her eyes from the "horrifying sight." I have seen this painting in London, and it is hugh, about ten feet long.

Bubbles first appear as "gas seeds" and are a part of all decompression procedures; their origins are the subject of this article. As I said, the story is both fascinating and of practical importance for the diver.

The Haldane Method

Virtually all decompression procedures in use today can be traced to John Scot Haldane, a respiratory physiologist who worked in England from the late 1800s to the early 1900s. His research on bubbles and decompression were among the earliest works. He founded the *Journal of Hygiene*, studied poisonous gases in coal mines, problems of heat stroke, chlorine gas in warfare [he made a form of gas mask during World War I], respiration at altitude and, for us, decompression sickness. He was tasked by the Admiralty's Deep Diving Committee to produce effective decompression tables to eliminate "caisson's disease" as DCS was then known. He produced tables and also performed studies on the physiology of decompression sickness.





The developer of the ***"stage decompression method"*** used today, Haldane originated the concept of rising to a depth near the surface in steps as contrasted with the method of slow linear ascents that was employed at that time. This rise in stages is known as the "Haldane Method," known to every scuba diver, if not by that name.

As the other portion of his *algorithm* [i.e., a calculation method], Haldane reasoned that blood flowed to various organs of the body in varying amounts, and thus the organs gained [or lost] nitrogen at different rates. To handle this exchange, he conceived of tissues with gain and loss expressed as an exponential function. Time was in the exponent and half filled or half empty yielded a time known as the "halftimes." "Fast" compartments had halftimes of minutes to tens of minutes. Slow compartments had halftimes on the order of hours. This is the same system that we are familiar with in the decay of radioactive material and the associated radioactive "halftimes."

Haldane knew that divers could ascend by a certain number of feet and not get "caisson disease" if these upward excursions were not too great. He reasoned that if "bends" did not occur then bubbles did not form if this upward ascent was limited to a short jump. Haldane had seen evidence that bubbles formed easily in supersaturated fluids outside of the body. Something was present there that was absent in the bodies of living animals.

The urine found in the bladder post-mortem is remarkably free from bubbles; on two occasions only has free gas been found. We have evidence here that the phenomenon must be due to supersaturation and the absence of "points," since we have very frequently observed goats pass urine after decompression which frothed freely on coming into contact with foreign surfaces.

- J. S. Haldane. The prevention of compressed air illness. *J. Hygiene Camb.* 1908 p. 415

He knew that *something* was needed for bubbles to form in the living body, and he called these "points." [We now know them to be the gas "seeds" or tissue microbubbles.]

This is well seen on watching under the microscope a stream of bubbles coming off some "point" in soda water. It follows that if the concentration if dissolved molecules of gas is not higher than some unknown point [*we would call this partial pressure today*], bubbles will not be formed. It is possible that the absence of bubbles from most of the solid tissues is to be explained by this non-existence of very small bubbles [*we would call these "micronuclei" today*] and the mechanical difficulties of the rapid aggregation of a sufficient number of molecules to produce large bubbles.

- J. S. Haldane. The prevention of compressed air illness. *J. Hygiene Camb.* 1908 p. 422

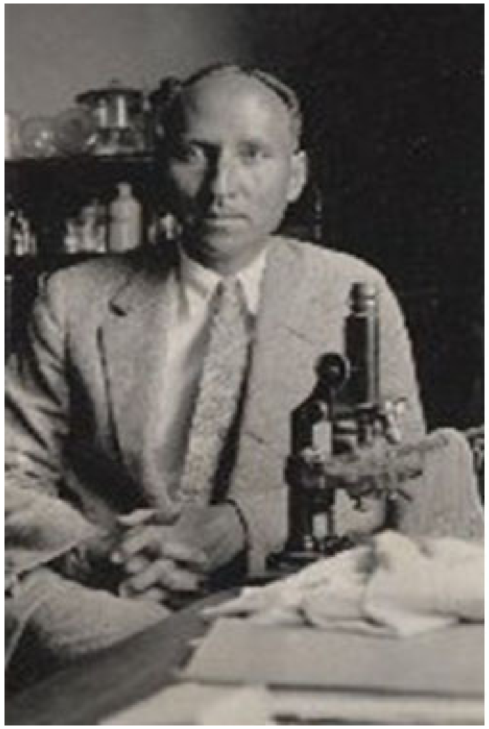
He did not know the details of micronuclei to the level known today – but that is not to say that the story is complete even now.

The Concept of Nucleation

For scuba divers, *nucleation* refers to a step in the formation of the gas phase in the body that eventually can result in decompression sickness. Divers have been taught that decompression bubbles ***form*** with ascent and the attendant decrease in ambient pressure. This is not actually correct – tiny microbubbles are there prior to depressurization. While decompression sickness cannot result without supersaturation, it can also not occur in the absence of micronuclei.

We can trace nucleation in diving back to a scientist by the name of E. Newton Harvey (1887 -1959). While Harvey was primarily interested in bioluminescence throughout his scientific career, during World War II he actively studied decompression sickness.

Harvey first became aware of fluid micronuclei when he studied the biological effects of ultrasound in the late 1920s. Bubbles formed in water around the ultrasound transducers, and Harvey knew that the energy was not sufficient to form microbubbles in the water. He reasoned that micronuclei *were already present* in the fluid. By the time he studied DCS, the idea of preformed micronuclei was already in his mind. The photos are of E. N. Harvey.



In Vivo GAS NUCLEI

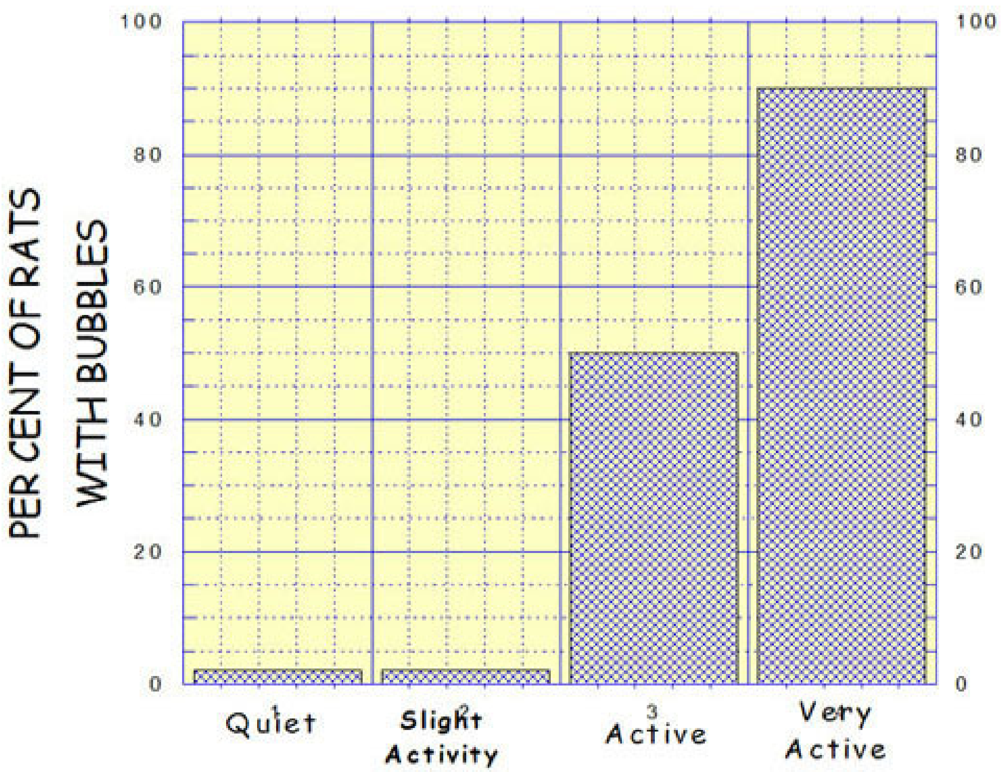
The formation of gas bubbles solely by decompression is not possible with the small pressure changes encountered in diving. Bubbles cannot form with the supersaturations of carbon dioxide in soda pop, but they do. This is possible because nuclei are already present in fluids - all fluids, all of the time. This is possible since fluids are exposed to air. Gas pockets are present in the container that holds the soda pop as well as the glass into which it is poured. Our body in contrast developed under water and no internal part was ever exposed to the air. However, gas "seeds" must be present at some time prior to depressurization in the blood, capillaries, and other tissues of out body. Let us examine how we might get out of this dichotomy

The ultimate in stable nuclei is *"Pop Rocks."* We are all familiar with this candy; it is formed from a molten sugar mixture that is saturated with carbon dioxide at pressure, depressurized, and then allowed to cool. The "nuclei" remain until eaten. This example is followed by the nuclei contained in *Mentos* and released when they are dropped into *Coca Cola*. Physical processes can also **enlarge** micronuclei. Expansion of a fluid as it exits a constriction can do this and is called Reynolds cavitation. We can tell bubbles form in a squeezed garden hose when water flows. It is sometimes called "boiling at room temperature." This effect is also used in the Guinness *Widget* to produce foam in their beer.

There is considerable experimental evidence to suggest that micronuclei exist in living tissue, although not with the longevity of *"Pop Rocks."* The containers in which the soda pop is bottled and the glass into which the pop is poured have all been in contact with air. The little nuclei or "air pockets" can easily be there, and we would have little difficulty imaging that. However, our bodies have developed from inception under water and our tissues have never been in contact with air [except for skin and lungs]. The simplest *physical test* for nuclei is simply to depressurize the liquid. If bubbles are seen, then nuclei are present.

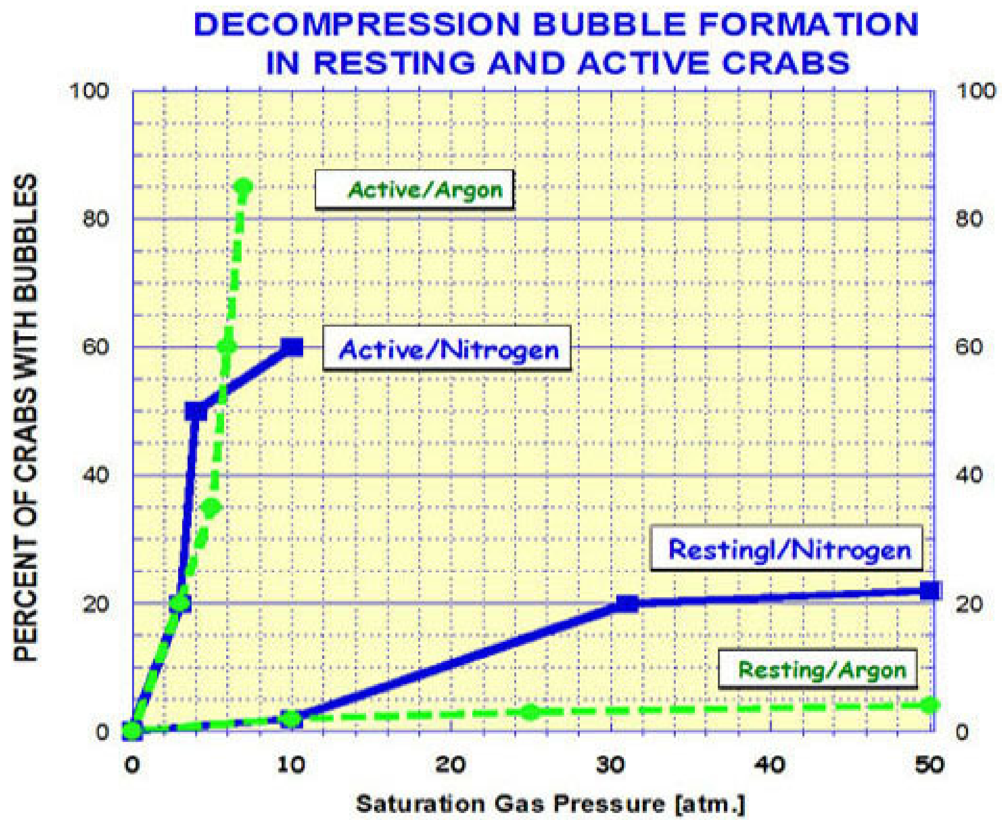
The studies of E. N. Harvey lead him to believe that the pressure changes in barophysiology were much too small for *de novo* bubble formation and micronuclei must be present in tissue fluids. These "seeds" came from musculoskeletal activity, he reasoned, and mechanical forces were postulated to be responsible for the relative ease by which a gas phase formed in living tissue.

The vast majority of evidence for muscle and joint activity as a provocative agent for stress assisted free-gas phase formation derives from animal experimentation. Early work was directed towards the genesis of a gas phase in the crews of high altitude bombers during World War II. Researchers showed that rats that had exercised at altitude displayed a greater number of vascular bubbles than those who were inactive when depressed to altitude.

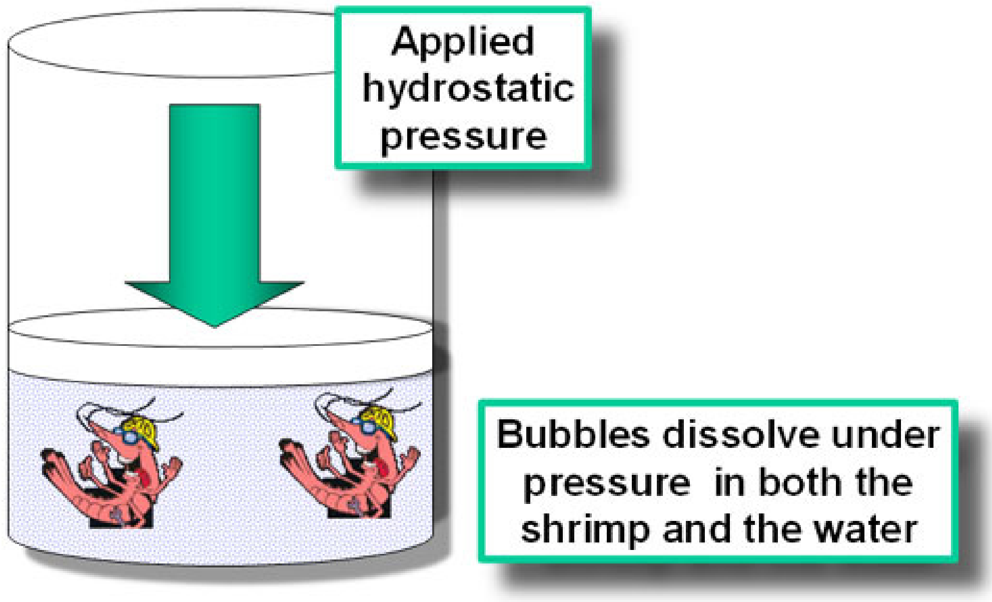


This is illustrated in the graph showing the percent of rats with bubbles when they are resting, active, or very active. Similar effects were shown with frogs.

A demonstration of this effect in crabs was performed by McDonough and Hemmingsen with crabs using argon or nitrogen. They restrained the creatures by gluing their feet to a board. The clear carapace allowed the counting of bubbles. When inactive, pressurization and depressurization produced few *in vivo* bubbles. When the feet were loosened, the crabs moved and a repeat of the experiment demonstrated many bubbles with much less of a pressure change. While this type of restraint works for crabs, it is hardly practical for scuba divers!



A truly fascinating experiment by Tony Evans and Dennis Walder MD with shrimp and compression demonstrated *in vivo* nuclei in living creatures. While these little crustaceans are water breathers rather than air breathers, the general effect is the same. Compression of water will cause the nuclei contained in it to dissolve. Shrimp in the water will also have their nuclei dissolve – if the nuclei are actually present. Evans and Walder pressurized shrimp [and the water that contained them] with air and then depressurized the system. Bubbles formed in the shrimp [and the water], if the container of water and shrimp was first hydrostatically compressed and then depressurized. In neither the water nor shrimp could bubbles be found. If later the shrimp were given an electric jolt, they twitched and bubbles could be seen forming. Physical activity produced bubbles.



A similar type of study was performed using rats by Richard Vann PhD. In the case of the rodents, hydrostatic compression [i.e., under water] was out of the question, since rats were air breathers. However, a sharp large pressure pulse with air was applied, then compression for an hour, and then depressurization. The pressure pulse was found to eliminate many bubbles, and a bigger spike was found to be more effective than a smaller one. Some bubbles did form since it was one hour between the spikes and depress and the animals had ample time to move about and generate some new nuclei.

There is a phenomenon call "isobaric counter diffusion." This occurs when a person [or animal] breathes nitrogen [a slowly diffusing gas] at pressure while surrounded by helium [a fast diffusing gas]. A change in ambient pressure is not required for copious venous bubbles to form. It is proof that *in vivo* micronuclei exist and if exposed to supersaturation for an hour, visible gas bubbles form.

Within the topic of **decompression** of scuba and deep-sea divers, nucleation control has not been given much examination, but rather the efficiency, and failure, of decompression tables has been dealt with ***solely by supersaturation control***. This has been accomplished by the calculated tracking and control of inert gas uptake and elimination in body "compartments," the original Haldane method. As a general topic, however, nucleation and gas micronuclei have been discussed by professional barophysiologists over the past century. Without micronuclei, decompression bubbles would virtually never form. Make no mistake - supersaturation is essential. You will form many micronuclei in the gym while lifting weights, but you will never get decompression sickness.

In general, homogeneous nucleation is difficult to obtain in the laboratory or in industrial procedures since liquids are not "pure" or free from exogenous nucleating agents, e.g., stabilized micro gas bubbles. Its study has therefore been limited by the difficulty of experimental techniques. Kinetic activity of a liquid (e.g.

micro vortices) is known to affect the process. The kinetic activity undoubtedly aids in the surmounting of the critical *nucleation energy barrier*. Such effects would be very important in living systems as encountered in decompression work. It is the kinetic effects that are quite unknown in decompression theory and little can be given in the way of data.

Nucleation involves processes that are described as being *large in degree* but *small in extent.* For a century, scientists have examined nucleation and phase changes, although not necessarily to the degree in recent decades. One form of nucleation is the process that produces minute solid or gas phases in liquids. Micronuclei are always present in the body, we believe today. Haldane thought that they were rare.

There are reasons for supposing that the living body presents nothing in the way of points or surfaces on which bubbles might arise in the blood or tissues as they do upon the glass and dust in soda-water.

- J. S. Haldane. The prevention of compressed air illness. *J. Hygiene Camb.* 1908 p. 410

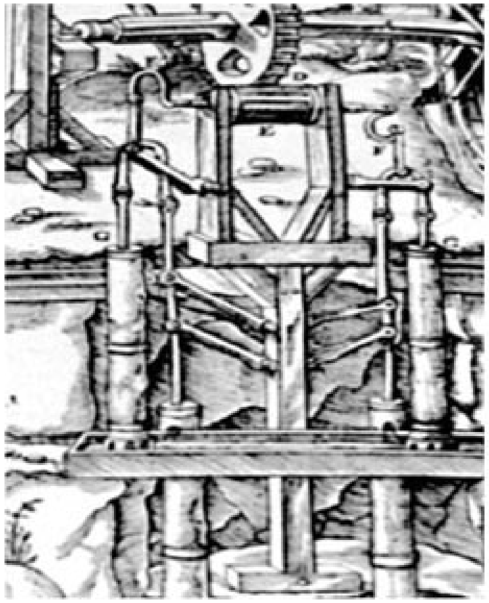
GAS PHASE FORMATION IN A LIQUID

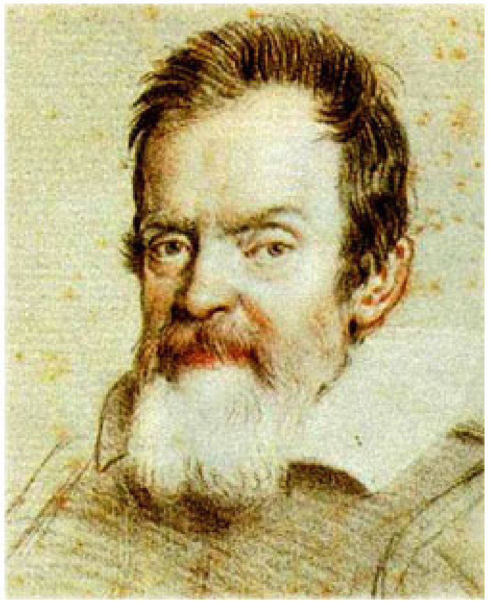
Let us first look at the formation of a gas phase in the body during decompression with a look at phase changes in water. Later we will look at these processes in living tissue. A starting point is the idea of *fracturing* of water, not something we commonly think of. With solids, fracturing is simple. Bending a sheet of metal back and forth, such as is done to break off a lid from a tin can, will cause it to split apart. The atoms of iron fracture in a plane and the metal separates. Liquids are different. They form actual *holes* between the molecules of the water. Yes, these holes are short lived, but they are there. When water is boiled, the holes become very large and visible. Holes are formed at constant pressure when the temperature is raised. This is termed boiling or *ebullition*. Holes are formed at constant temperature when the pressure is reduced, and this is termed *effervescence*.

In his study of pumps, Galileo realized that they would not raise water above a level of about thirty four feet. He found that the water column broke. He was the first to realize that liquids could "fracture" in the same fashion as a clay pot or a glass vase could break.

Up to this time I had been so thoughtless that, although I knew a rope, or a rod or wood, or of iron, if sufficiently long, would break by its own weight if held by the upper end, it never occurred to me that the same thing would happen, only much more easily, to a column of water.

- Galileo Galilei, *Dialogues Concerning TwoNew Sciences*, 1638





LIQUIDS AS A HOLE

The fracturing of liquids is what produces a limitation in the height to which a lift pump can draw up water. Galileo reasoned that this limit was the result of the "internal strength" of the water, what we call today the *tensile strength* of a liquid. This tensile strength is closely related to nucleation or the formation of a free gas phase, however tiny these holes might be, within a liquid phase.

Cavities are not something that one would really think about as being present in a liquid. This is probably because we do not see them, but when liquids boil, for example, they are very visible. This is a trick, you may be saying to yourself, but in actuality, these really are just the holes I am talking about. The holes are not "filled" with a vacuum; quite the contrary they are filled with the molecules of the liquid on the border of the hole, or bubble. Now, if the pressure of the molecules of the vapor in the bubble (cavity or hole) is great enough, equal to the external pressure of the atmosphere, then the bubble is stable. While most do not realize it, this is what *boiling* is to a chemist. It is a process that occurs when the *(vapor) pressure of the liquid equals that of the surrounding atmosphere.*

Henry's law states that gases dissolve in liquids in proportion to the partial pressure of the gas itself. If the total applied pressure is reduced, more dissolved gas (nitrogen for example) molecules exist surrounded by water molecules than is balanced. This balance exists whereby dissolved nitrogen molecules are surrounded and then free (not surrounded) in a pattern that essentially flickers back and forth many thousands of times per second. A pressure reduction, then, upsets this balance and the overall tendency is for the system to have fewer dissolved nitrogen molecules surrounded [*solvated*, as it is called]. Non-solvated nitrogen molecules group together and, in turn, form macroscopic gaseous nitrogen bubbles. It is necessary to understand these processes, to begin to comprehend the difficulties in developing "perfect" decompression tables.

Researchers have categorized gas phase formation in a liquid into separate mechanisms. The first process, or "spontaneous" nucleation, involves the separation of water and solvated nitrogen molecules into two separate groups without the prior existence of a small gas phase. The second process, "non-spontaneous," requires small gas (or more correctly, "vaporous") "seeds" to have separated prior to decompression and remain stabilized for a period of time, later to evolve into a tissue gas phase during the decompression portion of the dive. From theoretical arguments, "hole" formation in pure water requires a negative pressure [*"tensile strength"*] of about 1,400 atm. This is equivalent to ascending directly to the surface from 46,200 fsw – almost nine miles!

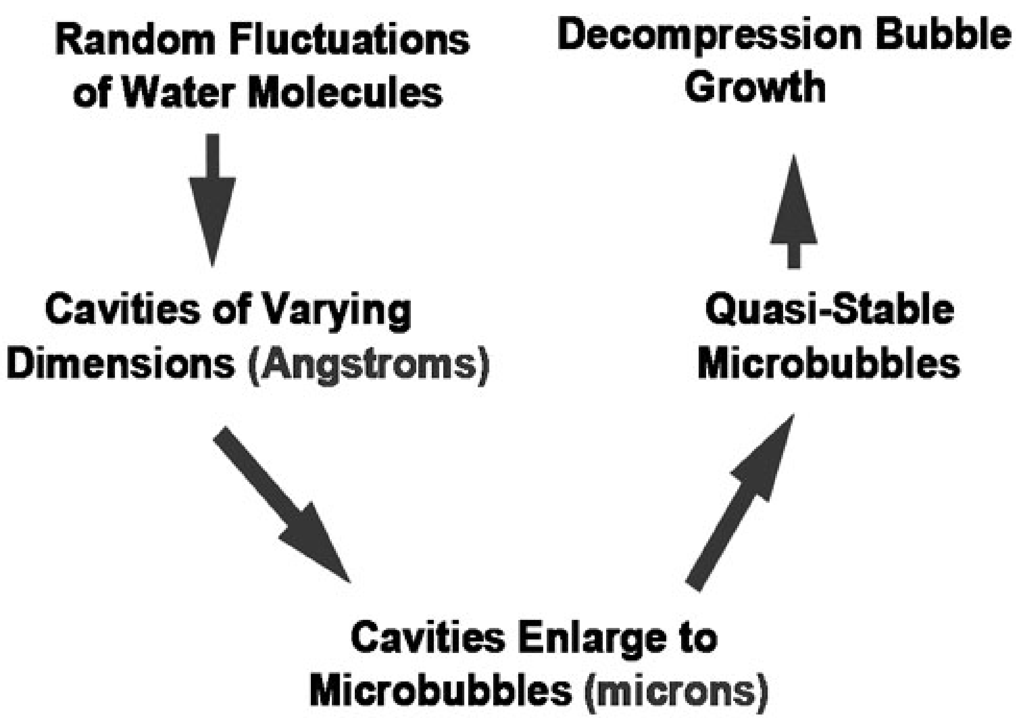
Clearly, this is not possible since our bodies are filled with micronuclei. The process starts with "embryos," the very smallest entities, and they are formed from thermal activity. The majority will be very small, submicron in radius. Physical activity of our muscles can transform embryos into micron-sized bubbles; the lifetimes of these will be short (tens of minutes, at most) in the absence of stabilization. It must be remembered that in all of the processes, the highly cohesive structure of water with its multiplicity of quite strong hydrogen bonds flanked by each water molecule (oxygen linked to hydrogen on a different molecule) must be ruptured to create a cavity. For a fraction of a second, this cavity will be filled with water vapor -- a tiny hole, a vaporous cavity, in liquid water filled with gaseous (i.e., random and basically unattached) water molecules. We can view the decompression gas phase as forming as follows:

- A micro, gas phase forms from thermally- driven stochastic [random] processes,

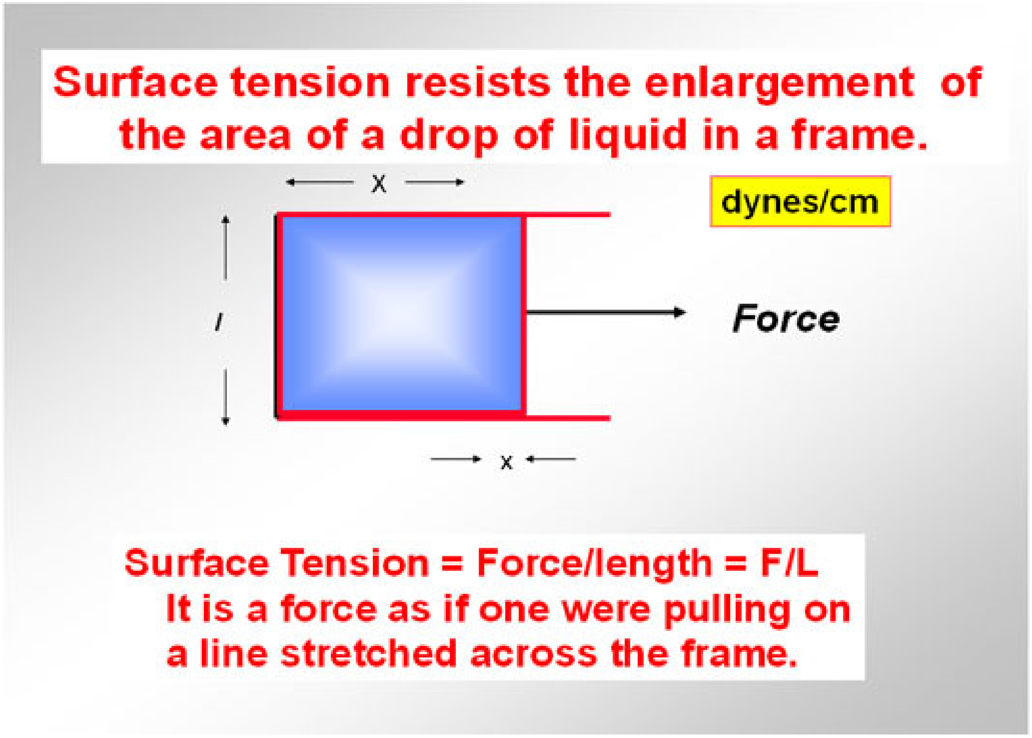
- This micro gas phase separates as minute bubbles, much less than a micron in radius,

- These can then be enlarged by hydrodynamic forces to result in nuclei, i.e., quasi-stable microbubbles,

- With local pressure reductions, these can be enlarged and inert gas from supersaturated fluid diffuses into them.



This brings up the question of, why do microbubbles collapse? It is the inward pressure from *surface tension* which in water is very strong. A film of water will resist expansion because of surface tension. It is possible to calculate the collapsing pressure within a microbubble by means of the Young-Laplace equation. To obtain an idea of the magnitudes of pressure this entails, if we consider a gas microbubble whose radius is 0.01 micron or 1/1000 that of a red blood cell, the internal gas pressure would be about 140 atmospheres. An incredible crushing pressure, indeed! This means that for equilibrium and stability, the dissolved gas must be supersaturated to this degree above the external pressure, which is negligible when the diver is on the surface. To achieve this, the diver must have taken up gas in his or her tissues in a dive to approximately 4,600 fsw!



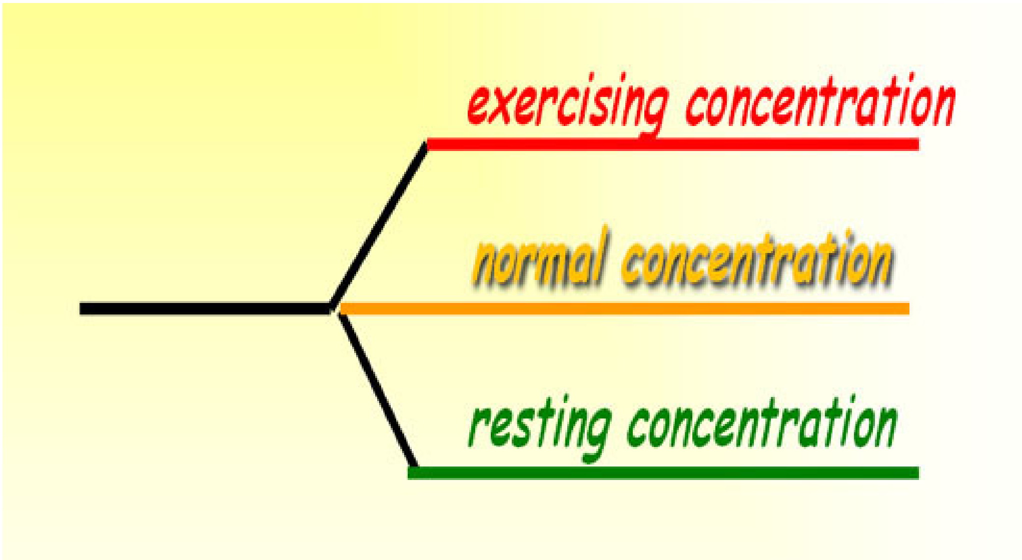
In decompression, kinetic activity of our musculoskeletal system has been postulated to assist in the cavity formation. Phase transformations proceed more easily when “assisted.” This is often accomplished in real physical systems by the presence of mechanical forces that reduce pressure in a local volume.

NASA AND STRESS-ASSISTED NUCLEATION

When astronauts exit the Shuttle orbiter for extravehicular activity or EVA [commonly referred to as "spacewalks"], they wear their space suit. This photograph is of an astronaut at the McDonald's on NASA Blvd; they normally would not be carrying a bag of French fries while on EVA.

This suit is at a lower pressure [4.3 psi] than that in the Orbiter [14.7 psi] and would result in DCS if some procedure were not followed. This is an oxygen prebreathe to washout much of the nitrogen in the body. It was found from ground based simulations that DCS occurs less in null gravity [0-g]. I have hypothesized that this is because of reduced musculoskeletal activity and less *stress-assisted nucleation*.

In the studies directed by me when I was at the Johnson Space Center, we found that there appears to be different DCS risk, which I link to different concentrations of micronuclei in the human body. There is that level formed from simple day-to-day activity when moving about on Earth in unit gravity, 1-g. This would be the level in the body of a scuba diver when decompression tables were derived. Nuclei number is not known in theory, but the concentration determines the susceptibility to DCS. In null gravity, the nuclei concentration is lower. When a diver is engaged in vigorous musculoskeletal activity, the concentration of micronuclei is greater. This activity could be swimming against a current while submerged, or post dive, e.g., when moving air tanks. This "exercising concentration" as I call it renders the diver more susceptible to DCS. The diver is "bubblier than a school girl on the night of her first prom!" Clearly, moderate rest following a dive is advantageous with respect to micronuclei formation and bubble growth, too much rest is deleterious, since it reduces blood flow that carries off dissolved inert gas.



Cavitation and the formation of microbubbles is a process that is usually detrimental and is avoided in engineering. Devices (such as the propeller of a ship) can produce pressure reductions in a fluid, generate cavitation bubbles, and cause erosion or reveal the location of a moving submarine. Definitely something to be avoided.

Good effects of bubble formation include ultrasonic cleaning and lithotripsy; some marine creatures such as the *Green Snapping Shrimp* produce microbubbles to stun prey. Divers would also like to minimize microbubble [“seeds”] as much as possible since this would lead to a reduction in DCS risk.

Negative hydrostatic forces (tension) capable of rupturing the water structure (overcoming its tensile strength) in an environment free of nuclei can be created by mechanical forces that transfer kinetic energy into bubble growth (*hydrodynamic cavitation*). Fracturing can occur when liquids pass through a constriction - remember the Guinness *Widget* - and it is termed ***Bernoulli cavitation. Microturbulence*** is well known in hydraulic engineering as a hydrodynamic cavitation mechanism. Nucleation that results from ***shock waves*** is the product of rupture of the water structure induced by forces of compression and rarefaction. These shock waves might even be produced in the lower appendages when walking.

Tribonucleation can effect the formation of a gas phase when two surfaces separated by a fluid are brought into near contact with one another and then parted. This is a process described by Campbell, termed ***“viscous adhesion.”*** Viscous adhesion is what allows us to pick up objects more easily when we have moist fingers to “click” our tongue against the roof of our mouth, and to “crack” our knuckles. It will also occur when the *walls of our capillaries* are *collapsed and then separated* – as occurs during muscular activity.

A variation of tribonucleation has been examined using a rolling ball in liquids. Bubble formation tendency was directly related to gas solubility in both olive oil and glycerol-water mixtures. Water alone was not found to produce vapor bubbles at any speed of the ball, presumably because of insufficient fluid viscosity. E. Newton Harvey and his associates studied cavitation where rods were rapidly withdrawn from a liquid by a spring mechanism, and they determined that very high velocities were needed unless the liquid was viscous.

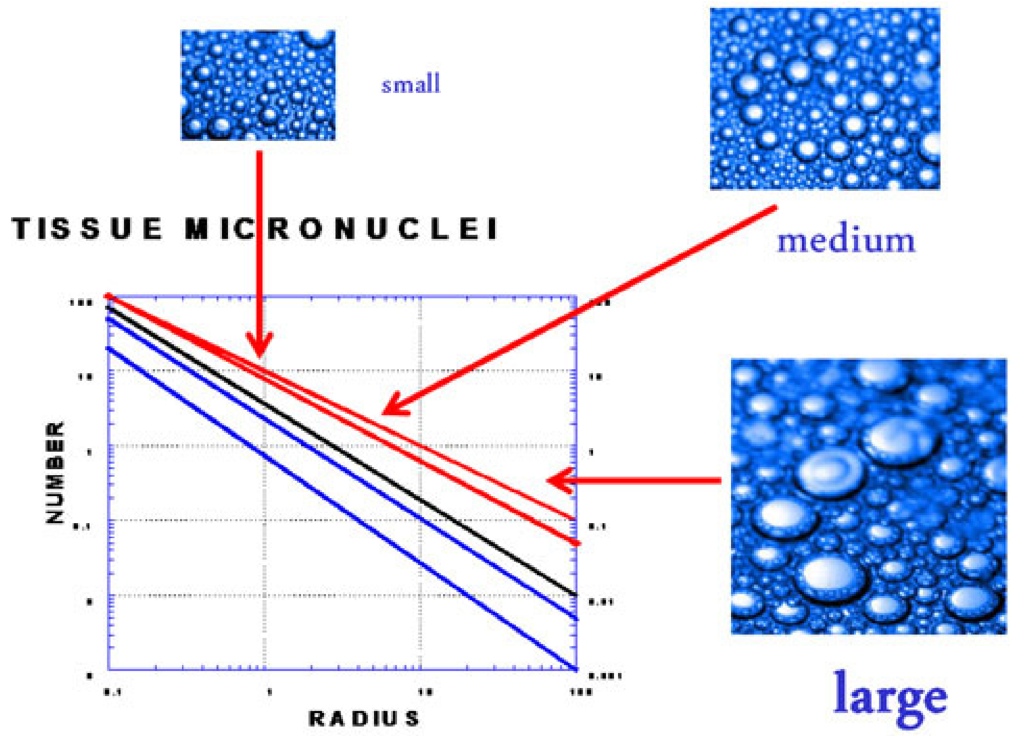
Most biological fluids can be classified as viscoelastic [gelatin deserts, for example, are very viscoelastic] and behave more as an elastic body than as water. It is possible that this cavitation tendency varies to some degree from individual to individual or from time to time in a given tissue, and it therefore plays a role in the tendency to acquire decompression sickness.

An experiment by Lee and Vann examined the loci of bubble formation in arteries, venous blood and capillaries and found them only in the later. This was a most interesting experiment where the major branches off the vena cava were ligated [tied off with a suture] following decompression. Bubbles were detected in the capillaries but never in the vena cava in these rats. This indicates that bubbles are *not present* in blood but actually *arise in capillaries*.

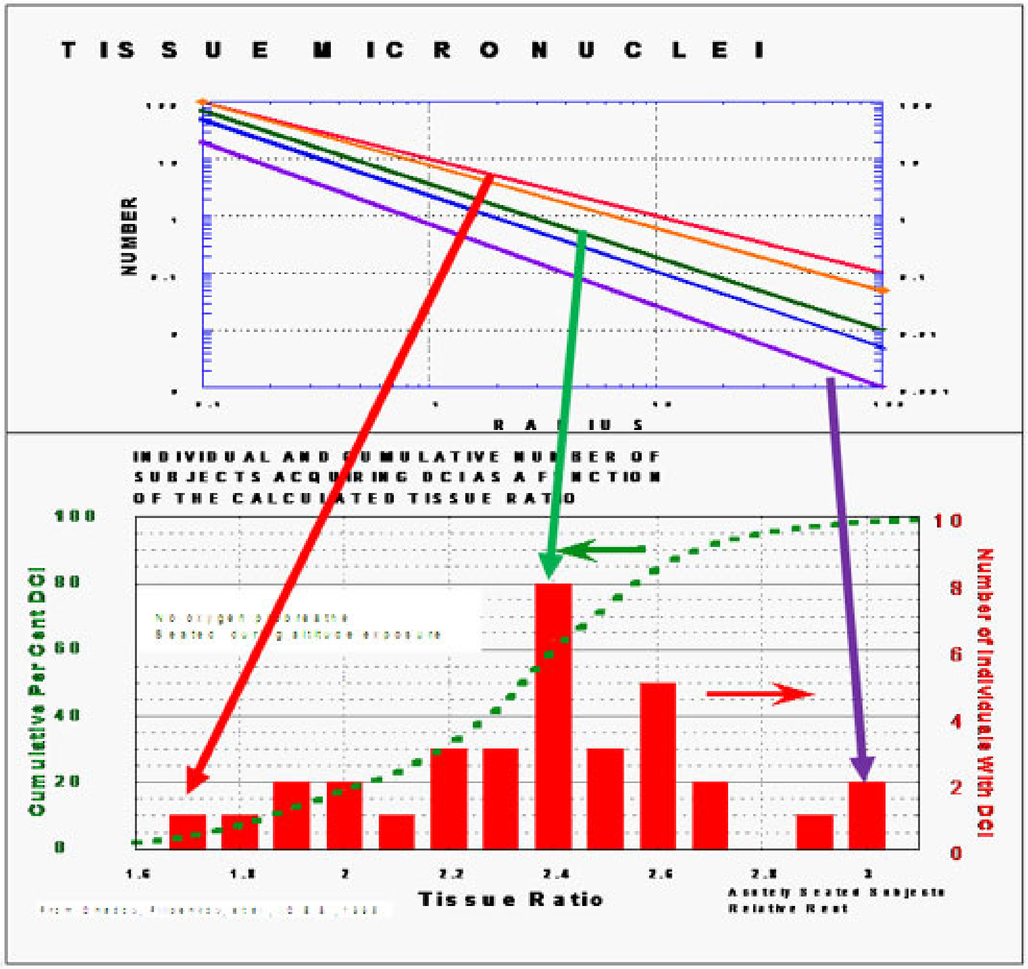
NUCLEI CONCENTRATION – AND WHAT DIVERS CAN DO

One can easily demonstrate for themselves the ephemeral nature of the “metastable limit” and the importance of nuclei in bubble formation. By adding some sugar or table salt to a glass of carbonated beverage, bubbles will be seen to arise. Minute air bubbles are entrained on the surfaces of the crystals. There will be a swift evolution of gas bubbles as the solution wildly effervesces and then becomes still. Adding some more crystals will produce another shower of bubbles in the solution. The process can be repeated many times over a period of at least an hour; recurrent effervescence follows each addition of nuclei in an ever decreasingly supersaturated solution of carbon dioxide. Clearly, bubbling of the carbonated beverage only ceases because we *exhaust the supply of nuclei*, not supersaturation!

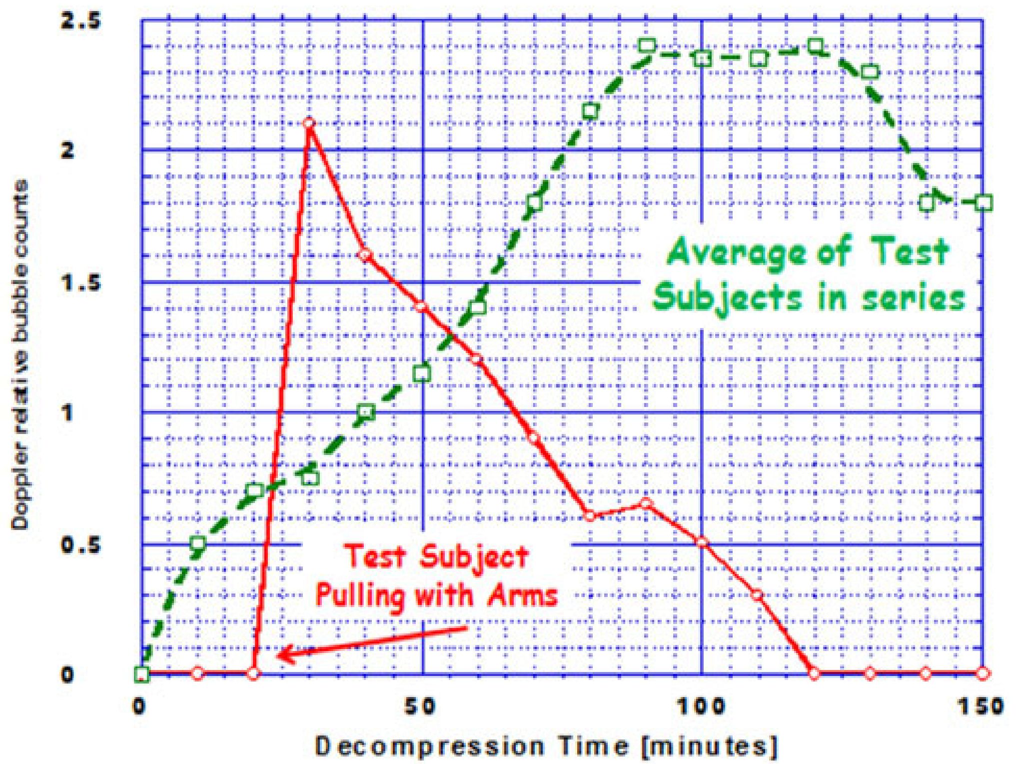
No matter how it is done, divers would rather diminish the nuclei number in their bodies as contrasted with increasing them. Gas micronuclei in opaque tissues are impossible to see. Cutting thin sections, a common microscopy technique, would only allow the nuclei to collapse or evaporate. We can gain some knowledge from an examination of data concerning water in oceans, lakes, and rivers. Ocean water has been measured in detail because of interest in its acoustic properties, especially with respect to sonar and submarine detection. Measurements indicate that ordinary water has many *tiny* bubbles, a medium number of *intermediate* sizes, and a few *large* ones. These display an exponential distribution. In the figure, we see a distribution of this type. It has many lines depicting what we might find from ocean water, lake water, river water, and tap water. There is always the similar pattern: many small, some intermediate, and a few large bubbles. None of these "seeds" is, however, larger than a micron, about 0.000039 inches. Three grains of common table salt in a row are about 1 millimeter. Therefore, we are looking at three grains divided by 1,000. That is one micron. Pretty small. We can expect that since liquids in general follow this patter, it would be found in the fluids of our body, were we able to determine them.



An experiment performed by Russian scientists demonstrated that decompression reviled different susceptibilities of test subjects to DCS. [While not proven, I would hypothesize that this susceptibility, in part, could be traced to differing concentrations of tissue micronuclei.] Thus we see that a fraction of the subjects were "susceptibles" and at the other end of the spectrum, some were "resistant" to DCS. My hypothesis is that nuclei concentration produced this difference, although I do not know yet what causes of this concentration difference. Considerable effort has been expended over the past several decades to produce a "biochemical cause" for decompression sickness. Regrettably, none has been directed at finding a *basis for a difference in susceptibility* and *resistance.*



demonstrate a different time course. While we might *speculate* about decompression bubble growth, laboratory studies show that it can – and does – happen.



This is not theoretical. What can *YOU* do?

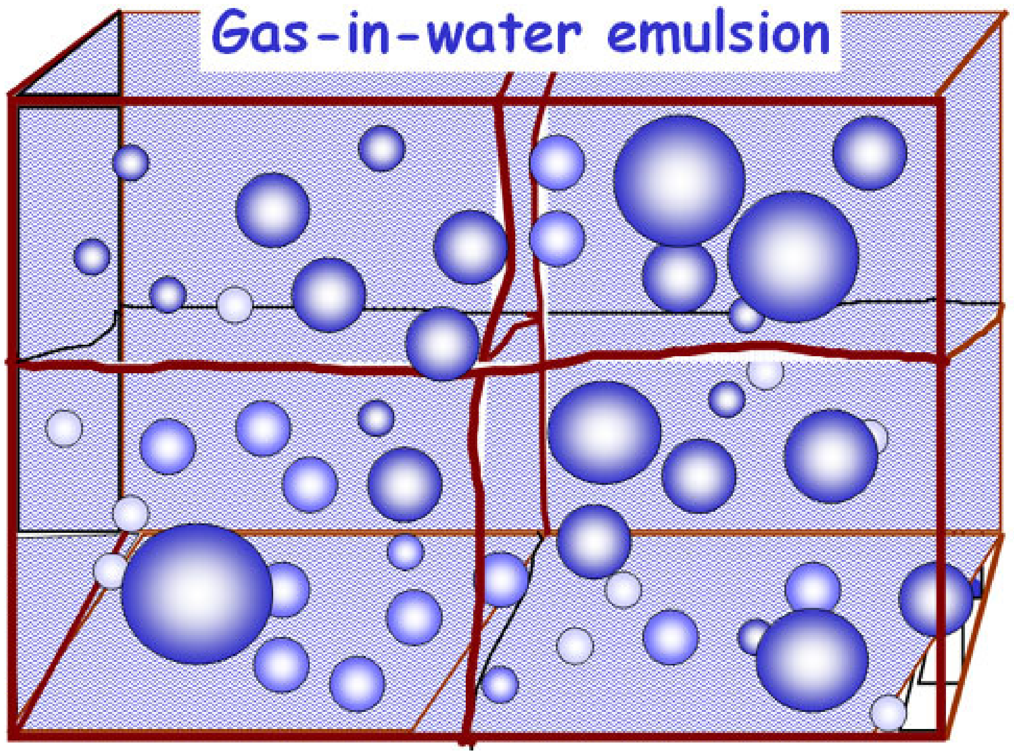
Do people really generate bubbles with physical activity? A test at NASA shows what happened when one test subject pulled very hard with his arms when he was not supposed to. He was intent on assisting the monitor in the chamber, although his assistance was not in the protocol. We see in the red line that immediately following the pulling, there was a spike in the Doppler bubble count when measured in that active arm. The average for Doppler bubbles in the arms for test subjects is shown in the dashed green line; test subjects

Divers believe that hauling air tanks during the surface interval does not have an effect on the dive outcome. Here is laboratory evidence that this is not so. Hauling, lifting, and climbing boat ladders are all activities that can negatively affect the DCS outcome. On my *"Ask Dr Deco"* forum, one diver questioned why he got DCS after walking up a hill that was only 500 feet high. He queried how such a small altitude change could be so bad. No, it was not the altitude; rather it was trudging up that five hundred foot hill. Another diver said that he ran up five flights of stairs to get batteries and got DCS. *See what I mean?* All bad ideas.

There is a physical reason for believing that surface tension can control the size of microbubbles, but limited laboratory studies do not bear this out with respect to decompression as much as I might believe. Compounds can be added to control bubble forming in certain situations. An example is the *antifoam* that is added to the washing fluid in carpet cleaners. We do not have any antifoam that can be added to a diver – not yet anyway.

An interesting experiment that can be done is to take some oil from your skin [around the forehead or nose, for example] and touch the foam on the head of a beer. The foam will immediately begin to collapse. I mentioned this in a Decompression Physiology class and some students tried it that night on one of their evening beer drinking excursions. It worked, but the fellow tried it with his nose and the other fellow's beer. It did not go over very well! Remember, your nose and your beer. Someday a compound might be found that can be added to the diver to reduce DCS.

Aristotle thought of Man as a "creature composed of Mind, Body, and Spirit." St Augustine stated "Mind, Body, Spirit, and Soul." I say that Man is a "gas-in-water emulsion." Well, I truly doubt my description will last as long as that of Aristotle or St Augustine. It is, of course, only for purposes of decompression physiology.



Thanks for reading.

About the Author

I have been interested in science since Grade School in the late 1940s. By the time I was starting high school, I was a budding chemist with a fairly sizable home laboratory in the basement of my parent's house [photo below, left]. Luckily, they were very tolerant of all my apparatus. I later went on to study chemistry at Michigan State University [East Lansing}, graduating in 1963 with a Bachelor's Degree. I went on to study biophysics and received an MS in 1967 [thesis title *"The Effects of Gaseous Anesthetic Agents and Water Vapor on the Electrical Conductivity of Lipid Coated Proteins"*] and a PhD in 1969 [thesis title *"Electronic/Protonic Charge Carrier Ratios in Solvated Biomacromolecules"*].

After graduation, I accepted a job as a research scientist at Ocean Systems division of Union Carbide. In 1975, I went to the Institute of Applied Physiology and Medicine [IAPM], Seattle, WA, as head of their hyperbaric laboratory. From 1977 to 1980, I was with the Underwater Medicine Section of the DFVLR in Bonn, Germany. I returned to IAPM for ten years, leaving in

1989 for the Johnson Space Center in Houston Texas. I was a research scientist investigating decompression sickness in the Medical Sciences Division.

In December of 2005, I retired and returned to the Seattle area in Issaquah. This photo shows me with another passion of mine, ancient history. The photo is in the Metropolitan Museum of Art in New York City.

Polish CCR

Text by Asser Salama

Photos by Haitham Aziz

Warning: This is serious (and dangerous) stuff. Trying what's coming next could injure or even kill you.

A fellow technical instructor in the Egyptian Red Sea resort of Hurghada built his own CCR, and I was invited to give it a try.

Tomasz Stas aimed at building a bullet-proof rebreather while keeping the cost as low as possible. That's why he did not just buy some spare parts and put them together. Instead, he used some of the popular house-hold products!

The scrubber and the head (manifold) are nothing but a water filter. The space inside holds around 2.7 kg (6 lbs) of soda lime. Three oxygen sensors are placed just under the head in a plastic mesh. The system includes one back-mount counter lung, and it's nothing but a ball. To clean the counter lung, a dump valve is installed. The counter lung is welded to the end of the scrubber. I don't know its exact size. The scrubber, head and counter lung are placed in a PVC pipe for protection. As for the mouth piece, it's a water valve.

Both the oxygen and the diluent are added directly to the loop through two hoses via two power inflators. Oxygen is added only manually. No automatic flow valve is installed.

As Tomasz is an electronics engineer, he built three electronic displays to monitor the ppO2. Two of them are in the same enclosure (handset), while the other is independent. They could be switched on and off via two magnetic switches.

The whole system costs around 500 USD, including the three oxygen sensors but excluding the first stages, the tanks, the tank mounts, second stage for bailout, backplate and wing. Also the system does not include any pressure gauges.

I've tried the system for about 15 minutes to a maximum depth of 5 meters (16 feet). In the shallows controlling your buoyancy on CCR is not as easy as OC, and every CCR feels different than the other. All in all, the feeling was better than expected. Tomasz tried his toy up to 85 meters (280 feet) and is completely satisfied with its performance. For more info contact him at tstas@tlen.pl or visit his web site (in Polish) at www.rafakoralowa.com.

The independent ppO2 electronic display inside its enclosure. The magnetic switch is the red button.

The mouth piece.

Oxygen and diluent addition via power inflators.

Tomasz and his home-built CCR.

Decompression calculations for trimix dives with PC software; gradient factors: do they repair defective algorithms or do they repair defective implementations?

By Albrecht Salm

Abstract
If there is more than one inert gas in the breathing mixture, the calculation of the decompression-time t_d has to be done numerically. We analyzed 480 square dive-profiles in the TEC/REC range with one freeware, two commercially available software-packages and via numerical methods (depth range: 30 - 80 m, bottom times: 20 - 60 min, helium percentage: 5 - 80 %, only normoxic mixes i.e.: no travel- or enriched deco gases, only ZH-L model, no adaptations with gradient factors). There are significant differences in the calculation of the decompression-times t_d with trimix gases, obviously dependent on the helium percentage. In the present analysis, these differences do not come from variations in the decompression algorithms.

Side Note
This is an abbreviated version of a paper which appeared in: CAISSON 2011, 26(3): 4 – 12. Several parts of this paper I presented during a lecture for which I was invited to the 12.th scientific meeting of the GTUEM (www.gtuem.org) , 03/20/2011 in Regensburg, Germany; the abstract is under: CAISSON 2011, 26(1): 61. The extended German version you will find at http://www.divetable.de/skripte/CAISSON/Extended_2011_03.pdf

Introduction
An „Algorithm“ is just a mathematical rule for inert gas bookkeeping during an exposure to overpressure. An „Implementation“ is the practical translation of this algorithm into a piece of software, be it for a dive computer or a desktop deco software. A „Gradient Factor“is a factor < 1. It is used to multiply the allowed / tolerated inert gas partial pressures in the various body tissues; thus a more conservative decompression method is forced via mathematics. With “ZH-L” a certain group of dissolved gas deco models is denoted, the researchers names are: Haldane, Workman, Schreiner, Mueller, Ruf, Buehlmann and Hahn (pls. cf. the references).

The classical, perfusion-limited decompression algorithms after Haldane et al. describe the absorption of inert gases per compartment through a mono-exponential function. Normally the term „Haldane Equation“ is used:

$$P_t(t) = P_{alv0} + [P_{t0} - P_{alv0}]\, e^{-kt} \qquad (1)$$

Variable	Definition
$P_t(t)$	Inert gas partial pressure within a compartment with the constant k [Bar] at time t after an instantaneous change in pressure
P_{t0}	initial partial pressure of the inert gas within the compartment at time t=0 [Bar]
P_{alv0}	the constant partial pressure of the inert gas in the alveoli [Bar], for t = 0 and thus for all t due to the boundary conditions
k	a constant, dependent on the compartment [min^{-1}], with $k = \ln 2 / \tau$
t	time [min]

The exponent k is basically the perfusion rate, i.e. the inverse of the half-time τ of a model tissue. These model tissues are called „compartments“. The adaption of a purely mathematical algorithm to a physiological system is done via a flock of these compartments, typically 6, 9 or 12, 16 and sometimes as well 20 (or even more). The variability comes with the different halt-times into play. A typical spectrum of these half-times is from 1.25 to 900 minutes; for e.g. in a dive computer for professional use, the EMC-20H from Cochran and the corresponding desktop deco-software Analyst 4 (www.divecochran.com).

The mainstream sources for these perfusion algorithms are well known and listed in the appendix. But now we want to try something new and draw upon a source which is relatively rarely used:

> [102] Hills, Brian Andrew (1977), Decompression Sickness, Volume 1,
> The Biophysical Basis of Prevention and Treatment

Formula (1) is on page 111, the relationship between the half-times and the perfusion rate is on page 113.

Limits of the perfusion-models

The perfusion-models for Air/Nitrox/EAN and Heliox as breathing gases are based worldwide on a very broad number of well-documented dives. They are mathematically straightforward and have since the papers of Buehlmann ([4], [5], [65]) enjoyed popular implementations in many dive computers and PC programs (Desktop-Deco-Software). The technical diver as such wants to dive deeper / longer and thus is inclined to forget the trusted envelope. Nonetheless this envelope is already published at length (e.g. in [63], p. 449 and 463) and is dealing with a couple of the following points, here just as a short overview and not limited to:

- only „inert gas-bookkeeping", only mono-exponential for one compartment
- these compartments are all in a parallel circuit, the linear connections like spleen -> liver & bowel -> liver are not considered
- inconsistent consideration of the metabolic gases O_2, CO_2 and H_2O
- „uneventful" decompression, only the gas in solution is considered and not the free gas phase (bubbles)
- no allowance is made for short-term pressure changes which are small against the fastest half-times
- the calculation of inert gas saturation and de-saturation is done in a symmetrical manner, i.e. with the identical coefficient in the exponential terms of (1)
- clientele / biometrics and adaption are not reflected in the algorithms
- as well not these circumstances, which affect tec divers even more due to massive impact on blood-perfusion: workload, temperature and excessive oxygen partial pressures
- and: the 2nd. inert gas; the 2nd. (n-th) repetitive dive; and, and, and, …

Just a small choice of sources to these points:

Thalmann, ED; Parker, EC; Survanshi, SS; Weathersby, PK. Improved probabilistic decompression model risk predictions using linear-exponential kinetics. Undersea Hyper. Med. 1997; 24(4): 255 – 274; http://archive.rubicon-foundation.org/2276

Tikuisis, P; Nishi, RY. Role of oxygen in a bubble model for predicting decompression illness. Defence R&D Canada, 1994; DCIEM-94-04; http://archive.rubicon-foundation.org/8029

Doolette DJ, Gerth WA, Gault KA. Probabilistic Decompression Models With Work-Induced Changes In Compartment Gas Kinetic Time Constants. Navy Experimental Diving Unit, Panama City, FL, USA; in: UHMS Annual Scientific Meeting, St. Pete Beach, Florida, June 3-5, 2010, Session A6.

Hahn MH. 1995. Workman-Bühlmann algorithm for dive computers: A critical analysis. In: Hamilton RW, ed. The effectiveness of dive computers in repetitive diving. UHMS workshop 81(DC)6-1-94.

Kensington, MD: Undersea and Hyperbaric Medical Soc. http://archive.rubicon-foundation.org/7998

Trimix tables

For Heliox (oxygen & helium mixtures) there is a great abundance of validated tables: quite in contrary to Trimix (oxygen, helium and nitrogen). There are none (almost). Surely enough there is anecdotal evidence of successful trimix-decompressions, but limited to a couple of custom mixes, with a limited group of test persons and limited in the dive profiles. But „validated“ here means a completely other league of game. It is a journal-led procedure in a decompression chamber, run for a big number of various depth/time combinations, each of them with big numbers of dives. The journal is a detailed and reproducible log of the following parameters: biometrics of test persons, time of the day, depth, time, ascent- and descent-rates, surface interval (even multi-day), breathing gas composition and- humidity/ -temperatures, temperatures in the chamber and wet-pot, type of immersion and work-load. The outcomes (DCS or # of Doppler detected bubbles) have to be checked via double-blinded operators. And when the number of test-persons exceeds the 3-digit limits and the number of test-dives is in the 4- or even 5-digit range (as with NEDU, DCIEM and COMEX tables) then there might be a certain tenacity. But none of the known trimix tables is meeting these requirements. Maybe a laudable exception is the NOAA trimix 18/50 Table from Hamilton Research Ltd., 1993, 1998.

Just for the fun of it we draw from the „Journal of Applied Physiology“ the number and temporal distribution of research papers concerning “trimix“ (title & keyword) from 1948 to 2010 and compared with other topics (Tables (1a) & (1b)):

title & keyword:	1948 – 2010	1976 - 2010
(air	13.466	10.845)
oxygen window	14	
decompression	709	572
ean / nitrox	128	
helium	1313	
trimix		**41**

Table 1a

The papers concerning „air“ are in brackets and only to compare the absolute numbers since the relationship to exposure to overpressure is not always the case. The first paper was around 1976; the graph below shows the last 20 years and features a peak in the year 2007. This results from short discussion-papers concerning the (in)-validity of Henry’s Laws, especially with binary (half/half) gas-mixtures:

Year	#		Year	#
1990	-		2001	1
1991	1		2002	-
1992	-		2003	3
1993	-		2004	-
1994	1		2005	1
1995	2		2006	-
1996	-		2007	8
1997	1		2008	-
1998	-		2009	2
1999	-		2010	1
2000	1			

Table 1b

The somewhat singularly paper in 2010 is from Ljubkovic et al. (pls. cf. the references), and reflects very well our topic here, however with a VPM / bubble model and is really interesting for hyperbaric (-diving) physicians. But generally speaking we have here the tendency that trimix plays only a somewhat junior role in serious research. To put it bluntly:

the heavily exposed trimix diver is his own guinea pig.

The decompression time t_d for un-ary mixes (i.e. only one inert gas like EAN or heliox) can be calculated directly with the Haldane equation (1). This is documented already and elsewhere (for e.g.: http://www.divetable.de/workshop/V1_e.htm), here is the analytic expression for the decompression time $t = t_d$:

$$t = - \tau / \ln 2 * \ln[(P_t(t) - P_{alv0}) / (P_{t0} - P_{alv0})] \quad (2)$$

The criteria for „safe" decompression within the perfusion-models is a simple linear (straight line) equation ([65], p. 117, resp.: [102], p. 119 ff):

$$P_{t.tol.}ig = P_{amb} / b + a \quad (3)$$

Variable	Definition
$P_{t.tol.}ig$	tolerated inert gas partial pressure, for each compartment, (analogue to M) [Bar], the sum of all inert gas partial pressures
a	limit of a theoretical ambient pressure of 0 Bar, i.e. the axis intercept [Bar]
P_{amb}	ambient pressure, absolute pressure of all breathing gases [Bar]
b	1/b pressure gradient: increase per unit of depth (dimensionless), i.e.: the slope of the straight line

These a-/b-coefficients are constants, tabulated for look up, e.g.: in [4] p. 27, in [5] p. 108 & 109, as well in [65] on p. 158.

A direct mapping of equation (3) onto other perfusion models, e.g. the „M-Value" model of Workman or Schreiner, is done via a comparison of the parameters and the conversion of the SI-units to imperial; described elsewhere and, as well, here: http://www.divetable.de/workshop/V1_e.htm)

During the course of the century the number and absolute values of the coefficients changed from author to author: this is mostly the reflection of an increasingly conservative decompression, that is: longer deco stops (pls. cf. Egi et al.).

The analytical expression (2) is only possible with one inert gas, in this case N_2 . With more than one inert gas the calculation of t_d has to be done numerically, via an approximation procedure, that is: by trial-and-error. With Tri-Mix we have 2: N_2 (nitrogen) and He (helium). Thus we have to calculate the inert gas absorption for these 2 separately. This is a standard procedure, already described by Buehlmann in [65], p. 119:

$$P_t(t) = P_{t,\,He}(t) + P_{t,\,N2}(t) \qquad (4)$$

The differences are in the molecular weights, the solubility coefficients and the diffusion constants (pls. cf.: Rostain JC, Balon N. Nitrogen Narcosis, the High Pressure Nervous Syndrome and Trimix. In: Moon RE, Piantadosi CA, Camporesi EM (eds.). Dr. Peter Bennett Symposium Proceedings. Held May 1, 2004. Durham, N.C.: Divers Alert Network, 2007; as well: [102], p. 118)

But now the criteria for „safe" ascent has to be adapted as well to 2 inert gases, (3) changes simply to (3*):

$$P_{t.tol.}ig = P_{amb} / b^* + a^* \qquad (3^*)$$

Here as well there is a simple procedure to determine these new a* and b* -coefficients. The old a- and b-coefficients (table look-up) for both of the gases are normalized with the prevailing inert gas partial pressures for each of the compartments (pls. see the remark in [54] on p. 86). Thus we have for any combination of a- and b-values for each compartment at any time t:

$$\begin{aligned} a^* &= a\,(He + N_2) = [(P_{t,\,He} * a_{He}) + (P_{t,\,N2} * a_{N2})] / (P_{t,\,He} + P_{t,\,N2}) \\ b^* &= b\,(He + N_2) = [(P_{t,\,He} * b_{He}) + (P_{t,\,N2} * b_{N2})] / (P_{t,\,He} + P_{t,\,N2}) \end{aligned} \qquad (5)$$

Please see as well the examples in [4], p. 27; [5], p. 80 and Rodchenkov et al, p. 474.

The ascent criteria is now time-dependent by itself, the a*- & b*-coefficients are via (5) married with the time-dependent exponential expressions of saturation/desaturation and no longer any constants as per air/EAN or heliox.

The mapping of the compartment halftimes from N_2 to He is normally done according to Graham's law with the square root of the proportion of the molecular weights (i.e.: ca. 2.65). This factor is now keyed in, uniform to all compartments. And exactly at this point we meet the criticism of serious researchers in the field: D' Aoust et al, p. 119 & 121; as well: Lightfoot et al, p. 453 and: Voitsekhovich, p. 210. In experiments we see the perfusion rates quite differently! The pivotal 2.65 is, so it seems, really valid only for saturation exposures (Berghage et al, p.6). But saturation is a state which even the bold tec-diver does not reach easily … (Well, there are bold divers and there are old divers. But there are no ... Ok, Ok: you already know the rest of the story ...)

Methods

To put it simply: the deco time t_d is now on the left and the right hand side of eq. (2), a simple analytical expression to solve for t_d is not possible due to the exponential sums. How can we then evaluate t_d?

Basically there are at least 3 simple methods. We look at them only skin-deep because they are described elsewhere (for e.g.: http://www.divetable.de/workshop/V3_e.htm)

A- „Trial-and-Error": for small increments in time, e.g. 1 second or 0.1 minute, we calculate all relevant terms and check if the ascent criteria is met. This is called a classical „numerical" solution.

B- „Quasi-Analytical": we accept tacitly an error by using eq. (2)

without changes. Thus we consider the a*-/b*-coefficients as constants for each phase of the decompression.

C- An approximation method: all the exponential terms are approximated via a polynomial expression, aka „Taylor Expansion“ (Bronstein, Chapter: Expansion in Series).

For commercially available off-the-shelf (COTS) desktop deco software method A) should be preferred since the computing power of topical PC hardware does not impose any waiting-time for the users. Thus quite in contrary to standard mix gas diving computers. Due to the relatively high cost of development for water-proof hardware and, in comparison to other mobile electronic devices like Smart Phones, virtually negligible lot sizes, there are regularly no full-custom ASICs in favour of relatively cheap standard chips. These standard chips are somewhat “slower” and brilliant in a gigantic energy consumption ...

The numerical solution A) consumes, in comparison to method B) more computing power and thus time and more variables and memory: all of the 3 we do not have plenty under water! It is thus self-evident to insinuate method B) where cost is at premium and we need a result on the spot.

How is this handled with commercial standard products? The crux is that producers of dive computer hardware and deco software are regularly not willing to answer such inquiries with hints to company secrets. Or, answers are cryptic and thus give room for conjecture!

But to answer this question halfway satisfactorily, we have developed the following experimental method: 480 square dive profiles from the TEC- and REC- domain with the depth range: 30 - 80 m (6 profiles at 10 m distance), and bottom times : 20 - 60 min (5 profiles in 10 min increase), with helium fractions: 5 - 80 % (16 profiles in 5% increments), only with one normoxic mix (i.e.: no travel gases and no EAN deco mixes) have been evaluated each with 4 software products and compared:

- two commercially available off-the-shelf deco softwares,
- one Freeware/Shareware version of DIVE (source: http://www.divetable.de/dwnld_e.htm , version 2_900), and, as well
- a private version 3_0 of DIVE.

This version 3_0 had implemented exactly the method A), the public version 2_900 is flawed with the “blunder” of method B). For the 2 COTS products there are no reliable statements available despite insistent and repeated inquiries.

As a first step, these 4 products have been tested against each other with 40 different air- and 40 different Nitrox/EAN32 profiles. Thus we checked the actual convergence of the numerical method A with the COTS products. As one paradigm we have the following table (2) with the TTS values for a square dive to 40 m with the bottom times ranging from 20 to 60 minutes:

40 m, Nitrox/EAN 32 bottom times [min]:	20'	30'	40'	50'	60'
TTS DIVE 2_900	8	16	28	42	55
TTS DIVE 3_0: numerical solution	7	17	28	40	57
TTS COTS product 3	5	15	28	41	53
TTS COTS product 4	7	16	28	41	54

Table (2): TTS vs. the 4 products; TTS = time-to-surface, i.e. sum of all deco stop times + time for ascent

As well a sensitivity analysis was made for the numerical solution in order to make sure that minor variations in the starting parameters do not lead to mathematical artefacts. In the end we compared the 4 against the „Gold Standard“, the „Zuerich 1986 table for air dives“

(ZH-86) of A. A. Buehlmann ([65], p. 228). Here we have deviations of + / - 2 min per deco stage, as well sometimes the staging begins 3 m deeper in comparison to the table. This comes mainly from the different sets of coefficients: the ZH-86 table uses the ZH-L 16 **B** set ([65], p. 158), whereas deco software or dive computers are using normally the ZH-L 16 **C** set ([65], l.c.). As well printed tables are treating truncations in a completely different way than dive computers. Even the great ex-champion from the NEDU (the United States Navy Experimental Diving Unit), Captain. Dr. Edward Thalmann had to admit, that a published diving table does not jar with a computer-output:

> "I think some were just manually adjusted. They just went in and empirically added five minutes here and five minutes there, yeah."

(Source: Edward Thalmann, [113] Naval Forces under the Sea: The Rest of the Story, p. 63 – 70, 197, 274, 361 and as well, the CD "Individual Interviews").

Similar things may have been happened as well with OSHA tables for caisson/tunnel work (until 1979). But these have been coined as „typographical errors" (Kindwall, p. 342).

To force comparability all the calculations are based solely on the set ZH-L 16 **C** ([65], p. 158) and there are no manipulations via gradient factors. As well there are slight adaptations of the dive profiles via ascent- and descent rates to make sure that the bottom times and the inert gas doses are matching.

Results

Evidently there are significant differences in the calculation of the deco times in dependence of the helium-fraction and the amount of decompression obligations, vulgo the inert gas dose, see chart (2). These differences are not due to variations in the decompression algorithm but rather exclusively through different ways of calculation.

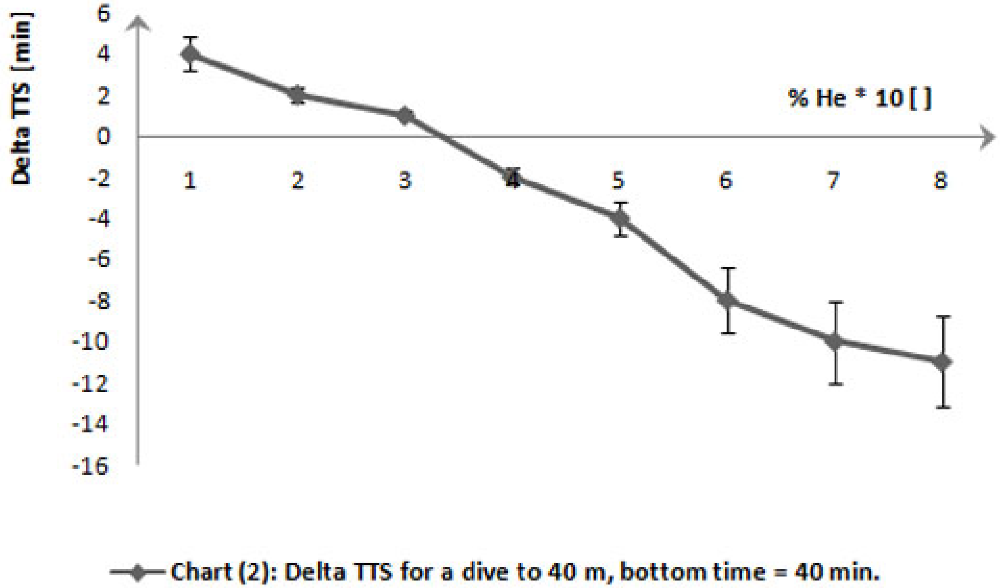


Chart (2) shows the deviation of the TTS in dependence of the helium fraction, here as an example for a dive to 40 m with a bottom time of 40 min.:

x axis: percentage of helium in the breathing mix: from 10 to 80 %

y axis: Delta TTS is a difference of the numerical solution to an arithmetic mean out of the 3 TTS according to**:** $\mathbf{\Sigma (t_{d,1} + t_{d,2} + t_{d,3}) / 3}$ **;** the $t_{d,i}$ being the calculated $\mathbf{t_d}$ of the products i = 1 - 3 (DIVE 2_900, product 3, product 4). The x axis is defined as the zero baseline of the TTS of the numerical solution. An "error" in [minutes] is coined as the deviation (Delta TTS) of this mean value against the TTS of the numerical solution. The calculation of this arithmetic mean was superimposed by the strong closeness of the t_d from the 3 products. The absolute errors (see the vertical error margins) are increasing with the increase of the inert gas dose and with the increase of the helium fraction. The above represented curve progression is more or less universal for all of the 480 square profiles. Speaking simplified, qualitatively:

- in the region of the helium fractions 5 % up to ca. 25 % the TTS is overrated: positive error; i.e. the TTS is too great, the decompression is too conservative.
- in the region of helium fractions which is relevant to most tec divers, that is ca. 30 – ca. 40 %, the error vanishes: Delta TTS -> 0, and
- increases with increasing helium fraction. In this region the error is negative, i.e. the TTS is too small, the decompression is too liberal.

Discussion

The results of the 2 COTS products and DIVE 2_900 came very close to each other thus a somewhat similar calculation method is supposed. But this „similar“ method means in plain language: the „blunder“ of DIVE 2_900 could be repeated in the implementations of the 2 COTS products ... To put it even more bluntly: the relative identity of the absolute values and the prefix leave room for the guesswork that the 2 COTS products are using method B). Well, there are quite a couple of other factors who could have been responsible for these deviations. To name just a few:

- undocumented gradient factors
- a respiratory coefficient unequal to 1
- another weighting of other inert gases
- another weighting of the water density
- „empirically“ adapted a-/b coefficients, especially for helium and as a consequence:
- small deviations from the original helium ZH-L spectrum of half-times (i.e. a mismatch of a and b with the half time)
- utilisation of the so-called „1b“ compartment instead or additive to compartment „1“ ([65], p. 158);
- ascent rates varying with depth
- different approach to truncations

„Walking stick“ solutions for software implementations due to restrictions of the hardware have been quite common in the early days of dive computers: for e.g. there was a product in Europe which could only interpolate linearly between stored values instead of calculating a full-blown saturation/desaturation. But even today there are implementations which rely on a modified ZH-L instead of the promised (advertised) RGBM model ...

But it seems that there are implementations taking this topic seriously. Amongst others there is a shareware with a VPM model (http://www.decompression.org/maiken/VPM/VPM_Algorithm.htm): „The analytic, logarithmic expression for stop times ... was replaced with a numerical solution of the restriction on the sum of He and N_2 partial pressures.“

Conclusions

What shall we do with these, admittedly rather theoretical considerations? By no means this should be made a public example for the developers. And in no case there is ample evidence to draw any solid conclusions, as described above. These are the reasons not to reveal any brand names. As well there is to consider, at least in Germany, the fair trade law, especially the §§ 4, 5 and 6.

But the situation stays very unsatisfying concerning the intransparent status of some implementations and the lack of open documentation of the „defaults" and constants. To put it in tec-lingo:

Is there really a ZH-L inside when the label reads "ZH-L"???

But the clear message is the following: a decompression time in a digital display, be it on a dive computer or a PC, is subject to interpretation! And this not so much due to errors in the measurements (pressure, time, temperature, ...) and other statistical contemplations but rather due to the method of programming and the choice of a solution for a mathematical algorithm; i.e.: the software technology, the implementation. The range for these interpretations is not only in ppm or per mill but rather, dependent on the inert gas dose and the helium fraction , in the one- or even two digit percent range …

To answer the question posed in the title finally:

1) Yes, with gradient factors we could repair defective perfusion algorithms. But the perfusion models work by far more satisfying than the topical hype around the bubble models tells. To underline this one with a historical one-liner:

"Haldane works if you use it properly!"

(R.W. Hamilton, Decompression Theory: 17th UHMS workshop, p. 135; 1978)

2) Yes, we need gradient factors to haul up to the safe side bad or negligent implementations for mix gases!

In a nutshell we have it here for a dive (depth 42 m, bottom time 25 min, mix: 20 % O_2, 80 % He) on chart (3): it is a screen copy of DIVE Version 3_0:

```
maximale Ceiling: 12.56
Vorschlag Haldane 2:1 [m] =   15
Vorschlag Hills, B. A.: DEEP STOP [m] =   27
PDIS fuer TAU =  15.98 min:  27.76 [m]
PDIS fuer TAU =  23.44 min:  21.89 [m]
PDIS fuer TAU =  34.67 min:  16.44 [m]
Eingabe der Austauchstufe in Metern & cm:(m.cm):
          Austauchstufe ist zu hoch:
          niedriger wie Ceiling waehlen!
 Deko Prognose:
15m Stopp Prognose Dekozeit:  1.00  Komp.#:  5
12m Stopp Prognose Dekozeit:  3.00  Komp.#:  5
 9m Stopp Prognose Dekozeit:  8.00  Komp.#:  7
 6m Stopp Prognose Dekozeit: 15.00  Komp.#:  8
 3m Stopp Prognose Dekozeit: 33.00  Komp.#: 10
TTS =   64.00
 Deko Prognose numerisch:
15m Stopp APPROXIMATION :      .25 Steps N=      1.
12m Stopp APPROXIMATION :     3.25 Steps N=     13.
 9m Stopp APPROXIMATION :     7.75 Steps N=     31.
 6m Stopp APPROXIMATION :    14.75 Steps N=     59.
 3m Stopp APPROXIMATION :    48.00 Steps N=    192.
TTS =   78.20
 Deko Prognose mit Gradientenfaktoren:  GFHI=   .9
18m Stopp Prognose Dekozeit:  3.00  GF =    .65  Ko
15m Stopp Prognose Dekozeit:  3.00  GF =    .70  Ko
12m Stopp Prognose Dekozeit:  6.00  GF =    .75  Ko
 9m Stopp Prognose Dekozeit: 10.00  GF =    .80  Ko
 6m Stopp Prognose Dekozeit: 20.00  GF =    .85  Ko
 3m Stopp Prognose Dekozeit: 47.00  GF =    .90  Ko
TTS =   93.00

 was jetzt? * * * 42 m, 25 min, 20 % 02, 80 % He *
```

Chart (3)

At first we see a couple of deep stop strategies and then the projection in details: the 1st. block (according to method B) with the deco stages and the TTS @ ca. 64 min is likely to be found with the COTS programs. The 2nd block (TTS = 78, method A) is the numerical solution, not truncated. For a printed table or a COTS product the rounding-on at every deco stage would result in a TTS of ca. 81 min. Application of gradient factors (block 3) with for eg. GF high = 0,9 and GF low = 0,65 yields a TTS of ca. 93 min. Thus feigning a safety buffer of 93 – 64 = ca. 30 min which we do NOT have in reality, because the „real“ numerical solution converges @ ca. 81 min.

Thus the deviations are in an order of magnitude where even the differences between the various deco models / algorithms become blurred, pls. look at table A in: http://www.divetable.de/workshop/Vergleich2_e.pdf. The discussions on which model is „better“ and which became here and there sometimes overheated could now be put into a cooler context. To put this one as well into tec-lingo:

„It doesn’t matter which model you use, provided it has a sound implementation!“ (© Albi, CE 2009)

Acknowledgements

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The other internet links are pointing to the abstract page at the Rubicon research repository: http://archive.rubicon-foundation.org/

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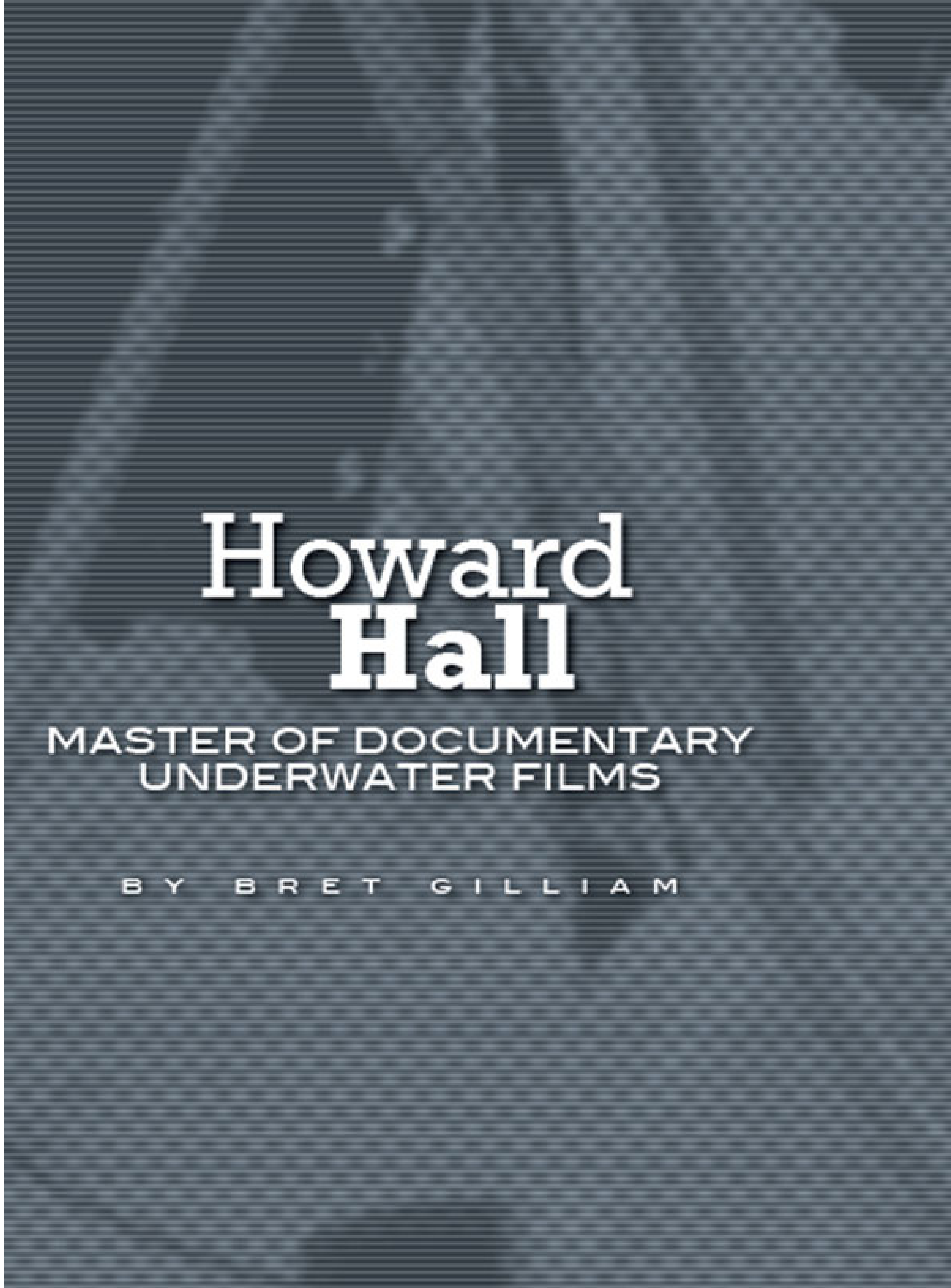
DAN: Divers Alert Network; www.dan.org
DCIEM (old label, now): Defence Research and Development Canada; www.drdc-rddc.gc.ca
Journal of Applied Physiology: http://jap.physiology.org/
NEDU: Navy Experimental Diving Unit; www.supsalv.org/nedu/nedu.htm
NOAA: National Oceanic and Atmospheric Administration; www.noaa.gov (resp. NOAA diving: http://www.ndc.noaa.gov/)
OSHA: Occupational Safety and Health Administration; http://www.osha.gov/, (the topical caisson tables are at: Part Number 1926.)
UHMS: Undersea & Hyperbaric Medical Society; www.uhms.org



Howard Hall has enjoyed huge success as a filmmaker. That may be the biggest understatement I've ever made. And even that concise praise would probably make him wince. Because, in spite of being blessed with an innate talent and instinct for creative filming that perhaps is only shared with an iconic figure like Al Giddings, Howard is the epitome of reticence... a seemingly shy, almost reluctant hero. Having been privileged to share stages with him over the years and to spend time in the field with him on an IMAX shoot, I can attest to both his striking intelligence, as well as his private gracious generosity. And he possesses a delightful sense of ironic and understated humor. Like Stan Waterman, an evening spent with Howard over dinner and wine is both entertaining and profound.

He got his start in film by spearing fish for Giddings on *The Deep* back in 1976, Howard has forged ahead to be recognized as one of the finest and most creative underwater cinematographers in the world. As a team, he and wife Michele have received seven Emmys for television specials. And they are considered the best to use the IMAX format underwater. Back in the summer of 1998, I caught up with them when we rendezvoused off Cocos Island where they were on their fifth three week expedition filming a new IMAX production, Island of the Sharks. They had chartered the 90-ft. *Undersea Hunter* while I had the 120-ft. Sea Hunter with an eager crew of rebreather divers aboard for the month.

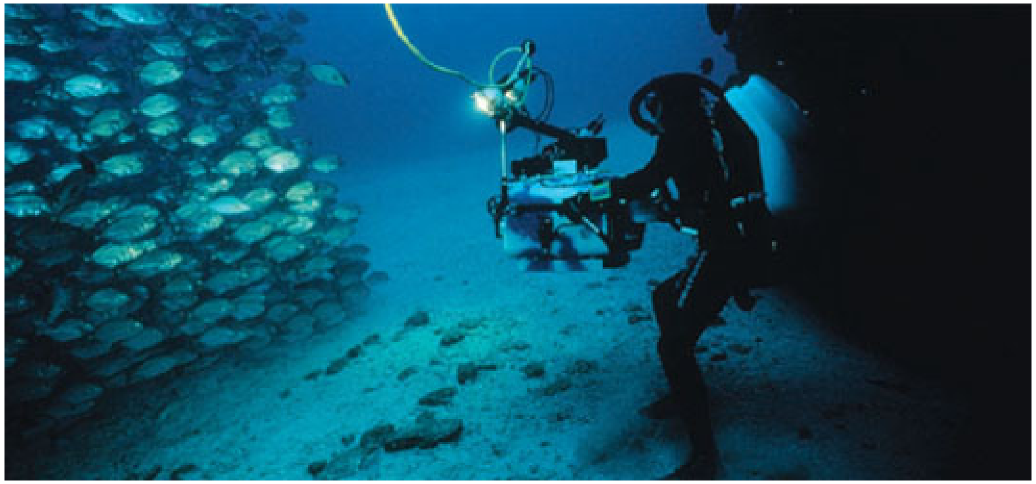
I invited Howard's crew over for dinner and drinks on our ship and a good time was had by all. Howard agreed to sit down with me and let the tape recorder run later in the week. So a few nights later I braved a typical Cocos downpour to drop in for the interview. All of us had spent about seven hours underwater that day thanks to the rebreathers and with the help of a few memorable bottles of red wine, I got Howard to talk about his work and how he got started.

In a world that is frequently populated with more than its fair share of pretentious, arrogant, pain in the ass, "I'm so important" types… Howard and Michele are almost impossibly nice. As attractive a couple as you'll ever want to meet, they're also incredibly patient and gracious. I watched Howard get backed into a corner the night he visited us aboard *Sea Hunter* by an over-eager tech diver who interrogated him without letup for nearly an hour. Poor Howard couldn't even eat his dinner. Finally, Michele and I interrupted Howard's cross-examination and banished the offender to the upper deck on the promise that he could bend a technician's ear about reconfiguring his rebreather unit.

I apologized to Howard for being subjected to such a barrage of questions. He replied that "it wasn't a problem with the volume of questions, it's just that he wasn't listening completely to my answers." How's that for a complaint? I love this guy. Even Michele threw her hands up and told him to finish his dinner already.

So on the promise that I would listen carefully and completely to all responses, the interview began while the rain deluge splashed occasionally into our wineglasses.

Okay, the obvious first question, when did you start diving?»When I was six, my parents took a trip to Guaymas Mexico and we would go snorkeling. I didn't know how to swim, but I learned to snorkel dive. I had one of those full-face masks with the pair of attached snorkels with the little cages holding ping-pong balls. I remember using that before I could swim and my parents watching over me from the pier while I tried to catch starfish in six feet of water. I snorkeled often after that. When I was in high school I took up competitive swimming and in my junior year took a LA County Scuba class.



When did you start to work in diving?»Almost immediately. I got a job at LA County Skin Diving Schools in Whittier and got my instructors certificate when I was a senior in high school. Then I went off to college in San Diego and found job at San Diego Divers Supply. Working as a diving instructor paid my way through college. I later moved over to the Diving Locker and worked there from 1972 through 1978.

When I started at the Diving Locker I was inspired by Chuck Nicklin who was supplementing his living by selling underwater photos as well as film assignments. A lot of pros came from the Diving Locker, Marty Snyderman, Steve Early, Flip Nicklin, Mark Thurlow – a bunch of guys got their start there. I started taking still photographs, writing stories for diving magazines and by 1978 I was able to make it a full time job.

I remember that one of you first jobs in professional film was on *The Deep*; you went on from there to do other things. Tell us about the progression of projects that you got into from there.»After the NBC Shark Special with Waterman, I went to work with Stan on several American Sportsman episodes. I produced a couple myself, one of which popularized the Marisula Seamount in Baja where Stan and I filmed schooling hammerheads and people riding manta rays. I then directed 16 episodes of Wild Kingdom over the next five or six years.

Marlin Perkins was with us on about half of those shows. Tom Allen who was a rep for Scubapro was with us on the other half. Marty worked on many of them as second cameraman. I was with Marlin on his last dive during the winter off Catalina Island for a film about squid. He was 80 years old. He was a great guy.

Jack McKenney was also instrumental in my career progression. He was very generous with his advice and support. He also recommended me to Hardy Jones for a film about dolphins on the Bahamas Banks. Hardy had already made one film out there using Jack. But Jack was already booked when Hardy called him the second time. So Jack suggested me. I got the call from Hardy and we eventually did a whole series of important films together. He was the first person to produce a film about the spotted dolphins of the Bahamas Banks. Hardy later went on to become an accomplished filmmaker and an important marine mammal conservationist.

Both Stan and Jack were important as far as getting me started, making it easy for me to get jobs, promoting me as a young cameraman. I worked with Stan on many different things and Jack recommended me on a variety of projects. I learned a great deal from both men. I learned a lot about professionalism from Stan, how to work with people and keep everything in proper perspective. Stan once said, “Every time I see someone else achieve something great, a little piece of me dies.” Then he laughed. He was making a joke, but there was a lot of truth to the statement. It’s easy to envy another’s success, but it’s a laughably stupid emotion. Stan handles it better than anyone I know. What I learned from Jack was much different. I studied Jack's camerawork. Jack was doing things that even today most underwater cameramen can't begin to figure out. He was a genius with an underwater camera.

Such as?»Jack was the first guy I ever saw to use a tripod and bright surface powered lights to do macro cinematography underwater. I remember seeing one of his films at a film festival in San Diego and there was this spectacular close up shot of a nudibranch crawling across the reef. It was full frame, unbelievably colorful and rock steady. I'd never seen colors like it. So I learned how he did it. It was done with tripods, heavy weights, and lots of light and special macro lenses. He went to a great deal of trouble. Most underwater photographers would have just hand held the shot, but Jack was a perfectionist. Jack was doing the most sophisticated underwater wildlife work of his time.

Speaking of state of the art camerawork, you went from 16mm to larger format to IMAX. What was it like to do the first underwater IMAX 3D production?»Graeme Ferguson, one of the founders of IMAX, called me up one day. He had seen *Seasons in the Sea*, a film I produced that won best of show at the Wildscreen International Film Festival. Graeme wanted me to do the first ever IMAX 3D film underwater. I couldn't believe it. At first I thought it was a joke. He wanted me to write the script, set up the logistics, go where ever I wanted to go, just do it. It wasn't until after Michele and I met with him that I really began to believe it was going to happen. The problems were almost overwhelming. The camera was just being finished at a cost of 3 million dollars. Bob Cranston and I booked a trip to Toronto to see it and to create the concept for the underwater housing. The camera itself weighed 340 pounds with a full load of film. The housing was going to come in at around a ton. To our surprise IMAX did a fabulous job of building the housing based on our design concept. Of course, it should be a good piece of work, the cost was $350,000. It was possibly the most expensive underwater housing that was ever produced.

Let's talk just a minute about the dimensions and the weight of this thing.»The housing weighed about 1,300 pounds depending upon how it was rigged. It was loaded with two 2,500-ft. rolls of 70mm film. That's 5,000 feet of film. The weight of the film load alone was 50 pounds. By the time you purchased the film, processed it, and printed it to IMAX, that single load cost $25,000! And that single load of film ran for only seven minutes. It cost $60 a second to run the camera and it took five seconds for the camera to come up to speed and another five for it to ramp down. That's about $600 just to pull the trigger to see if it will run. The whole thing was just about half the size of a Volkswagen beetle.

So how did you move it around underwater?»Slowly. If there was any kind of current at all, it was impossible. We couldn't work in current. Surge was problematic too. We made the film in California where surge is a given. If you got caught between the camera and a rock, it could crush a hand or break ribs. Usually, we took the thing down and mounted it on a tripod. In some cases where there was dead calm, two of us would handle the camera and do slow moving shots. There were some shots where we pushed it through a kelp forest. But once you got it going, it was pretty much out of control. We spent over $50,000 building a thruster system to propel the camera. But I simply didn't have time to learn to fly the thing. We made one dive with it, crashed a few times, and gave it up.

We worked at Anacapa, Santa Cruz, Catalina, San Clemente, San Miguel, and even off La Jolla. The nice thing about it was I figured I

The massive IMAX 3D camera and housing in the California kelp, *Into the Deep*, 1994

was fail-proof. The film was being made for a single theater in Osaka, Japan. I never dreamed the film would be shown in the United States. But by the time it was done, there were 12 IMAX 3D theaters in the US and all of them had booked the film. It debuted at the new Sony IMAX Theater on Broadway at Lincoln Center and it sold out! It was the highest grossing single screen in North America during Thanksgiving of 1994. It was still playing on Broadway four years later and highest grossing IMAX 3D film ever made at the time. Incredible. Today it still ranks in the top three or four highest grossing IMAX 3D films and is still playing.

There are very few couples that have been able to make their careers work as well as you and Michele. When did you guys meet?»Michele and I met in May of 1975. She had decided to learn how to scuba dive, found Chuck Nicklin's Dive Locker in San Diego and signed up for lessons. Marty Snyderman signed her up and put her into my class. I started at the Diving Locker in 1973. The Deep came along in '76. That was probably my first big break. I had already been shooting still photographs, recently published my first photos in National Geographic magazine, which was a major milestone for me. Chuck Nicklin got me involved in The Deep. I was basically a gopher, my job was to spear fish and attract sharks in order create the shark sequences for the movie. I was a very minor player.

You worked on one of the best action sequences in *The Deep* out in the Indian Ocean or the Coral Sea, right?»It was the Coral Sea and that is the only part of the production in which I was involved. I was there only to do the shark work; I never met Jackie Bissett, Robert Shaw or any of the other actors.

Did you know Al Giddings prior to *The Deep*?»I had never met Giddings, Stan Waterman or Jack McKenney. I met all those people in the airport as we departed for Australia. Jack and Stan became incredibly important in the years that followed, in developing my career. Stan has been a mentor for me. I learned a great deal about underwater cinematography technique from Jack McKenney, he was way ahead of his time. Both of those guys bent over backwards to help me get started in this business. During The Deep I learned a lot about leadership from Al. And, of course, Chuck Nicklin was my original inspiration and got me the job in the first place.

Well, I guess that Stan actually remembers your name then?»(laughing) Well, about once a year he does. I guess you met him about the same time I did and I think he remembers you more often than me. Bret, it's interesting to reflect that when you and I met Al Giddings we both thought he was this legendary older guy who had been around forever. He was only 39 and we're both now about a decade older than he was then.

Back to technology advances, we are sitting here talking to you underneath the wing of a specially designed mini-plane on floats.»Well, the ultralight is a solution to a difficult problem. Giant format films typically contain aerial photography; there is almost no IMAX film that has been made without this type of photography. Producers of large format films tend to feel that aerial shots are sort of a must. Everyone, myself included, wanted aerials but to get a conventional aircraft to Cocos Island is not practical.

When we were in the pre-production stages of the film there was a float plane that flew out to bring passengers to a sportfishing operation in Cocos. That organization has closed business and the float plane is no longer in Costa Rica. A round trip flight from the mainland to Cocos Island is 600 miles. So, therefore to fly from the mainland to Cocos with the IMAX camera and shoot a three-minute load of film and then return to the mainland would be out of the question.

Almost any helicopter or float plane that flew to Cocos would have to refuel by landing on a boat or on floats, weather permitting. I considered all of these options and in the end an ultralight presented itself as the most practical solution to the IMAX camera problem. Obtaining, testing and the shipping of an aircraft of this caliber to Cocos would not be easy. To make the project happen we recruited John Dunham, a good friend of mine, to help collaborate on the preparation plans. John is qualified to operate a wide variety of aircraft including the ultralights. This Cocos film was an opportunity to get John involved in productions, so I commissioned him to buy an aircraft, rig and test it for the handling of IMAX aerial camerawork. It was an expensive production to get the aircraft to Cocos, but it has worked out great. We have shot ten rolls of film to date and have had no technical problems to speak of.

In addition to the aircraft and the very technical camera systems utilized in this project you were one of the first crews to embrace the use of rebreathers.»We became interested in rebreathers when we completed a film on the Sea of Cortez in the late 1980s. The film contained an important sequence on hammerheads, these sharks will spook at the sound of scuba bubbles and were extremely difficult to approach. I had been down there many times before, filming hammerheads, for programs such as *Wild Kingdom* and *American Sportsman*. For all of those films, I had free dived to get into the schools of hammerheads, which was tough. Swimming down sixty or seventy feet, with a 50-lb. movie camera, and remaining long enough to get a usable shot of twenty to thirty seconds is very hard. Swimming back to the surface after taking the shot is much more dangerous and difficult. For this film I wanted to find a way to get into the school of sharks and remain filming for a while.

The film we were making was called *Shadows in a Desert Sea*, which was made for the PBS series *Nature*. Anyway, I dreamed of having a closed circuit rebreather for getting into the schools of Hammerheads without spooking them. I remembered seeing the Electro Lung advertised in *Skin Diver* magazine back in 1969 and wanted one ever since. Of course, Electro Lungs were not on the market long, a half dozen divers were killed almost immediately and the lawyers shut the product down. In the late 1980's, there were no rebreathers available to civilians so I began to look for ways of getting my hands on a Navy Mark 15. Unfortunately, at the time one could only obtain a Navy Mark 15 by stealing it from the U.S. Navy and that was not going to work.

I began working with Bob Cranston who had some military contractor experience from his days working for DUI (dry suit manufacturer). Bob knew some individuals involved in the Mark 15 program and it just so happened that our timing was perfect. Biomarine (manufacturer of the Mark 15) had just lost their bid to build the new Mark 16. As part of their bid for the Mark 16 contract they had built a prototype called the Mark 15.5 or Mark 155. When Biomarine lost the contract for the Mark 16, that left the prototype rigs in limbo. We started out by leasing a pair of 155s from Biomarine for use during the filming of the Shadows project. Later we managed to purchase two of the units. Initially, we were terrified of the things; everyone told us that we were going to kill ourselves. During each dive we made a dive, the list of people who had died on the Electro Lung ran through my mind. We memorized the manual, developed our own equivalent air depth tables, and taught ourselves along the way. It took about 50 hours underwater before we began to feel comfortable. But eventually, we got great schooling hammerhead footage including the first record of mating hammerheads ever filmed.


Howard and Michele Hall with IMAX camera, Cocos Island, 1990

Have you modified the rebreathers for your use since then or are you basically using them the way they were?»Our Mark 155s are now highly modified. It would be easier to list the parts that we haven't changed rather than list the modified parts. We've modified the plumbing to provide low-pressure diluent and oxygen for BC inflation and emergency open circuit. We've created a mounting system, modified the mouthpiece design, and dramatically altered the static balance. We've altered the counter lung size, changed the primary electronic logic circuit, and gone to LED displays. Mark Thurlow is now working on a new secondary display that will incorporate an alarm system. The 155 is not an easy system to use right out of the box, there is no facility for BC inflation and no open circuit back up. With our system, if you need to go to open circuit, you have about 20 cubic feet of diluent to breathe and then you can switch a valve and breathe about 20 cubic feet of oxygen. The units are now working extremely well; I personally have logged just over 715 hours (as of 2007 more than 1900 hours) and feel more comfortable and safer on my rebreather than I do on standard scuba.

How much of your shooting are you doing on rebreathers as opposed to open circuit?»We are doing almost all of our shooting on rebreathers now. About 95%. The primary reason we are using rebreathers would probably surprise you, it surprises everyone else. The silence of bubble-free rebreathers is not the major advantage in wildlife film work. Certainly, there is a difference between the way animals react to you when using a rebreather as opposed to open circuit, but the difference is not so great that it justifies the huge additional logistical hassles that come with rebreathers.

The reason we use closed circuit rebreathers is because we get an optimized gas mix at any depth we go to. Our decompression is minimized, and the life support capacity is essentially unlimited. We can potentially stay down up to twelve hours on any dive we make. That's a really big deal. We no longer determine what we are going to photograph based upon how much air we have in our tanks. We simply stay down until we get the shot or until we are physically exhausted. The air supply clock no longer runs against us. Unlimited dive duration – for natural history film work, that's a giant advantage!

What was your typical working bottom time on this shoot?»Typically, it takes us an hour and a half to shoot a single roll of IMAX 2D film. That may seem surprising since each roll is only 3 minutes long. But the shortness of the running time is balanced by the cost. Those three-minute rolls cost over $3,000 to buy, process, and print. It takes a long time to set up each shot and we try to wait until everything is perfect before we press the run switch.

Depth of field is a big problem in 70mm photography, so we do much of our camera work from a tripod. The tripod weighs 65 pounds and we usually anchor it down with an additional 50 pounds of lead weight. When things are going well, Cranston, Thurlow and I will often stay underwater while our surface crew recovers and reloads the camera. We have had mornings when things happen much faster, one time we shot five rolls on a single dive and stayed underwater for nearly four hours. To date, we've shot 242 rolls of film here at Cocos (some of which was above water wildlife and aerial photography) and I've logged 271 rebreather hours and 197 dives. And we have one more 22-day trip to go.

I understand you have had some vision problems,»I accumulated more than 90 hours underwater during our first 22 days of shooting out here in Cocos. Towards the end of that trip I began to notice significant problems with my eyes and by the time we were on our way home, I couldn't see well enough to get around the airport terminal.

Michele called DAN as soon as we got home and no one knew what the problem could be. Finally we found a doctor in Pensacola, Florida who knew what was causing my vision problems. Dr. Frank Butler, a Captain in the Navy who works a lot with the SEAL Teams, said I had hyperoxic-induced myopia. It's a condition that is not uncommon among patients treated for burns or skin disorders in hyperbaric chambers under high partial pressures of oxygen for long periods. Although it had never been seen in divers, to his knowledge, he was sure it was induced myopia.

Hyperbaric patients are generally treated daily for 90 minutes or so at oxygen pressures well over 2 atmospheres, much higher exposures than we are getting on our rigs. But 22 days at four hours a day at 1.3 atmospheres of oxygen was enough to cause my vision problems. He suggested that hyperoxic induced myopia has not been seen in divers because nobody has put in so much time at 1.3 atmospheres for so many days straight. The good news is that it usually goes away after a few weeks once out of the water. It took three weeks for my eyes to normalize after that first trip.

Tell me about the film you are making now.»The film we are doing now will be titled Island of the Sharks. It is being produced by Michele and is directed by me. It's a Howard Hall Productions endeavor and our diving crew includes Bob Cranston, Mark Thurlow, Mark Conlin, and Lance Milbrand. We're also getting some diving help from the Undersea Hunter's dive master, Peter Kragh and from Avi Klapfer. We are making the film for WGBH Nova Large Format Films; they produce the PBS series *Nova* and have made a number of giant format films including Special Effects that received an Academy Award nomination. Susanne Simpson was the director of Special Effects and is now our Executive Producer. We began discussing this project with Nova about four years ago and received the contract to make the film about two years ago – long before El Niño began to raise its ugly head.

Had you done anything with *Nova* or is this a new company that you are working with?»No, I have never done anything with *Nova* before, although Susanne and I discussed the idea of making a large format film as far back as 10 years ago. It has actually taken us this long to make it happen which is typical in the film business. Our projects usually take several years of development and then six months of pre-production followed by a couple of years of production before they are finished. We actually began building the IMAX camera housing for this film before we started production of our recent television series, *Secrets of the Ocean Realm*.

What's the budget on this film?»It's in the neighborhood of five million dollars. It's a little hard to be specific because there are a variety of parts to the budget including promotion and educational outreach. To do the actually filming and post-production, we will spend about four million dollars.

Is that a pretty large budget for a documentary film or is that standard?»That would be a really big budget for a television documentary; large format film budgets typically run between three and six million. If the film were to be shot in 3D, the budget would be more like about $8 million. Island of the Sharks is a 2D film; our budget is right about in the middle for a project of this dimension. Typically, what people do is not create a script and then cost it out to come up with the budget, instead an average budget amount and what the market will bear will determine the cost. On Island of the Sharks, we will spend over 130 days in the field, most of which will be diving at Cocos Island. I could probably get by with less time out here, but because I have so much time, the film should be terrific. If it's not terrific, I have no excuse.

In this case you are doing this entire film at Cocos. Tell us why you picked Cocos as a spot for production and how you picked your support facilities.»Obviously, Cocos is a great place to dive and there are some spectacular animals here. But really the decision to make a film at Cocos is a combination of what the site has to offer and the logistics available. The logistics are incredibly important whether I'm doing a television film, but especially, if I'm doing a giant format film. What Cocos had to offer was good diving, good marine life, and an excellent logistical support. Our support vessel, the Undersea Hunter, is ideal for this operation. Avi Klapfer's operation is very slick and professional, the vessel is capable of handling the huge IMAX camera equipment and there is space for crew and all our stuff. And we bring tons of stuff, literally. We fill up one entire cabin on the boat with just film; we bring 800 pounds of 70mm film with us on every expedition!

We'll spend nearly a million dollars on film, processing and printing and the boat cost is also substantial… but we needed a substantial vessel. It was crucial to have a crane that can lift a 250-lb. camera system into the skiff, and skiffs that could hoist the camera on and off-board. We couldn't do it from inflatables. Logistics was a big part of the decision to work at Cocos. If the Undersea Hunter were stationed in the Galapagos, we would be making the film there.

But here in Cocos you pretty much have the whole place to yourself, don't you?»Well that's partly true. Other divers seldom get in our way. Mostly, everybody has been quite courteous about diving where we were trying to work. The disadvantage to Cocos is that there is not a lot on the reef, very little invertebrate growth and not many small animals. It has been hard to get a lot of color and variety into the film.


The sun sets between Cocos and Manuelita over Chatham Bay, 1998

Bret Gilliam

You have ex-military rebreathers, an ultralight aircraft, and state of the art camera systems. What else do you want? If you could look into your wishing ball, what would take your filming another step forward?»My life is already over-complicated. The older you get, the more of this stuff you accumulate. I look back on the days when I would go spearfishing with fondness. I would put on a weight belt, mask, fins and snorkel and go diving. It was so simple; it could be done in an afternoon not an entire month. Now, my diving is always a major logistical production.

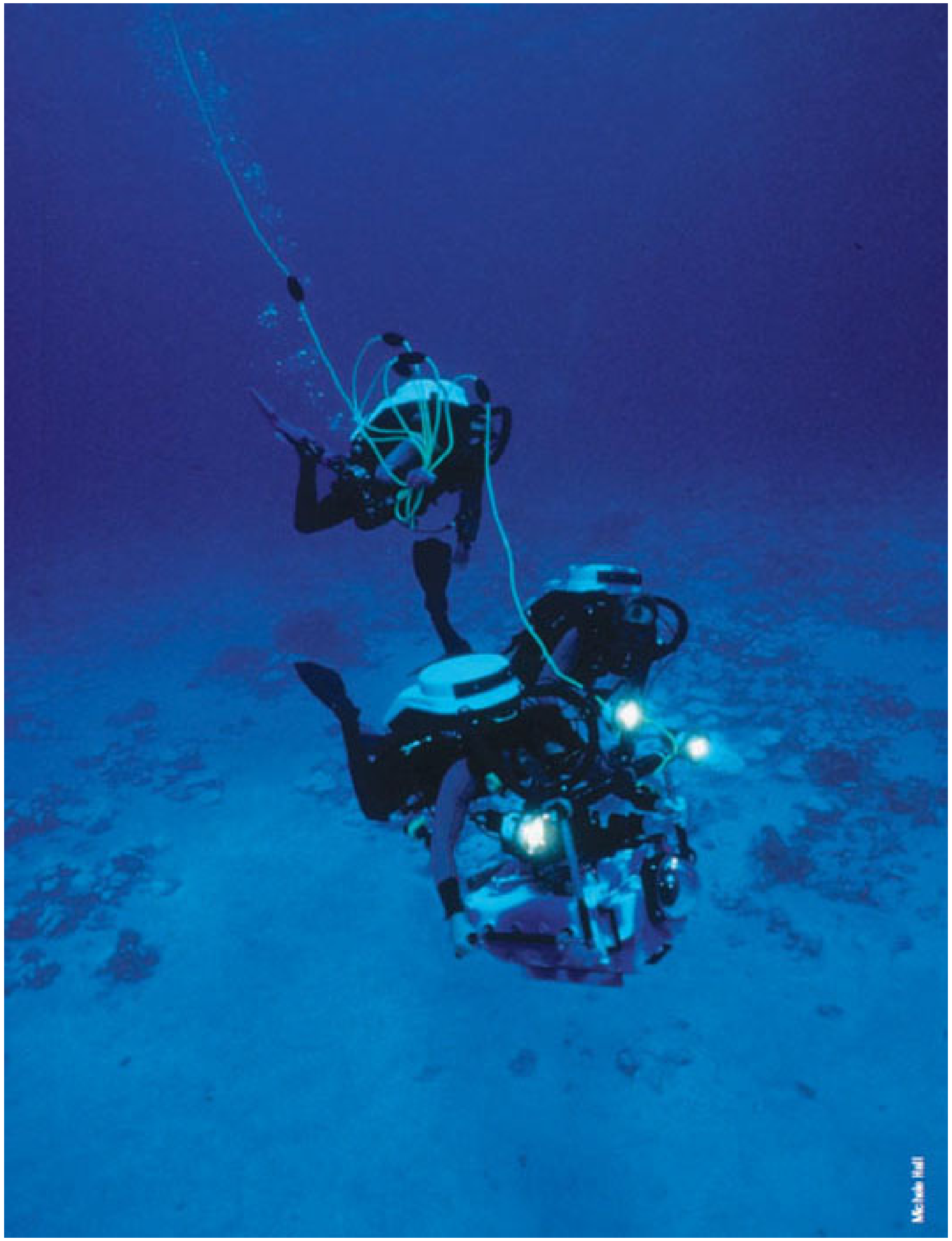
Of course, you didn't get $4 million to go out spearfishing either.»No that's true. I'm not knocking it. Anybody who feels sorry for me is completely crazy. I might say that I would really like to have a 120-ft. ship with a submersible on the back. But the truth is, I don't want that. Things are as complicated as I want them to get now. Having said that, my next film will probably be an IMAX 3D film. I've already directed one of those and it's considerably more difficult than what we are doing here.

You also did some IMAX work with humpbacks on the Silver Bank; tell us a bit about that experience.»It's been my experience that the only way to get close to whales is if it is their idea. Typically, what we do is go out in our boat and approach the whales as close as we can without disturbing them. We put the boat in idle so they knew where we were and would wait to see if they get friendly. Usually, they move off on their way. In order to get anything good, the whales have to cooperate. During the weeks we were on the Silver Bank, we had one or two very good days. On one day the whales followed us around all day. We used open circuit to film the whales on the bottom at ninety feet. Anyway, we went through two tanks of air and four rolls of film each, Cranston and I. When we went back to the Coral Star, our liveaboard, the whales followed us and we dived with them the rest of the afternoon right under the big boat. You couldn't scare them away. Michele shot some terrific stills. The whales were having a ball.

You have how many trips scheduled on the *Undersea Hunter* out here to Cocos?»Each trip is 28 days long and we get 22 full days of diving at Cocos. This is spread out from January through October so that gives us time for the seasons to change. Bait balls tend to occur at one time of year versus another, birds tend to nest seasonally. By spreading out the expeditions it gives us a chance for best weather and our best chance at the marine life. If we get skunked on one trip, then we have a chance to catch up.

This year in particular because of the El Niño, you must have had some fairly twitchy moments when you didn't have marine life that you might normally have expected.»We picked the worst year in meteorological history to make this film. There is no question about that. When I saw you at the Boston Sea Rovers in March you were asking me about the prognosis for your own rebreather expedition coming up for the month of August. At that time I hadn't even seen a shark. In fact, until this week when you showed up I still hadn't seen a hammerhead. Now they're all over the place again.

Timing is everything. I must be your good luck charm.»Yeah, I guess so. But our advantage is the type of scheduling we do when we make a film; spreading it out over a period of a year or a year and a half with very long expeditions in evenly plotted spaces throughout the year. Even in a really bad year, like this one, we are bound to get some good stuff. We were here sixty-six days before I saw my first hammerhead! But they're back now and the stuff we got when the hammers were gone is all good material. This is going to be the best film we've ever made. Hammerheads are important to the film, but there are many other things in the film besides hammerheads.



After 110 days of diving you are going to accurately depict diving at Cocos, even though you have had some slim pickings in the beginning due to El Niño.»I think we are going to get everything that Cocos has to offer. We may not get the whale sharks or manta rays. They may not come back in time. But we will certainly get the hammerheads, they are back now and we have a lot of other very good stuff that even people who have dived here for years haven't seen. We have a bait ball sequence that will completely amaze you.

How much time have you allowed yourself to cut and edit this film. Are you going to spend a lot of time in a dark, air-conditioned studio somewhere?»We have allowed from October 20 until April 1 of next year to cut the film. Fortunately, our studio is in our home. We're walking distance from an excellent reef break in Del Mar and when editing I almost always start the day with two hours of surfing. That's how I stay sane.

Many people would say that you have an ideal job. You basically had an unlimited budget, you've picked one of the best film and dive crews and you're working from the best support vessel available maybe in the world. Where else could you go to hope to do better?»Cocos is a special place. There is no question about that. But I'm happy making films almost anywhere where the ocean is natural and there are not too many people. I suspect that our next project will be a coral reef film, shot substantially in the Caribbean. Probably much of the work will be done in the Bahamas. I'm happy diving the Caribbean but I am actually just as interested in the small animals as I am the big stuff. It's great to see a school of hammerheads, but I get as big a thrill out of seeing some unusual small animal behavior. That stuff fascinates me and I get a real charge out of seeing something new and unusual even if it's small and the behavior is very esoteric. My films tend to reflect my passion for the small and the weird.

What about terrestrial stuff?»We climbed all over the island, on Manuelita and completed work on nesting birds. The plan is to do more in October when the brown boobies are nesting, we have already filmed red-footed boobies nesting and we did a fabulous sequence on fairy terns.

Any of the wild pigs?»No pigs. The pigs, deer, cats, and rats on the island are feral and we're trying to keep the wildlife as natural has possible. Basically, that leaves birds and crabs.

Do you know what your next film will be?»Well, it won't be pigs. I'll do us all a favor and stick to fish.

I concluded that interview back in 1998 and waited until 2001 to pick up again. In the last three years Howard had managed to indulge every diver's dream with a trans-Pacific itinerary that included just about every atoll and island James Michener ever thought Howard most people haven't seen and you'll appreciate his candor and informed perspective on a slew of topics pertinent to divers... including his frustration at finding a parking spot at the beach.

You started out in San Diego as an instructor and dive store employee. How has the area changed since l969 from a diving perspective?»I came to San Diego in 1969, got a job teaching scuba diving and enrolled at San Diego State University. Dive instruction financed my college education and I have been diving in San Diego waters ever since. How has the diving changed? For the most part there is simply less of everything. There are less lobsters, abalone, moray eels, schooling fish, Blue sharks, Mako sharks, and just about everything that swims, floats, or crawls on the bottom. There are some major exceptions. A moratorium on killing giant sea bass seems to have worked wonders. Now we often see giant sea bass where we almost never saw them 30 years ago. Harbor seals and sea lions seem more plentiful since people began expressing displeasure with fishermen for shooting their heads off every time they took a fish off a line.

But for the most part, wildlife populations are in steep decline. Everywhere. Water quality is also in decline. Visibility averages much less here than it did a few decades ago. Perhaps as disturbing as wilderness decline is the reduced access to our beaches. Today getting a parking place on a weekday is a major achievement. Forget about it on the weekend. Traffic congestion getting to the beach is so bad it's often more fun to stay home and watch a Sea Hunt rerun. Almost all beach parking is now metered. In the summer you have to walk over the bodies of sunbathers to get to the water. With all your diving gear on you crush a few in process, but it doesn't matter much because there are so many no one really notices.

What is the most serious environmental problem threatening San Diego waters?»Almost any winter day within a week of the most recent rainstorm you can find "Polluted waters. No swimming" signs posted on numerous California beaches. The list of environmental problems and their severity becomes larger every day. Pollution, beach erosion, over-fishing, introduced alien species, all impact diving here as they do in virtually all ocean environments. Anyone who has been diving longer than 10 years can attest to the fact that the ocean wilderness is in decline. In general, all environmental problems are related to one single factor. Population. As long as global human population continues to increase, all other efforts to save our environment is just pissing against the wind. Ironically, population would be the easiest environmental problem for governments to solve. With tax incentives, social pressure, and education, governments could affect population reduction. But no one dares talk about that very much.

Religion is a wonderful thing, often corrupted by greed and stupidity. Many people questioned whether the planet could handle six billion people when we reached that level a few years ago. When the Earth didn't implode immediately as population passed six billion, conservatives said, "See, no problem." But when you get a terminal disease you don't necessarily die immediately. Sometimes years may pass before you feel symptoms. I believe Earth cannot support our present population, let alone continued population growth. Imagine today's rate of deforestation, global warming, decline in natural resources, loss of biodiversity, environmental pollution. Then look ahead 500 years and try to imagine half a millennium of today's rate of environmental impact. That certainly produces a horrible mental image! Sure, everyone says, "Well, something will happen to solve these problems by then." Well, certainly they're right.

Something will happen, but I doubt anyone will like the solution when Mother Nature decides to dish it out. The stupidity of ignoring population growth as the number one most critical environmental problem amazes me. It's unequivocal proof that there is no intelligent life on this planet. Well, except for you and me, people who agree with me and, of course, the dolphins and whales.

How has California diving changed from a business perspective?»I'm not really tuned into the sport diving business today. But I sense that there is a decline in the spirit of adventure that seemed to inspire our generation. I think young people stay at home watching TV and playing video games and explore their natural world much less then our generation was compelled to do. Certainly, there is less exploration left to be done. Hell, now they're leading tours for the blind to the top of Everest! That's great for blind people, but it does take some of the romance out of mountain climbing for young people. As for diving in San Diego, there seem to be fewer dive boats, dive shops, and beach divers. But maybe I just haven't been looking. I can't get a parking place at the beach.

One reason young people are less interested in nature is that their parents don't let them out of the house. Television media has completely terrorized parents by sensationalizing every horrible child abduction and abuse case. The media is commercializing these sordid tales, selling soap using other people's misery and their audience's fear. Certainly these terrible things happen. But they are not happening with any greater statistical frequency than when you and I were growing up. But the effect is that parents are terrified to let their children out of their sight. Even those parents not terrified by the media would today be ostracized if they "neglected" their children by letting them go outdoors to play. A recent study showed that children who have unsupervised wilderness experience grow up to be much more environmentally concerned than those whose wilderness experience is either limited or supervised. So in addition to everything else, we are producing a generation that won't care about environmental issues as much as we do.

Do you still like southern California life style or do you long for a 4,000-acre ranch in Montana or to live on an island in Maine?»I occasionally fantasize about "going Giddings." Al has a fabulous ranch hidden away in Montana somewhere. You live in splendor in Maine. Anyway, I'd like either location. But I have to be near the water. I like to dive locally and I surf several times a week. Southern California is great for both. When the crowds eventually threaten our sanity, Michele and I may move northeast. But for now life is still great in Del Mar.

After starting as a still photographer, what led you to film?»Money. Back when I worked at the Diving Locker, owner Chuck Nicklin could often be heard saying, "You can't make a full-time living as an underwater photographer." He would sell photos to dive magazines, general interest publications, occasionally National Geographic and it seemed true that this income only represented a nice supplement. But then he'd get these three-week gigs to go off filming something in 16mm making real money. The potential was obvious. So after developing a reputation as a still photographer and photojournalist, I began setting my sights on 16mm assignment work – where the money was. The trick was breaking into the tiny fraternity of underwater cameramen.

A few months later I was talking to Stan Waterman on the phone. Stan had been co-director of underwater cinematography on The Deep along with Giddings. He complained that he had been offered a contract to make a film about sharks but couldn't think of anything new to do. I asked if he had ever seen footage of Blue sharks before. When he said he hadn't, I offered to send him my three rolls. "Oh, I didn't know you were a film cameraman," he said with surprise. "Oh, sure I am," I said, deciding that this was not technically a complete bald-faced lie. Anyway, the long and short of it is that the footage had some really new and exciting things on it – people hand feeding sharks, which was completely new then. Stan showed the footage to his clients in England and was awarded the contract. He hired me as second camera and never asked about my film experience. The film was shown on prime time and my film career was off and running.

Doing assignment camera work is one thing, producing and directing your own films is quite another. When did you start making your own films?»The best way to learn an art is to study someone else's work. If you want to learn underwater film work, just watch television. If you don't understand a specific technique, write it down and ask someone. But most of the answers are obvious by just watching other films. I used to do that all the time. I would watch animal behavior films made in Africa by Des and Jen Bartlett or by Alan Root and sit on the couch as say. "I could do that underwater." Or, "Why doesn't anyone do that underwater?" Or, "I could make great behavioral films underwater." Blah, blah, blah. Michele finally got sick of it and one evening said, "Well, why don't you just shut-up and go do it?"

So I wrote a one-page letter to the executive producer at PBS *Nature* suggesting I do a film about the kelp forests of California. I never expected to get a response, but figured that would get Michele off my back. As it turned out, I had recently been underwater cameraman on a very popular episode of Nature called The Coral Triangle. David Heely, then executive producer for *Nature*, decided I was worth taking a risk. His two-page letter in response to mine said basically, "Ok." I almost went into shock. I spent two years making the film on a budget of $135,000 excluding post-production costs that I traded out for distribution rights with a company in England. The film, *Seasons in the Sea*, was the first true underwater animal behavior film. It won a Golden Panda award for best of show at the Wildscreen film festival

MacGillivray Freeman Films

Capturing aerial sequences over Tahiti for *Coral Reef Adventure*, 2001 which is, for natural history film producers, just like winning best picture at the Academy Awards. Winning that was like being given a credit card with no credit limit or obligation to pay the money back. My career went from pushing a load of bricks uphill in a wheel barrel to flying a jet.

You obviously made a brilliant film.»Actually, let me tell you how that works. I came along with the right idea at the right time. I didn't evaluate business demand and say to myself, "the market is primed for a good underwater behavior film." I just happened to have a talent for capturing good behavioral stories on film. Just like a frog has a talent for catching flies with its tongue. No genius to it. I didn't know I would be any good at it until I saw the film's success. I also had a coincidental passion to make a behavioral film that had nothing whatsoever to do with market demand or timing. I just wanted to do it. It just turned out that I made my film at that single best moment in history when it was most in demand. No one was more amazed by its success than me. I can't compare myself to Bill Gates, but imagine if Bill were 10 years younger and started his career 10 years later. What do you think he would be doing for a living? Running Microsoft? I suspect he would be just another computer geek writing programs for someone else's operating system. He came along with the right idea at the right time. Seasons in the Sea was the right film to make at the right time to make it. I was very damn lucky!

Your wife, Michele, has obviously played a huge role in the success of your company. How do you keep work and play separate and who handles what duties in the business?»Well, that "shut up and just do it" comment certainly had something to do with kick-starting my filmmaking career. Actually, our talents and strengths complement each other almost perfectly. I do the creative work and she handles the business operation. She now produces the films we make and I direct them. I select a filming location; she constructs the logistical plan for getting there and handles all the details. I create and oversee the film budgets. She writes the checks and balances the books. I edit the films; she handles the incredibly complicated business of post-production. When we finally get out on the boat to start filming (which is the easiest part of the filmmaking business) I do most of the camera work and Michele shoots most of the production stills. She has now become a more prolific still photographer than I.

If she wears the pants in the business side of things, how do you look in a dress?»Actually, I am not forced to become that submissive. Well, not often anyway. We almost never question each other's decisions. We almost never argue. Even I find that incredible when you consider that we produce IMAX films entirely in-house with multi-million dollar budgets and without any additional office help. It's just Michele and me. Most IMAX films are produced with a staff of 20 or more.

How has the nature film business changed in the last five years?»As I mentioned earlier, I got started in the natural history film production business at just the right time for an underwater animal behavioralist. If I went fishing with my proposal to do Seasons in the Sea today, no one would be biting. Pure animal behavior films, where you only see the natural wilderness and rarely see humans, are called (in the natural history business) blue chip natural history films. A few years ago, blue chip fell out of favor. Now, *Crocodile Hunter* is in. This change in audience demand is probably a result of over-production in blue chip natural history and the proliferation of animal channels. Just over 10 years ago we only had the Nature series and National Geographic specials. Now we have numerous channels dedicated to natural history. I guess people got tired of seeing lions catching zebras and eagles feeding their young. Like any other business, however, I think this one is cyclical. I think blue chip natural history will come back. I hope so because, like the frog and his tongue, I'm not sure I have any talent for doing anything else.

We're familiar with your incredible IMAX work but understand that you are shooting a lot now with the HD format. How do you like this and is it the wave of the future or simply the next fad?»I have about a quarter million dollars invested that says High Definition Video is more than a fad! I'm invested up to my neck. The gear is phenomenally expensive. The camera is about $90,000. If you want a lens that's another $25,000. How about a battery? $800. And, gee, you want to look at what you shoot? Better get a monitor - $15,000. But don't worry. It won't take up much space. It's only a 14-inch monitor. You want a big monitor? Belly up! How about a tape deck? Don't even think about it! So yeah, I think HD is more than a fad.

Is that why you recently sold off all your old 16mm library?»Certainly, that is part of the reason. I believe that footage originated on 16mm won't measure up when HD goes mainstream. Michele and I didn't want to watch all our magnificent wildlife footage depreciate. So we sold it and are now starting over in a format with much higher resolution. We had also produced *Secrets of the Ocean Realm* largely from our library footage. Producing our own series was one of our reasons for building the library. Now that was done. We were offered a great price. And frankly, I now really look forward to revisiting all those locations and animals with my new camera. Between film contracts Michele and I will be running trips all over the oceans capturing sequences.

***Island of the Sharks* got great reviews and everyone who saw it was impressed. Did IMAX do as good a job as you would have liked in promoting it and getting it in as many theaters as possible?**»Ah, politics! The answer is no. It was probably a mistake selecting IMAX as a distributor. Especially at that time, a couple years ago. At that time IMAX stock was selling at over $30 and they were riding high on the promise of the IMAX format being accepted as the new Hollywood format for narrative films. Within a few short years, there were as many commercial IMAX theaters (usually in feature film megaplexes) as there were institutional theaters (like at natural history museums and aquariums). There was talk of major film directors making their next films in IMAX. IMAX preferentially promoted and distributed their Hollywood style films over their educational library. Island of the Sharks was not promoted well by IMAX.

Making narrative films is extraordinarily difficult even with mega-budgets. IMAX is a much more expensive production process than the typical Hollywood feature and, yet, to be profitable IMAX films had to be made with a fraction the average Hollywood budget. Making "Hollywood" features in IMAX is like trying to win the Indianapolis

500 with bicycle! I admire IMAX's ambition, but they came to a gunfight with a pee-shooter. Earlier we were talking about "the right idea at the right time?" Well, I think IMAX simply had the wrong idea at the wrong time. Anyway, the upshot is that Island of the Sharks sat on the distributor's shelf while IMAX's feature attempts were promoted. Actually, the film is now beginning to play more widely and perhaps it will emerge as a sleeper. It's not a perfect film. The writing is poor and the story jumps backwards in some places. But it was reviewed very well and filled theaters where it was shown.

What happened? I didn't think the writing was that bad?»It wasn't good. Still you would think that if you spent five million dollars you would always be able to make a good film. You may wonder why so many Hollywood films are so bad. Well, it's perfectly clear to me. Money often creates more problems than it solves. When you have a budget of five million, you have lots of people involved in positions of influence. All of them think they are writers and directors. And they have rights of approval. I don't wonder how Hollywood films (or other IMAX films for that matter) get to be so badly made. I understand that completely. What I don't understand is how a large budget film ever manages to be good. That's a miracle and I don't have a clue how it happens. Few people do.

Tell us about your role in the IMAX *Amazing Caves* project. Did you enjoy working with Wes Skiles?»That's a funny story. Greg MacGillivray, producer of Journey Into Amazing Caves, wanted the best underwater crew he could get. He wanted Wes because he was the best at filming in caves. He wanted me because Wes had no experience with IMAX cameras and because I own the best IMAX camera housing for the job. When Wes learned that I was coming along as cameraman, I think he was worried. Maybe horrified is a better word. Because I was already a big-time IMAX director, he figured I might want to run the show. Because I had no experience in caves (hell, I'm not even cave certified), he figured my insisting on running the show would be a very bad idea. I think Wes also felt he needed to prove himself with the camera. He wanted to be "the cameraman." Wes and I had never worked together before, so his trepidations were justified. Anyway, I didn't run the show. I did just what I was told by the underwater director, Mr. Wes Skiles. In the real world of major film production, the director has all the talent, makes all the decisions, composes the image, and outlines all the camera moves. The cameraman pushes the "on" button when the director says, "Roll camera," and pushes the "off" button when the director says, "Cut." Get the picture? When you see *Amazing Caves*, you're looking at Wes' work despite the fact that I held the camera.

So, did Wes quickly settle into his role as Director?»It took Wes a few days and I'm not sure he ever was happy not holding the camera. But it did work very well. Wes dove with an AGA mask and the rest of us used Buddy Phones to hear what he was saying. I had an OTS mouth mask I could use when I needed to ask Wes a question or tell him I had screwed up and we needed to do a shot over. But most of the time Wes did all the talking. Sometimes he never stopped. During our 1/5 of a mile swims in and out of the Dos Ojos cave system, he would regal his mute crew with jokes and his philosophy on life. You could take your Buddy Phone off, but then you'd risk putting it back only to find Wes screaming, "Hey stupid, I'm talking to you."

Did Wes ever handle the camera?»Yeah, and that was a major point of irritation to me. After years of experience handling the IMAX system, I knew that it took a practiced talent to do good work with it. Then Wes insisted on doing a couple shots where there simply wasn't room for both of us in the hole. Instead of botching the shots or being overwhelmed by the camera, he did the shots gracefully and perfectly the first time, completely validating his premise that my presence on the project was entirely unnecessary.

Is he really a relative of that guy from *Deliverance* or does he just sound that way?»Wes carries around a set of artificial teeth that he inserts when addressing his crew during less serious moments. The teeth and his associated manifestations make him seem like someone deprived of oxygen at birth and raised by the guy from Deliverance. It's both funny and terrifying. Without the teeth, he becomes a completely normal guy - for a backwoods hick from the Florida swamp.

So, how did you like cave diving?»Actually, I had no appetite for cave diving whatsoever until I saw a television film Wes had made showing how beautiful some of these caves are. If I hadn't seen that show, I might not have taken the job when Greg offered it to me. Anyway, I found cave diving disorienting at first, but then I began to become accustomed to the protocols and then it started to be fun. During my first day I began a cave dive class with Dan Lin. We never finished and I never got certified. Wes decided we all had more pressing obligations than teaching me enough to know what I was doing. While taking the class, I watched Dan put a line arrow on backwards. That scared the hell out of me. He caught the mistake a moment later, but I can see how easily cave diving can get spooky. After a few days, I was doing the long swims in and out of the cave unsupervised. I really enjoyed it.

And do you think cave divers are crazy?»Of course, they're completely nuts. But they're not stupid. In that element, they are superior divers. In the ocean I almost never see someone with better buoyancy control than me. In Dos Ojos, all of the divers had better buoyancy control than me.

Tell us about your most recent project that took you across the Pacific including Fiji?»The film will be called Coral Reef Adventure. It's another IMAX film and is produced by MacGillivray Freeman films, producer of Amazing Caves. Michele and my roles in this film are a bit unusual for us. I directed the underwater sequences and Michele was the line producer. We will also appear in the film. In fact, the film is largely about us and how we make underwater IMAX films. Greg MacGillivray is the director and has the unenviable task of trying to make us look good on film. Despite the questionable on-camera talent, I think it's going to be a great film.

Yes, but will it be an "adventure?"»You know, "adventure" might be defined as an exquisite balance between the passion for exploring the unknown and the fear of it. In fact, this film was more an adventure than most of the films we've made. We wanted to justify the Coral Reef Adventure title by legitimately pushing our personal limitations and the limits of underwater film production. We did both. We pushed the envelope way out there.

For example?»A lot of our filming was done with air diluent below 200 feet. And we went deeper than that. Below 250 feet we went to trimix. And believe me, shooting IMAX below 300 feet is really out there.

What were you filming down there?»We did one sequence on Gray Reef sharks at the mouth of the Rangiroa pass. Those were all air dives to between 200 and 250. But our deepest dives were in Fiji filming Richard Pyle capturing undiscovered species of fish in what he's calls "the twilight zone."

Richard Pyle is the ichthyologist who dives a Cis-Lunar rebreather?»Right. Richard's logged over 50 dives deeper than 350 feet where he has discovered numerous new species. With us, he logged a few more. On one of his dives he descended below 400 feet.

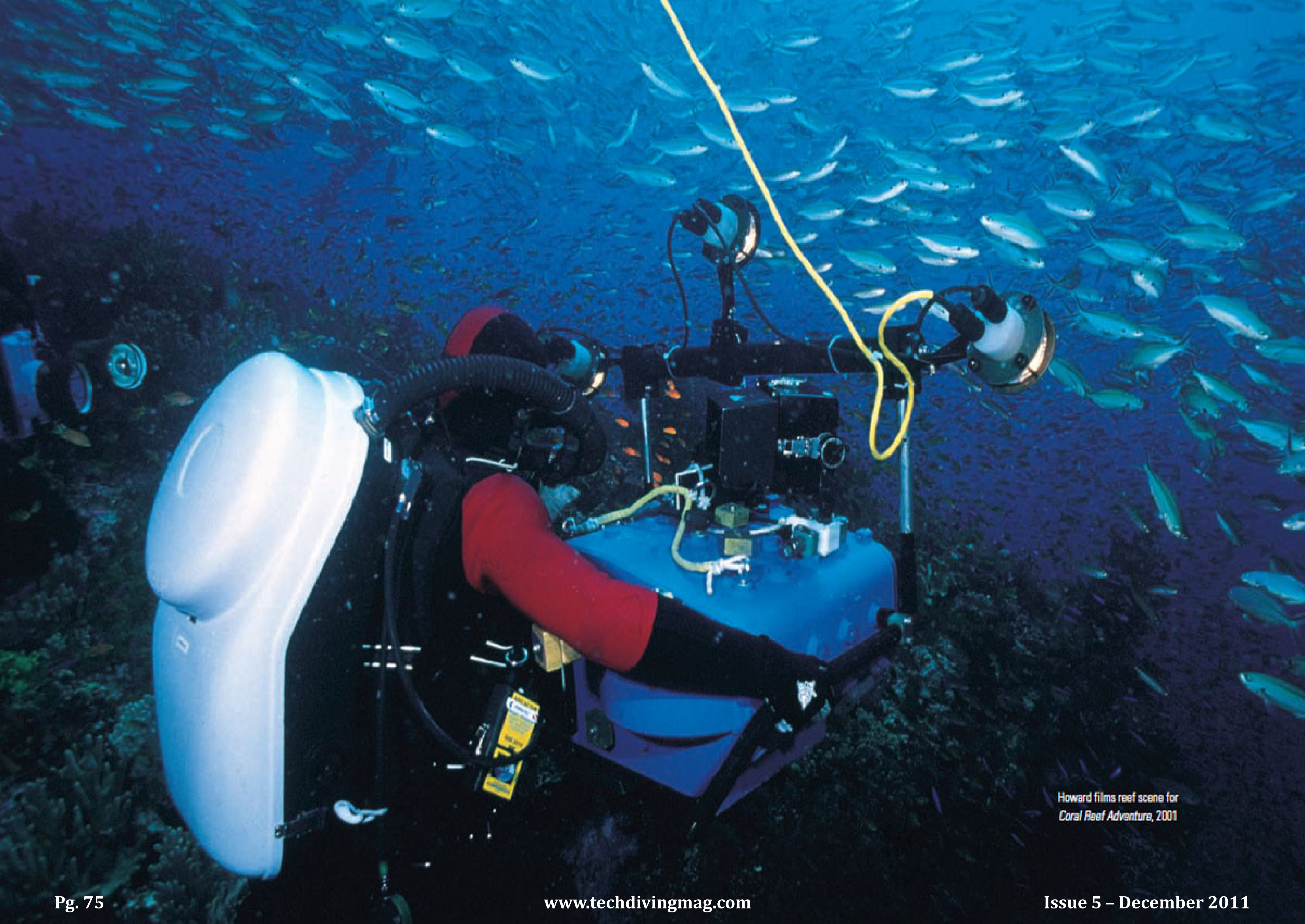
Did you follow him down to 400 feet?»No. I made several dives below 350 and my deepest was just over 370 feet. But keep in mind these were not simple technical dives (if trimix dives can ever be simple). Not only were we carrying trimix rebreathers and emergency bailout gas, but we were also carrying not one but two IMAX camera systems! One IMAX camera weighed over 100 pounds and the other was over 250 pounds. We also were equipped with special experimental OTS underwater communications, underwater lights, and all of Richard's capture gear. As you know, over-exertion can be a serious problem doing deep trimix dives. Well, try swimming around with a 250-lb. camera system and a few bailout tanks along with an 80-lb. rebreather! Try it in a current!

Who were the other divers?»I carried the larger IMAX camera with Mark Thurlow assisting. Bob Cranston carried the second camera with Dave Forsythe. And, of course, Richard was in front of the cameras. That makes five.

I didn't know your IMAX housing could go that deep.»Well, it can't! In fact, the other housing, the 100-lb. system, was housed in a 1/16-inch thick aluminum splash housing. Both would have crushed like paper cups if we took them below 200 feet. The splash housing was only rated to 10 feet!

You did take them down, didn't you?»Yeah, but we modified them first. We attached air tanks to the housings and pressurized them during descent. That's how we shot IMAX at 350 feet using a splash housing. The camera was always at ambient pressure.

Well, that seems like a simple enough solution. It seems to have worked?»Not without problems. These cameras were not designed to work surrounded by gas at more than 10 atmospheres. That's pretty thick stuff. The smaller camera nearly always jammed below 300 feet. It just couldn't move the film through gas that dense. The larger camera failed to run 50 percent of the time, but the problem was electrical. We spent months trying to figure it out. The camera would simply not ramp up to speed when at depth. But would then run fine as we ascended to shallower water. After 21 trimix dives, we finally solved the problem before our last deep dive of the project. It turned out to be a small cork clutch that was compressing and causing the electrical switch failures. Ironically, on this last deep dive with the problem solved, the camera jammed anyway for an entirely unrelated reason.



Howard films reef scene for *Coral Reef Adventure*, 2001

That must have been massively frustrating?»Yes, but it was also great fun making the dives. Still, dedicating an entire day and obligating a crew of five deep divers to four hours of decompression only to have both cameras jam as soon as they were switched on did cause some jaw clenching. Fortunately, for each dive the camera jammed, we made a dive where it ran flawlessly. We did get the footage we needed to make a great sequence. Certainly, that is the deepest divers have ever used IMAX cameras.

Did Richard catch any new species?»Actually, he did. He caught a beautiful new species of wrasse about six inches long. It was pink and yellow. And when he caught it the camera was running and it didn't jam. It makes a great sequence.

How did you like diving in the "twilight zone?"»I loved it. Funny, earlier we were talking about the lack of places to explore for young people. Well, below 200 feet almost every reef is unexplored. The potential is spectacular. And it is different down there. You see animals you've never seen before and many are undescribed. No one has ever seen them before.

What was the most exciting thing you saw on a deep dive?»Well, there were two spectacular encounters. We saw a Thresher shark swim by 20 feet away at about 300 feet. The camera jammed on that one, for sure. And on one dive we saw an enormous school of Hammerheads - more than 200 sharks. As far as I know, schooling Hammerheads were not known to occur in Fiji. Well, they do below 300 feet! I was out of film for that one.

You chartered the *Undersea Hunter*, your support vessel from the Cocos film project. How did you convince Avi Klapfer to send it half way around the world and back?»Money. No, actually, Avi loves this kind of challenge. Given the choice, he would use the Undersea Hunter full-time for film production all around the world. Unfortunately, these mega-budget underwater documentaries are few and far between. I've been fortunate to be able to bring two to Avi. But it could be a long time before there is another project that can justify such expense. I'd love to do it again and will keep my eyes open for any opportunity. Working with Avi and the Undersea Hunter has been a superb experience. The boat is extremely well run and well maintained. Avi is also quick to make major modifications in order to accommodate IMAX equipment and even the ultralight aircraft we used for shooting aerials.

Why not charter locally in each region?»Well, we did that too. We also used the Nai'a in Fiji. Rob Barrel and Cat Holloway were our guides and the Nai'a supported some of our crew on one of the expeditions. Nai'a is a beautiful vessel and a more comfortable boat than Undersea Hunter. But it is not configured well for IMAX production. Launching, recovering, and maintaining the IMAX system and all the other IMAX gear would have been difficult on Nai'a.

What do think of all the recent shark hysteria?» Ouch! That's a loaded question. Personally, I think it's stupid and tragic. Professionally, as an underwater filmmaker, it's great for business. Certainly there have been a few spectacular attacks this year. Due to those unique cases, however, every shark encounter is now major news. The number of shark bites in Florida was no greater this year than last. But this year, get bit by a halibut on your big toe and you're on prime-time news! It's good for underwater photographers, but it's bad for the dive business and it's bad for sharks. And don't you think there's something fishy about the story of the little boy who tragically lost his arm to a Bull shark in Florida? Do you know any human being powerful enough to wrestle a healthy seven-foot Bull shark to shore barehanded? I don't. I sure couldn't do it. I suspect there is more to that story than we are being told.

Has the Discovery Channel's *Shark Week* series degenerated into a freak show of bad science in pursuit of a reality show audience?»No, definitely not. It has always been a freak show of bad science in pursuit of a reality show audience! This is largely due to the poor budgets most of the film producers have to work with. But Discovery doesn't always limit their production to low budget programming. Occasionally, there are some real gems on Discovery's Shark Week. The high-budget shows made by talented professionals can be really well done. I watched several of the *Shark Week* shows and thought they were excellent. Unfortunately, you never know which you're going to see when you tune in. More unfortunately, the audience may not always be able to tell the difference.

What is your dream film project?»A dream project? Well, I'd like to get a film contract to make 10 high definition films in the locations of my choice... California, Cocos, British Columbia, the Tropical Pacific. The budgets would be enormous allowing me to bring all my friends along on only the best boats. The contract would specify that I own all the footage rights for my library. I would have 10 years to do the work and would not be obligated to deliver anything worth a damn.

What person or persons have been your greatest influence?»As an underwater cameraman, two individuals stand out. Stan Waterman and Jack McKenney. Stan taught me a lot about the business and professional attitude. Jack was the best technician I've ever seen. I fashioned my photographic style much after Jack's work. As a filmmaker, Des and Jen Bartlett, Alan Root, and Hugo van Lawick taught me much about capturing animal behavior sequences on film and making that into a compelling story.

You've been doing this a long time, what advice can you impart to the next generation of aspiring underwater filmmakers?»The best advice I can give may be not to take any advice too seriously. Natural history filmmaking is a passion. The odds of being successful at breaking in are enormously against you. Still, if the passion is overwhelming, the odds don't matter. Go with your heart and enjoy the process. It's the process that really matters. The true reward is finding justification for being out in the wilderness appreciating beauty purely for the sake of beauty itself, not in seeing your pictures in print or on television or in cashing a check.

Editor's note: There are about 50 copies of the original book still in Bret Gilliam's personal inventory. They are available as a Signed/Numbered Limited Edition personalized to each buyer by Gilliam at $200 each, including shipping. He can be contacted for purchase at bretgilliam@gmail.com.

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