Decompression calculations in the OSTC

How does the OSTC dive computer calculates the no-stop limit and deco stops? What are gradient factors (GF) and how do they affect my deco?

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Basics of decompression

What happens during diving?

Let's start with a simple model (figure 1): In a large vessel there is a second small vessel with a small opening at the bottom. Water flows from the large vessel into the small vessel trough the hole in the bottom, because of the bigger pressure in the large vessel. The bigger the pressure difference, the more water is forced through the opening per time unit. The filling level in the small vessel will look as shown in figure 2 over time.

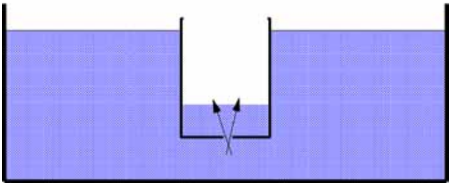

Figure 1

The more the filling level in the small vessel is aligned with the filling level in the large vessel, the lower the pressure difference is and the less water flows over time until the level is finally equal. If the small vessel is lifted, the pressure difference occurs again, but this time in the opposite direction, since the water column in the small vessel is now higher than the water level in the surrounding large vessel. As a result, the water flows from the small vessel back into the large vessel, at the beginning, when the pressure difference is still large, the water flows quickly and then, with increasing adjustment, slower and slower. So just as in the previous case, only the other way round (figure 3).

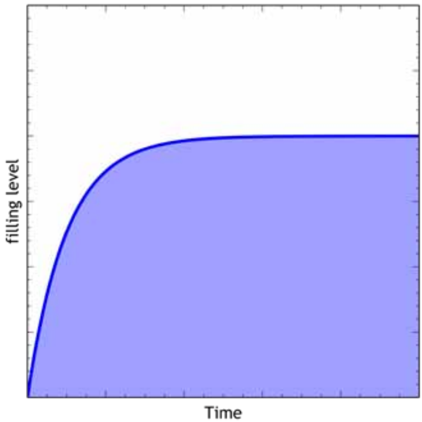

Figure 2

What does that have to do with diving?

The big vessel is the body of water in which we dive. The small vessel is our body.

The gas we breathe from our regulator has the same pressure as the surrounding water. Our body consists to a large extent of liquid, like the small vessel in the model above. Just as water flows in and out through the opening in the small vessel, the gas that we breathe during diving

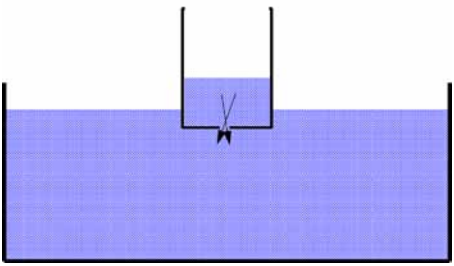

Figure 3

flows into our lungs, passes into the bloodstream and is distributed in the tissues of our whole body.
As long as the pressure of the water surrounding us and thus the pressure of the gas in our lungs is greater than the pressure in the tissues of our body, the gas that is dissolved in our blood enriches in our body tissues. The pressure in our body tissues rises, initially quickly, then increasingly slower, until at some point the equilibrium is reached.

If we now ascend, the pressure of the surrounding water decreases. At the moment that pressure becomes smaller than the pressure in our body tissues, the direction of transport of the dissolved gases reverses. They are now transported from the bloodstream back into the lungs, returning to their gaseous state and we breathe them out.
Unfortunately, our body is not infinitely pressure-resistant: If the pressure in the tissues of our body is too high compared to the external water pressure that „holds" our body together, the gas stored in our body tissues will no longer stay in solution and begins to form gas bubbles on the spot. This can then lead to a decompression accident (figure 4).

Decompression accident
In order to avoid such a decompression accident, we must make sure that the pressure difference between the pressure in our body tissues and the pressure of the surrounding water will not become too great. The extent of this pressure difference has been studied for over 100 years and various models have been developed over the years.

These models are ultimately mathematical

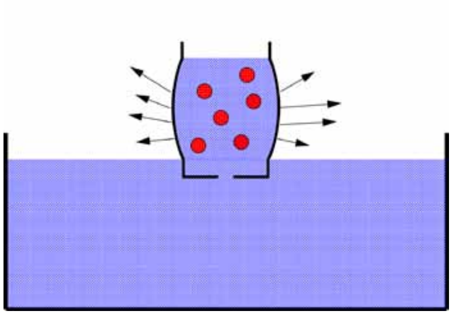
Figure 4

formulas to determine how much pressure builds up in the body tissues depending on diving depth and bottom time and these attempt to calculate when one can just return to the water surface without the pressure difference becoming too great. This is called „no decompression time".

If you stay at depth longer than this no-stop time, you can use the models to calculate the depth at which you have to stop your ascent to prevent the pressure difference becoming too big. During this stop, also known as „decompression stop", the gas dissolved in the tissues is continuously removed from our body via the bloodstream, the lungs and our exhalation. After some time, enough gas has been removed and the pressure in the tissues has decreased enough that the ascent can continue - to the water surface or to a next decompression stop at a shallower depth.

The Bühlmann ZH-L16 decompression model

The OSTC dive computer uses the model set up by the Swiss professor Albert A. Bühlmann, more precisely his model „ZH-L16“. This is a widely used model. The ZH stands for Zürich, its place of action, and the 16 for 16 tissues, which are calculated in this model.

16 Tissues

In contrast to our simple model with the one vessel that should represent our body (see figure 1-3), Bühlmann found out that our body is in reality more complicated: Instead of the one „opening“ (The width of which is the amount of gas that flows into our body depending on the pressure difference) Bühlmann‘s model uses up to 16 vessels to reproduce what happens in our body. Each of these 16 vessels, called „tissue“ in the model, has a differently sized„opening“, so that at the same pressure difference different amounts of gas enter or exit the individual tissues. The tissue number 1 is the fastest to equalize with ambient pressure, the tissue number 16 the slowest (figure 5).

Half-lives

In the model, these different lengths of times needed to equalize pressure are called „half-lives“. After one half-life has elapsed, the pressure difference is reduced to half. After two half-lives, the difference has halved again, to a quarter, and so on. This applies in the same way when gas enters the tissues as when it leaves them (figure 6).

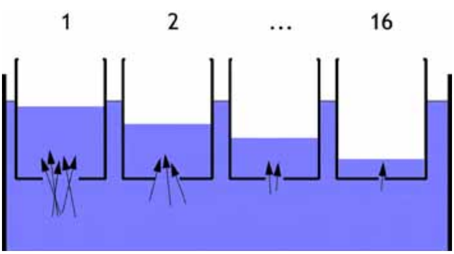

Figure 5

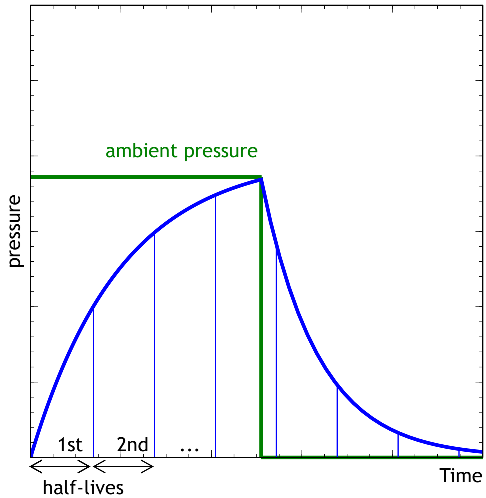

Figure 6

Fast and slow tissues

In the Bühlmann ZH-L16 model, the fastest tissue has a half-life of 4 minutes, the slowest of 635 minutes, i.e. over 10 hours. Since we usually do not dive for several hours, the tissues with the long half-lives, the so-called „slow“ tissues, will also absorb a little gas, but by far not as much as half of the balance to equalize with the water pressure at the bottom depth. On the other hand, the fastest tissue with a half-life of 4 minutes and the second fastest tissue with 8 minutes, often achieve pressure equalisation before we begin to ascend. Therefore, the pressure in the tissues over the duration of the dive will be approximately as shown in Figure 7.

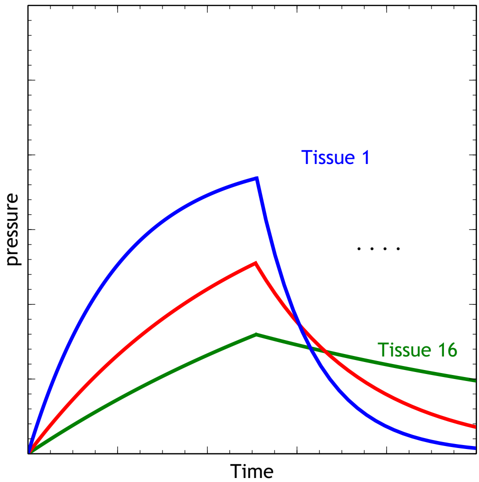

Figure 7

Tissue graphics in the OSTC

Dive computers measure the water pressure and continuously calculate the pressures in the tissues based on the half-lives. The OSTC does this every other second and you can follow the result on its screen (figure 8).

The bars are arranged from top to bottom from the fast tissues to the slow tissues. The longer the bar, the higher the pressure in each tissue. The color of the bars indicates whether a tissue is saturating or - when ascending - is already reducing pressure again: Orange bars indicate that the pressure in the tissue is increasing, turquoise bars indicate that the pressure is falling.

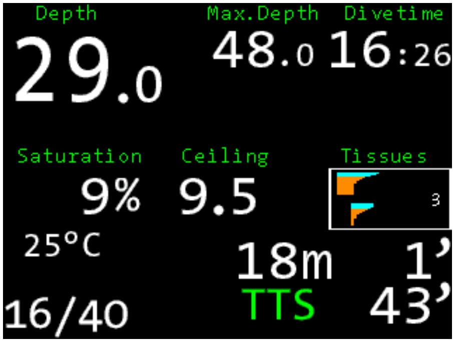

Figure 8

No deco time and deco stop

How is the no decompression time or the depth of a decompression stop determined? With the help of many experiments and field studies, Bühlmann determined the maximum permissible overpressure for each of the 16 model tissues. As the physician Robert D. Workman had already discovered, this maximum permissible overpressure is not constant, but depends on the ambient pressure: The deeper we dive (the higher the pressure of the surrounding water), the more pressure the tissues withstand beyond the pressure of the surrounding water before the gases dissolved in them begin to bubble out in the form of gas bubbles.

This can be illustrated graphically in a diagram (figure 9). The black line stands for equal pressures of tissue and environment. Below this line, the pressure in the tissue is less than the ambient pressure, so the tissue will fill and its pressure will increase. Above the black line, the pressure in the tissue is greater than the surrounding water pressure, the tissue is said to be „supersaturated“. In this state, the tissue will release gas and its pressure will decrease over time according to the half-life.

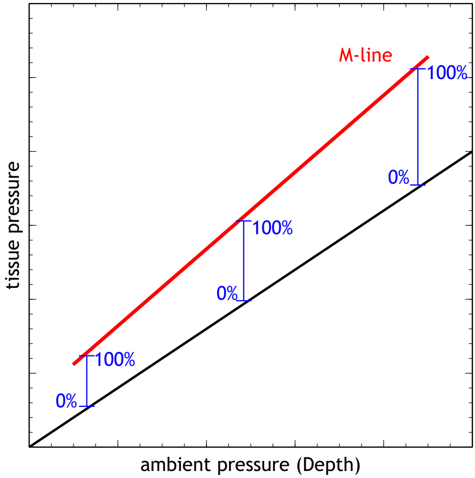

Figure 9

M-line

The red line indicates the maximum pressure the tissue may have. The blue scales measure the amount of overpressure in the tissue. As can be seen, the scales are longer in the direction of greater water depths, the tissue tolerates more overpressure at greater water depths than at shallower depths. In order to avoid a decompression accident, the tissue pressure should always be below or at most on the red line, the „maximum value line" or short „M-line". Where it lies in a concrete case can be indicated by the blue scales both as a pressure value (physically in the unit bar), and as a percentage value between the black line as 0% and the red line as 100%. If it lies beyond the red line, the result is a value greater than 100%. If it lies below the black line, it is strictly speaking not defined, but is set to 0% for simplicity's sake. This percentage measures the (relative) oversaturation of the tissue, it is the „saturation number".

Now in the Bühlmann model ZH-L16 there is not only one but 16 tissues. Each of these 16 tissues has its own M (maximum value)-line. According to the model, the „fast" tissues with the shortest half-lives tolerate significantly more overpressure than the „slow" tissues with the longer half-lives. Therefore, the M-lines of the fast tissues lie above the M-lines of the slow tissues (figure 10).

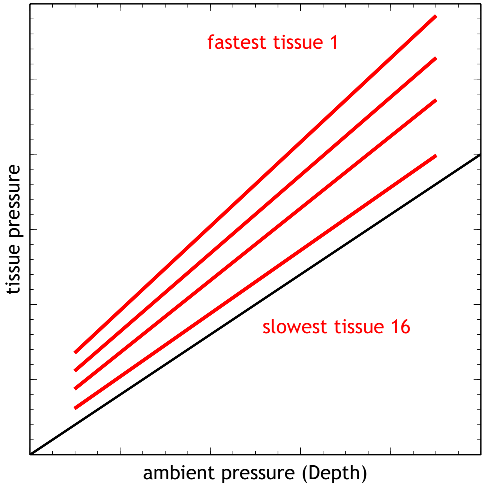

Figure 10

Because of the different half-lives during the dive, the individual tissues build up pressure at different speeds and because each tissue has different, depth-dependent maximum values, each tissue has its own saturation value at any time.

Leading tissue

Since all tissues should remain below their respective M-lines, the tissue that has the highest saturation number is the tissue that determines our no-stop limit or the depth of the decompression stop. It is called the „leading tissue". When the OSTC calculates the pressures in the 16 tissues, it also determines the respective saturation numbers and displays the largest saturation number found (saturation, figure 11).

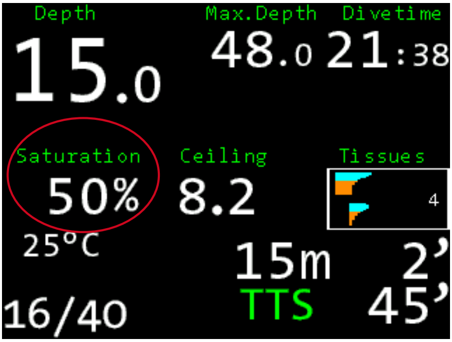

Figure 11

Roll change

Which tissue is the leading tissue changes in the course of the dive. At first it will be one of the fast tissues as they build up pressure quickly. However, as they release pressure just as quickly and also tolerate a lot of overpressure, the ever slower tissues will gradually assume the role of the leading tissue. Although they have built up only little pressure, they will not be able to release it again quickly and can also only tolerate less overpressure. The OSTC also indicates which tissue is currently the leading tissue with the small number in the tissue chart (figure 12).

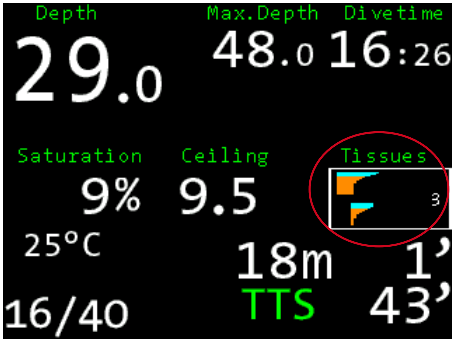

Figure 12

Ceiling

Another value that the OSTC continuously calculates is the „Ceiling". Ceiling is the depth at which the first tissue will reach 100% saturation. As long as the Ceiling is displayed as 0, you can ascend directly to the water surface, you are within the no deco limit.

If the Ceiling depth is greater than zero, this is the depth at which you must stop at the very latest to give the tissues time to release pressure, this allows the Ceiling depth to decrease and you can emerge a bit further. This will happen continuously until the ceiling finally becomes zero and you arrive at the surface.

With this knowledge you have nothing to do but to dive in such a way that the indicated saturation value is not greater than 100% or that you never come shallower than the indicated ceiling depth and never ascend faster than 10 meters per minute (this is anchored in the model), then you dive within the limits of the Bühlmann decompression model, i.e. within the range where according to the model the probability of suffering a decompression accident is very small.

Personal influence
Why only very small? Well, the Bühlmann model ZH-L16 is „only“ a calculation model, which has been tested on a broad basis and for many years, but in the end it does not know anything about your personal physical constitution, the way you dive and many other factors. It is calibrated to the „average“ diver, so to speak. So even the M-lines described above cannot be sharp separators between the areas of too high tissue pressures and harmless overpressures. Rather, it is the positions of transition zones in the direction of increasing risk of suffering a decompression accident.

By diving in such a way that you remain below the M-lines, i.e. below a saturation value of 100% or always somewhat lower than the ceiling depth calculated according to the model, you can further reduce the risk of a decompression accident - at least as far as the risk factors are within the sphere of influence of the model. Dive computers support you by allowing you to include safety factors in the displayed no-stop time and in the depths and durations of the decompression stops. The OSTC dive computer offers the possibility to set two types of safety factors, which you can activate individually or together:
Saturation factors and gradient factors (GF).

Saturation Factors
With the saturation factors, two percentages, you influence the half-lives of the model. The pairing 100%/100% stands for the original Bühlmann model ZH-L16. If a saturation factor greater than 100% is set, the tissues will build up pressure more quickly in the model calculation. At a setting value of 110%, for example, the calculated tissue pressures will increase by 10% faster than it would be the case with the pure model. This means that all other calculated values determined from the tissue pressures are „ahead of time“, i.e. the tissue pressures are artificially increased and thus the saturation values are overestimated and the no-stop time shortened.
With a saturation factor that is greater than 100%, you can, for example, take into account strenuous dives during which increased physical activity leads to increased blood flow and thus more gas transport into the body.

The counterpart of the saturation factor is the desaturation factor. This also has an effect on the calculation of the half-lives of the tissues, but in contrast to the saturation factor it always has an effect when a tissue desaturates, i.e. reduces pressure. With the desaturation factor, you can artificially slow down the calculated pressure reduction, which in turn causes the calculation results to lag behind during the emergence phase and thus makes them more conservative. For example at a setting value of 90%, the calculated tissue pressures will drop 10% more slowly than according to the pure model. This factor can be used to take into account conditions that can slow down gas transport from the tissues, such as cold or an unfavourable BMI (body mass index).

Gradient factors (GF)

Gradient factors according to Erik C. Baker are a further means of affecting the calculations of a dive computer, with the aim of achieving more conservative values for the no decompression time, the ceiling depth and all deco stops. Also here the value were 100%/100% for the original Bühlmann model ZH-L16. The two percentages are „GF low“ and „GF high“, the GF low is specified first, then the GF high (for example: 50/85).

GF high
With a GF high value smaller than 100% we reduce the maximum permissible overpressure in the tissues that the OSTC uses for calculation of the ceiling depth and the no-stop limit.
Put simply: If you set a GF high of 80%, then the ceiling depth shows that depth at which the leading tissue has a saturation of these same 80% of the Bühlman-maximum value. In the same way the no-stop limit is calculated so that when reaching the surface exactly at the end of the no-stop limit no tissue will have more saturation than 80%. Without gradient factor it would be 100%.

GF low
If the no decompression time is exceeded, then the GF low comes into play: The depth of the first decompression stops is calculated this way, that at a given stop depth there is no tissue with a saturation that will be greater than the set GF low percentage.
In addition, the depth of the displayed deco stop is rounded to the next multiple of 3 metres in the direction of greater depth - in keeping with tradition.

GF high
Limits the maximum allowable tissue saturation on reaching the surface

GF low
Limits the maximum allowable tissue saturation on reaching the first deco stop

Shifting the M-line
Internally, the gradient factor acts on the M-lines of all tissues. It reduces the gradient of the M-line as well as shifts the entire M-line in the direction of the pressure line. This reduces both the excess allowable overpressure per excess depth and the total allowable overpressure.
The original M-lines of the Bühlmann model corresponds to a gradient factor of 100%. The pressure equivalence line corresponds to a GF of 0%, which would not allow any permissible supersaturation and thus no pressure reduction in the tissues. Since with a GF of 0% the emergence would be practically forbidden, a GF of 0% cannot be set in practice. In the value range from 1% to 99%, the M-line, according to which the OSTC calculates, is placed proportionally to the percentage value between the original M line and the pressure line (figure 13).
The further you lower the M-Line, the more conservative you make the load on the leading tissue. While you are keeping the leading tissue well below its maximum possible saturation, the slower tissues have often not yet reached the pressure equilibrium, but are actually still saturating. So while you are protecting the faster tissues, the slower tissues, which also tolerate less overpressure, continue to saturate. This leads inevitably to the fact that the lat-

er stops in lower depths, where the slower tissues only begin to saturate, must become longer.

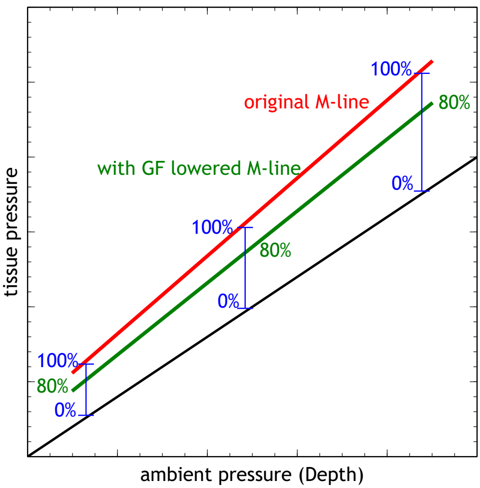

Figure 13

If the GF low determines the depth of the first deco stop and the GF high the reaching of the surface, what happens on the stops in between? There are two possibilities:

The values of GF low and GF high are the same: Then the duration of the stops is calculated in such a way that at the end of each stop the ascent to the next stop depth will not just bring any tissue above the set GF percentage of saturation.

The values of GF low and GF high are different: In this case, different maximum saturation values are applied for each stop depth, linearly averaged between GF low/ GF high and the depth of the stops.

This must always apply:
GF low ≤ GF high (figure 14).

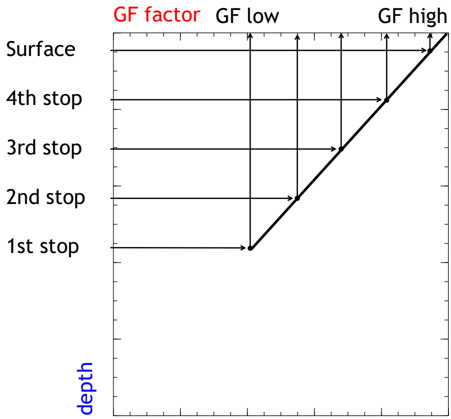

Figure 14

Why and when should you let a dive computer calculate a slightly different gradient factor on each deco stop?
In the description of the M-lines it was said that the tissues tolerate a higher overpressure at a higher ambient pressure. The pressure in the tissues is caused by the gas dissolved in them. As long as you dive with air or nitrox, this gas is nitrogen. Although air and especially nitrox contain not only nitrogen but also oxygen, which of course is also transported into your body tissues, it does not accumulate there because it is constantly consumed by your body's metabolism on the spot. Thus the classical Bühlmann model calculates the saturations and the maximum permissible tissue pressures with the half-lives and M-lines of nitrogen.

Calculation with Trimix

Now more and more divers are not only using the gases air and nitrox, but also „Trimix", which is a mixture of oxygen, nitrogen and helium. Like nitrogen, helium is not consumed by the human body, so it accumulates in the tissues in addition to nitrogen and contributes to the increase in pressure in these tissues.

Helium is a very light gas, whose molecules are much smaller than those of nitrogen, and the ratio between the amount of gas dissolved in the tissue and the resulting increase in pressure is different from that of nitrogen. Therefore, the half-lives and M-lines of nitrogen do not apply to helium. In fact, for helium there is a second set of half-lives and a second set of M-lines with which the dive computer calculates the behavior of helium in the tissues and combines the results with those of nitrogen.
Unlike the half-lives and M-lines for nitrogen, those for helium have not been so extensively tested - in fact, they are more mathematically derived from those for nitrogen by proportioning the physical properties.

Actual technical divers now show that the assumption that the tissues could tolerate a higher supersaturation at a higher ambient pressure is not as true for helium as it is for nitrogen, so the M-lines for helium have become too steep in the mathematical derivation. And exactly this is compensated in technical dives with Trimix as breathing gas, in which the permissible overpressure is reduced on the first stop with the GF low more strongly and is then increased stop by stop slowly in the direction of the GF high (figure 15).

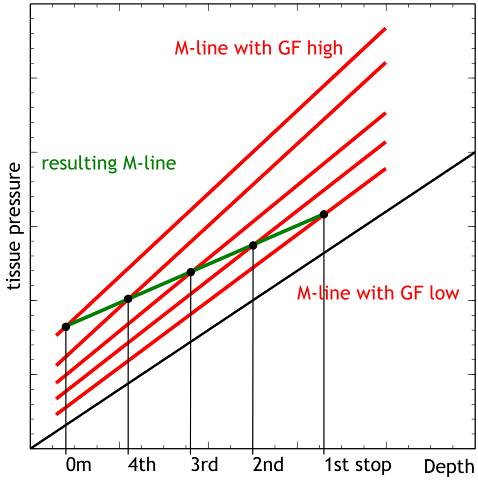

Figure 15

A request at the end

OSTC dive computers don‘t have an „error mode“, they don‘t switch off even in case of gross violations of the Bühlmann model and they don‘t have any secret model extensions that affect the calculations in an unexplained way. If the limits of the Bühlmann model are exceeded, this will be indicated, but the OSTC will continue to calculate the model only in the manner described here in order to provide you with further data in a comprehensible manner.

However, a dive computer is only a technical device following its programmed rules. As such, it can and must only be a tool that helps you making decisions. Never blindly trust the numbers and clues it may display. You need to understand what happens during your dive so that you can safely complete your dive even in the event of a malfunction or failure that can never be completely ruled out.

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