UNDERSTANDING A DIVE COMPUTER

by S. Angelini

Mares S.p.A.

The decompression algorithm in a dive computer is an attempt to replicate the effects of a dive on the human body using mathematical formulas. The on-take and release of nitrogen is simulated using a certain number of so-called compartments, each of which represents a tissue group in the body. So for instance we have a compartment representing the muscles, one representing the bones etc.

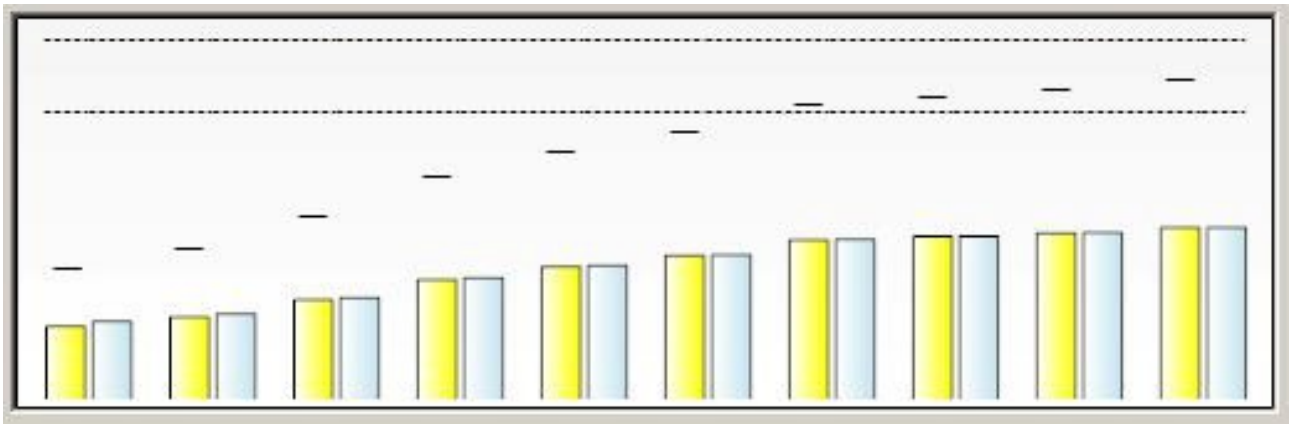
The tissues are identified by their half time[1], a parameter indicative of the speed at which it takes on nitrogen. The Mares algorithm utilizes ten tissues, with the following half times in minutes: 2.5, 5, 10, 20, 30, 40, 60, 80, 120 and 240. Tissues with short half times are called “fast”, tissues with long half times are called “slow”.

Each tissue is also identified by a second parameter, the so-called M value[2]. This represents the ratio of the maximum amount of pressure with respect to ambient pressure which a given tissue can tolerate. The term used to describe excess pressure in a tissue with respect to ambient pressure is “supersaturation”.

In essence, a dive computer tracks the ongassing and offgassing of nitrogen in each tissue, based on the time-depth profile and the half time of each tissue. The control criterion for a safe ascent is that no tissue exceeds the M value during the dive or upon surfacing.

The evolution of the pressure, or tension, in each tissue is described in a dedicated screen of Dive Organizer. The ten tissues are presented on a horizontal axis, with the half times increasing from left to right.

Each tissue is represented with two vertical bars. The height of the left represents the instantaneous load calculated at any given moment in time.



The height of the right reflects the projected value after an ascent to the surface at 10m/33ft per minute from the current depth. This is very important because during an ascent nitrogen is still being exchanged

[1] The name stems from the definition that within this time, a tissue will reduce the difference from its initial state to the new condition by half. Within two half times a tissue reduces the gap by 75% (50% of the remaining 50% in the second half time), by 87.5 in three half times, 93.75% in 4 half times, 96.875% in 5 half times and 98.44% in 6 half times.

[2] In the Mares RGBM algorithm, M values are dynamic and adapt themselves to the profile.

and this must be accounted for (this is quite obvious when one considers that an ascent from 40m/130ft lasts at least 4 minutes, almost twice the half time of the fastest tissue and almost a full half time of the second fastest tissue).

Depending on the status of the tissue at a given time, the bar to the left can be a little bit higher or a little bit lower than the bar to the right. It is higher if the tissue is rather full of nitrogen and during the ascent is going to offgas due to the diminishing pressure. It is lower if the tissue is still rather empty and in spite of the diminishing pressure encountered during the ascent, will ongas more than it will offgas (obviously, every tissue will offgas if near enough to the surface).

Note that, for the slow tissues to the far right, due to the long half times, the difference during an ascent is imperceptible and the two bars representative of a tissue have the same height.

We normalize the vertical axis so that for each tissue the M value is 100, and then draw a horizontal line at 100 and at 130. Since the M values are not the same for each tissue (faster tissues tolerate more supersaturation than slower tissues), and since all tissues start the first dive with 0.79 atm of partial pressure of nitrogen (saturation breathing air at atmospheric conditions), it results that at the beginning of a first dive the tissues to the left are lower than the tissues to the right (their height being 100 divided by the corresponding M value). We use the term “first dive” to refer to a non repetitive dive, so that there is no residual nitrogen from a previous dive to alter the landscape. Everything described in the following applies to repetitive diving as well, of course, with the only difference that the starting point is not with all tissues at 0.79 atm of ppN2 but at whatever level left by the previous dive and interceding surface interval.

Corresponding to each tissue, the graph presents also a small horizontal segment, superposed to the left bar of each tissue. The position of this segment along the vertical axis represents the partial pressure of the inhaled gas. During a dive you will see this segment move up and down with increasing/decreasing depth. In case of a gas switch, say from air to 50% nitrox, there will be a sharp jump in the position of this segment.

The position of this segment along the vertical axis plays an important role in understanding the tissue dynamics, since the distance between it and the top of the bar represents the difference in nitrogen partial pressure in the tissue and in the inhaled gas, i.e. the driving force of the gas exchange. This is also called pressure gradient. If the two are far apart, there is strong ongassing or offgassing (within the limitations of the half time). If the two are close, the tissue is almost in equilibrium. Note that, for easier interpretation of the graph, when the segment is ABOVE the bar and thus the tissue is taking on gas (partial pressure of inhaled gas is higher than the partial pressure in the tissue) the bar itself is YELLOW; when the segment is INSIDE the bar and thus the tissue if offgassing (partial pressure of inhaled gas is lower than the partial pressure in the tissue) the bar itself is GREEN.

We mentioned a horizontal line drawn above the one representing the M values. This represents the maximum tolerated tissue pressure at a depth of 3m/10ft. As much as any right bar crossing the lower line during the dive signifies that we have a decompression obligation, any right bar crossing the upper line means that we are violating the safe ascent criterion at that depth and hence implies that we have a 6m/20ft obligation. This can be extended also to a 9m/30ft stop and beyond, but we limit our representation to these two lines.

Description of a typical dive

We utilize a square dive to 30m/100ft for 30min because conceptually it is the easiest profile to describe the various aspects of the algorithm. The profile is depicted in figure 1, and here we also see the tissue load at the very beginning of the dive. The lower horizontal line is the M value, and the height of each bar is referenced to it. Since the M values decrease as the half times increase, the height of the bars increase from left to right. We see that the small segment representing the partial pressure of the inhaled gas is aligned with the top of each bar (saturation at atmospheric conditions). In case of a nitrox dive, the segment would be inside the bar, indicative of the fact that breathing nitrox on the surface would lead to initial offgassing.

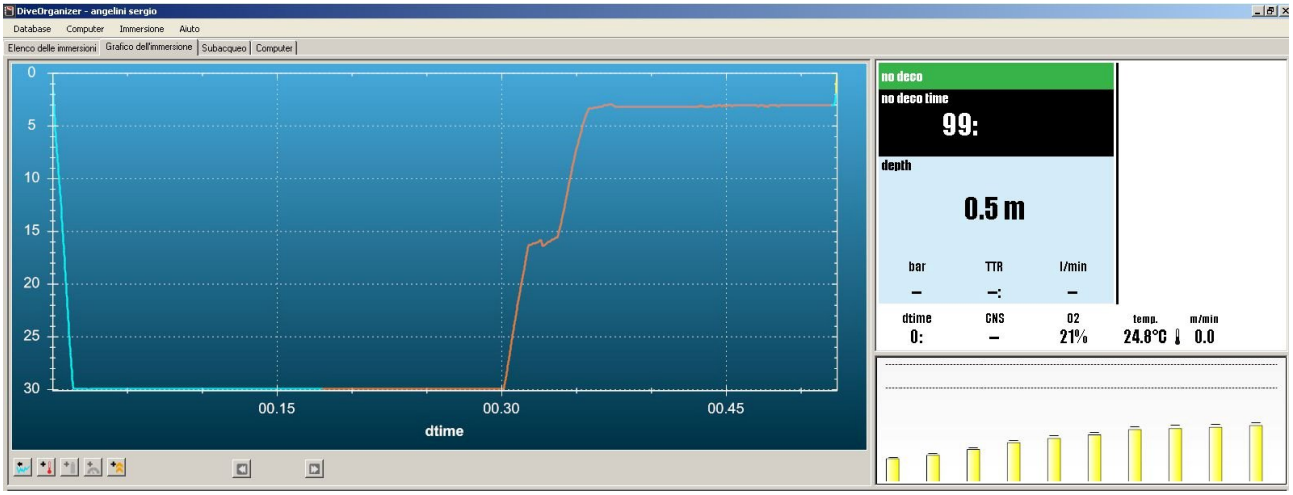


Fig. 1: Beginning of dive.

In figure 2 we see the situation at the end of the descent: the bars have grown slightly in height as nitrogen has been absorbed over the minute and a half long descent. We can see also that the segments representing the nitrogen pressure in the inhaled gas have travelled upwards, indicative that gas is being forced into the tissues at a speed proportional to the distance between each segment and the top of each bar.

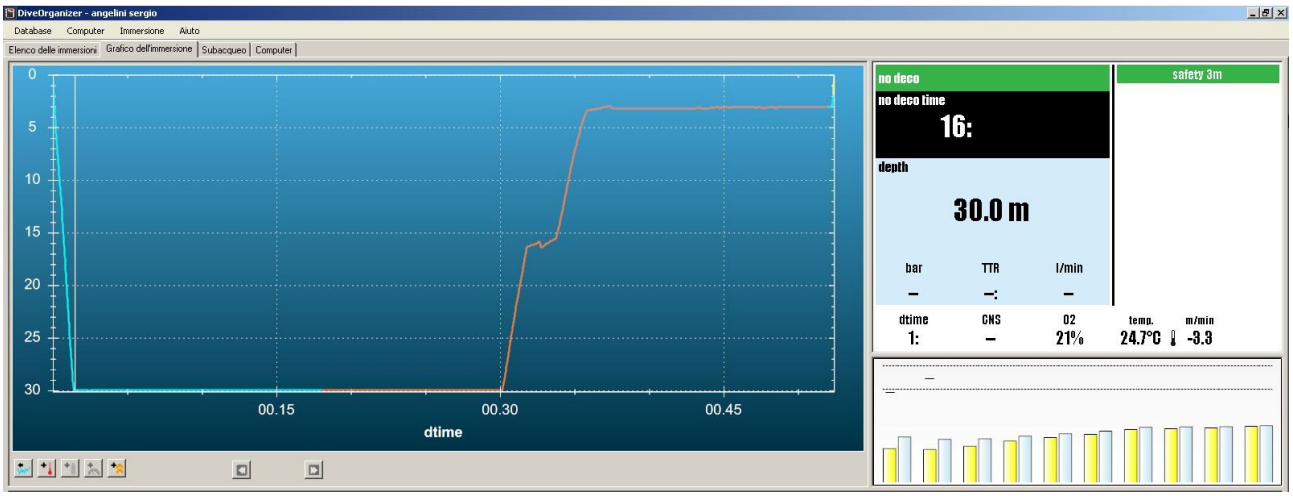


Fig. 2: End of descent.

At constant depth, the speed at which a tissue ongasses diminishes over time, as the difference in pressures between inhaled gas and tissue tension decreases. This can be seen graphically because the segment symbolizing the inhaled nitrogen pressure does not move (since the depth is constant) while the bar increases as nitrogen is absorbed, so the two get closer. If one stays long enough at a constant depth, the tissue will reach the segment[3] and no gas transfer takes place any longer: the tissue is said to be saturated. In figure 5 further below we can see that after 30 minutes at 30m, indeed the 2.5 and 5 minutes tissues are saturated, while the slower tissues are farther away from pressure equality the longer the tissue half time.

In figure 3 we see the situation at minute 17, just prior to the end of the no deco limits: we can see that the fastest tissue is practically saturated (the segment and the top of the bar coincide) whereas the very slow tissues have grown only very little. But what stands out most in this instance is the fact that the right bar of the third segment is about to touch the horizontal line. Indeed, at the very next time step, show in figure 4, it will cross this limit.

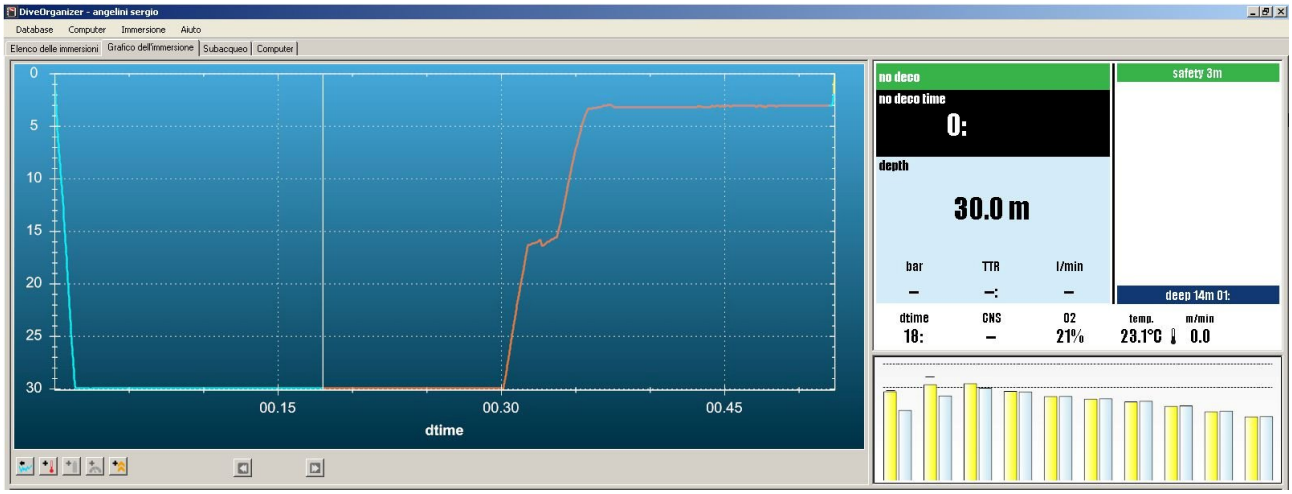


Fig. 3: End of no deco limit.

Here in figure 4 the third tissue has reached the limit of the horizontal line. As discussed above, this signifies that this tissue, if taken to the surface at 10m/min, will be in violation of the safe ascent criterion and hence this is the beginning of the decompression obligation. For easy graphic interpretation, the bar itself turns from blue to red. What is also interesting is that the left bar of the second tissue is also over the limit, but this tissue would offgass enough during a normal ascent not to violate the safe ascent criterion.

[3] Pressure equality is reached asymptotically, but in practical terms we can consider this to happen within 6 half times.

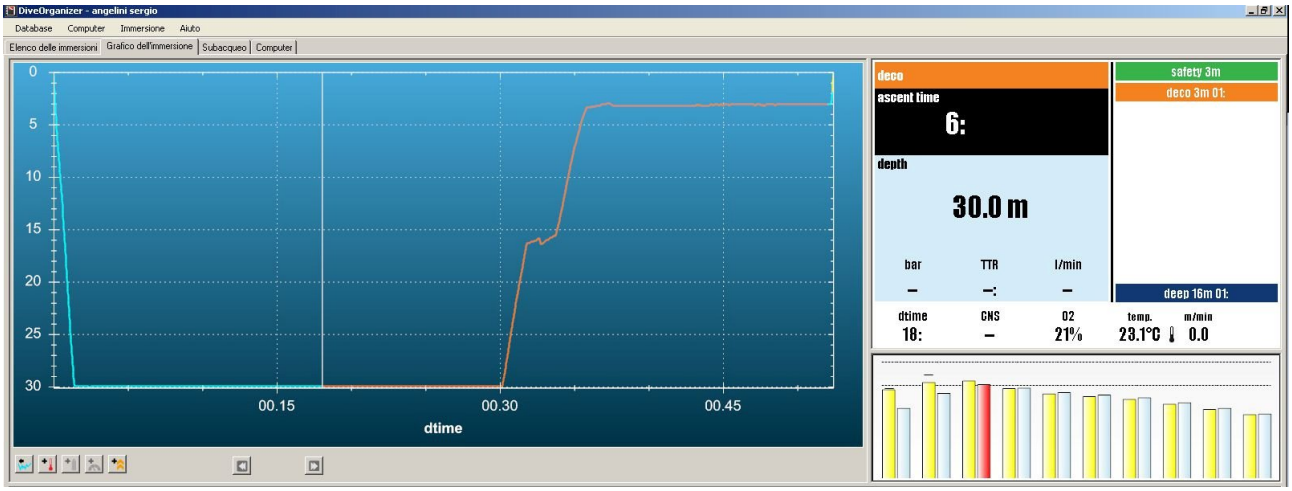


Fig. 4: Beginning of deco dive.

Let's now take a look at the end of the 30m/100ft section, here in figure 5: we see that the safe ascent criterion is violated by 5 segments. Curiously, the first two tissues, now both saturated at 4atm absolute pressure, will offgas enough during ascent not to ever violate the safe ascent criterion. In other words, for dives up to 30m the first two tissues are never going to be the limiting factor. If we now ascend by just a meter or so, figure 6, we see that the first two tissues are immediately switching over to offgassing, which makes sense since they were saturated at 30m, so that any decrease in pressure will bring the little segment underneath the top of the bar.

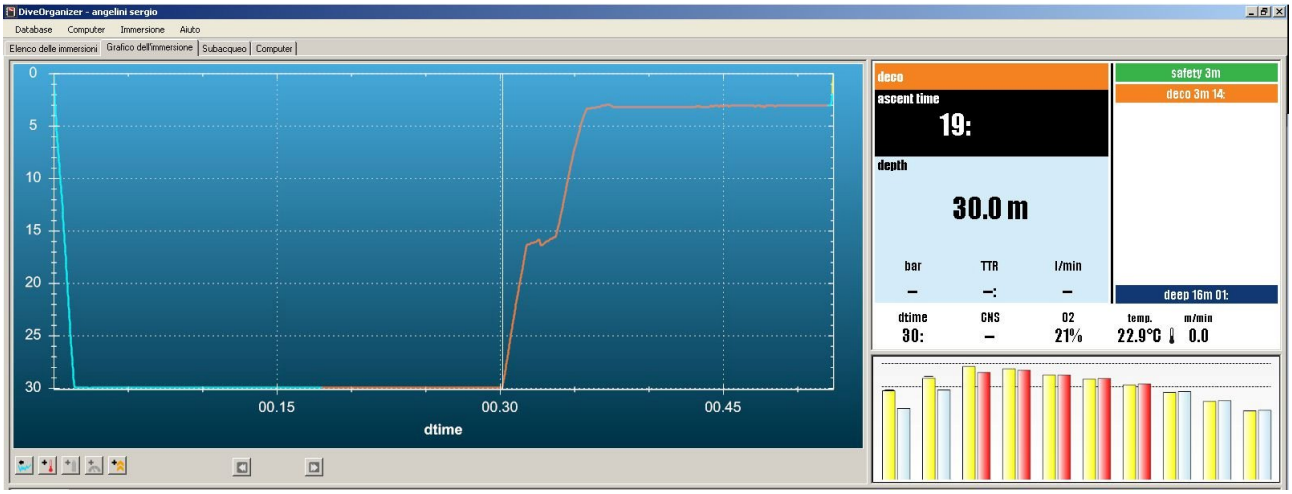


Fig. 5: Tissue status at the end of the 30m/100ft stay.

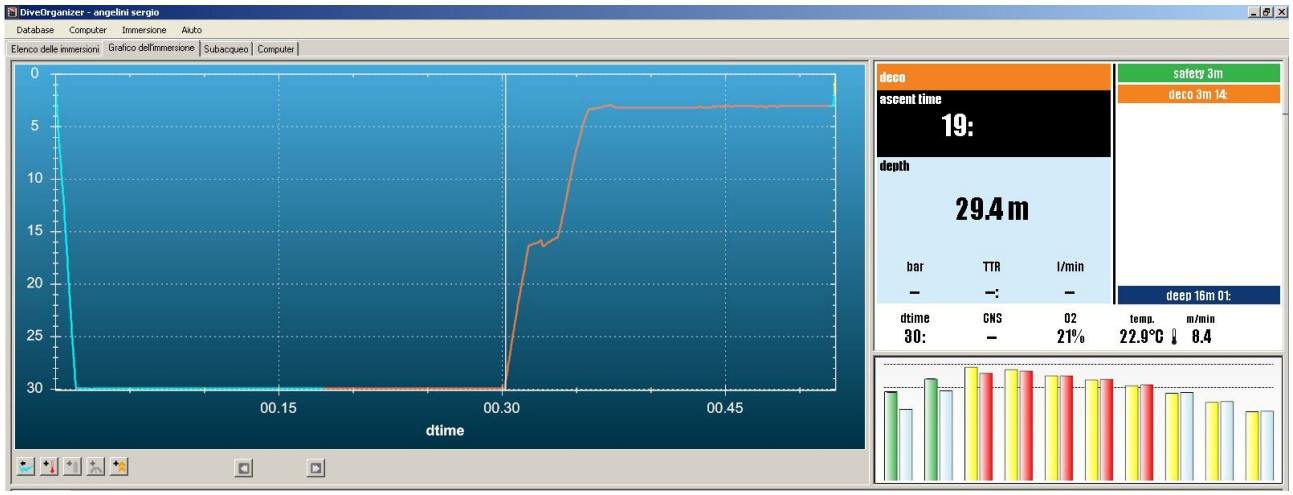


Fig. 6: Tissue status upon beginning of ascent.

Let's now ascend to the depth of the deep stop, figure 7: we see that the first four tissues are offgassing under an appreciable gradient (distance from the top of the bar to the horizontal segment). The fifth bar is still ongassing, but at a very reduced gradient. Only from the 6th tissue onward is there still considerable gradient for ongassing. This is the 40 minute tissue, so a two-minute deep stop here will hardly affect the status of its tension. The 2 minutes however will allow the fast (and sensitive tissues) to get rid of a good amount of gas while the ambient pressure is relatively high, thus controlling microbubble growth. Thus we see how for this profile, even from a purely theoretical point of view, a deep stop can be seen as advantageous during an ascent.

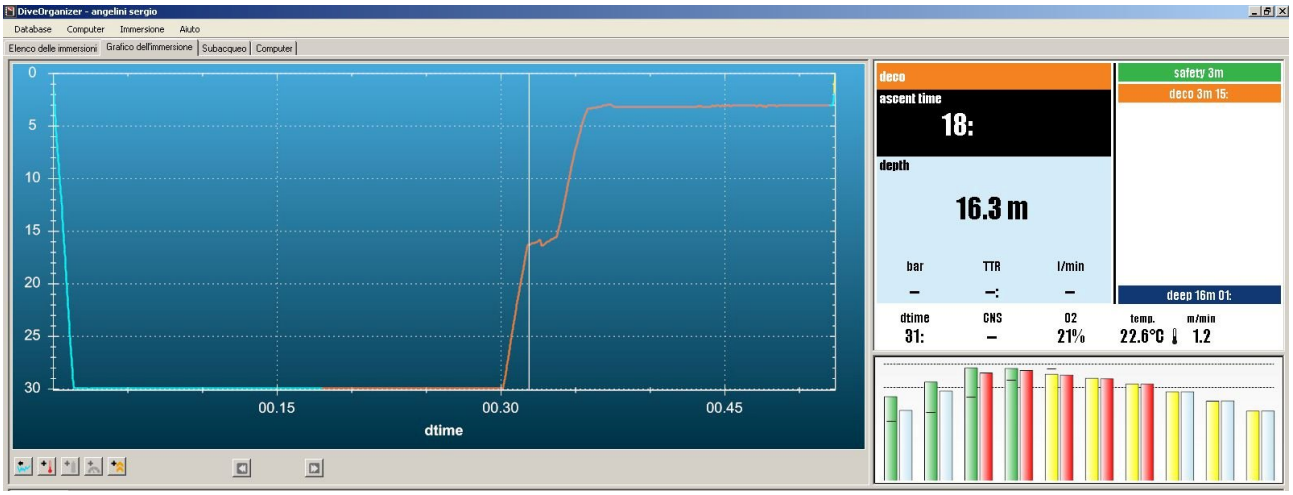


Fig. 7: Tissue status during deep stop.

We now proceed to the depth of the deco stop, figure 8, and see that all but the slowest tissue are offgassing, and still 5 of them are violating the safe ascent criterion. We see however that the pressure gradient for forcing nitrogen out of the tissues is rather high.

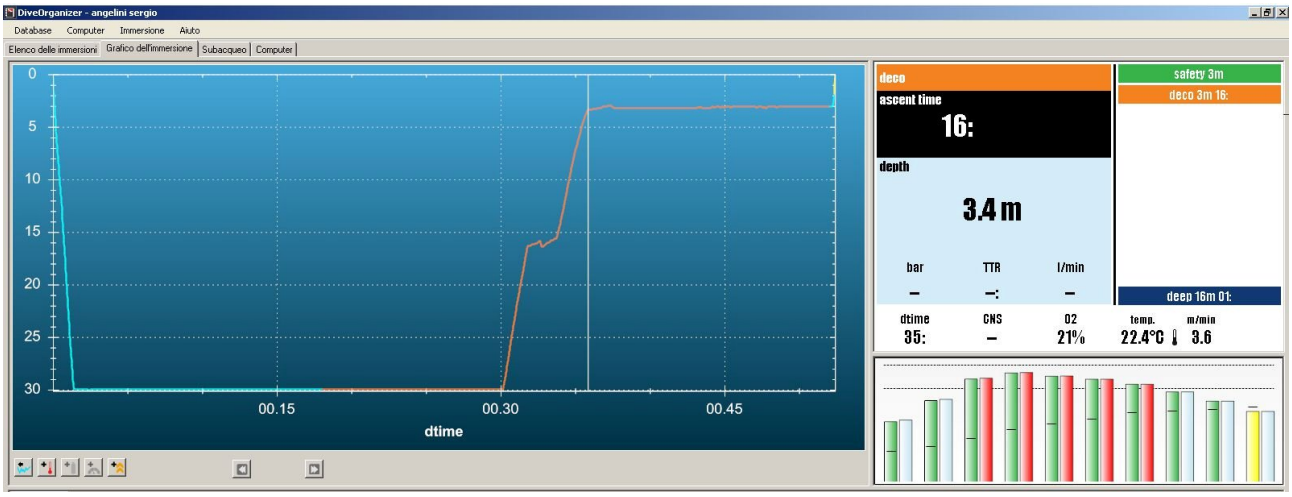


Fig. 8: Tissue tension at beginning of deco stop.

In figure 9 we see the situation at the end of the decompression obligation: all blue bars have brought themselves below the limit line. However, there is no margin of safety, the bars are barely satisfying the criterion for a safe ascent.

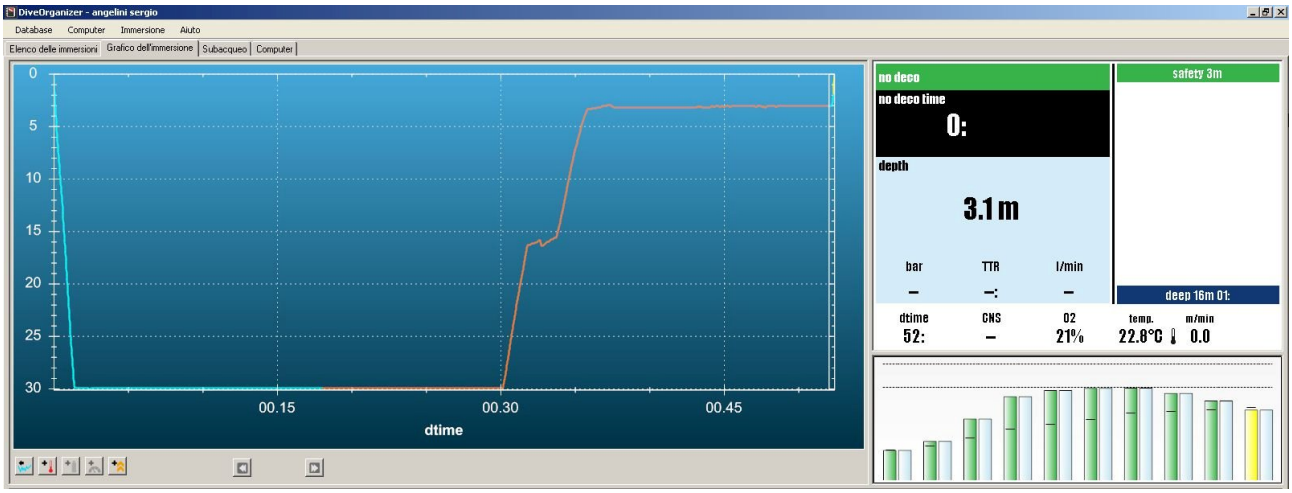


Figure 9: Tissue tension at the end of deco stop.

The next figures depict the situation during a real dive with a gas switch. In particular, they show the tissue situation just before and just after the gas switch. It is quite obvious why using a high O2 deco mix is so advantageous! The partial pressure of nitrogen in the inhaled gas droppes significantly, and not only are two more tissues offgassing rather than ongassing, but the pressure gradients for ongassing have increased significantly in the tissues that were already offgassing. So if in the previous figure we saw that a deep stop can be explained theoretically, in the case of a gas switch stopping right after the gas switch is even more useful.

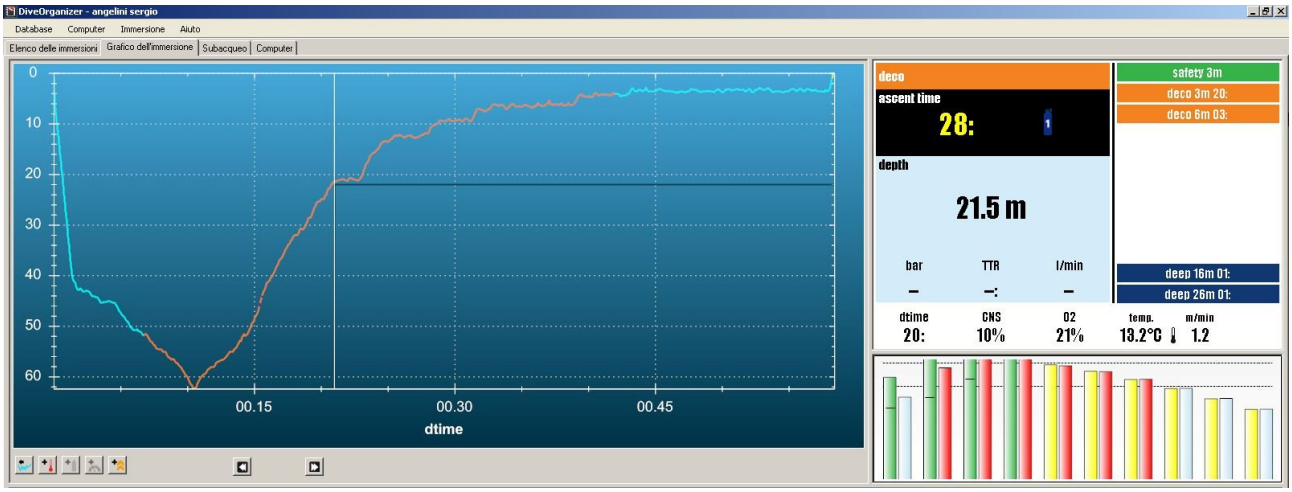


Fig. 10: Tissue status just prior to a gas switch.

Notice also that in this dive we also have a 6m/20ft obligation, and graphically this is represented by some of the right bars having crossed the upper horizontal line.

Fig. 11: Tissue status just after a gas switch.

We use a different dive profile to discuss the merits of extending a stay at 3m beyond the end of the decompression obligation (i.e. safety stop). The two figures below, 12 and 13, show the tissue status at the end of mandatory decompression and then 5 and 19 minutes later. The bars decrease further and the farther the bars from the lower horizontal line, the safer the dive. But since the speed of offgassing diminishes as the gas itself is released, the highest gain is towards the beginning of the safety stop and becomes less and less efficient as the duration is extended. Basically, the purpose of a safety stop is to reduce the tissue load beyond the minimum requirement (M value) and this is done quite efficiently with a 5 minute stop at 3-5m/10-15ft depth.

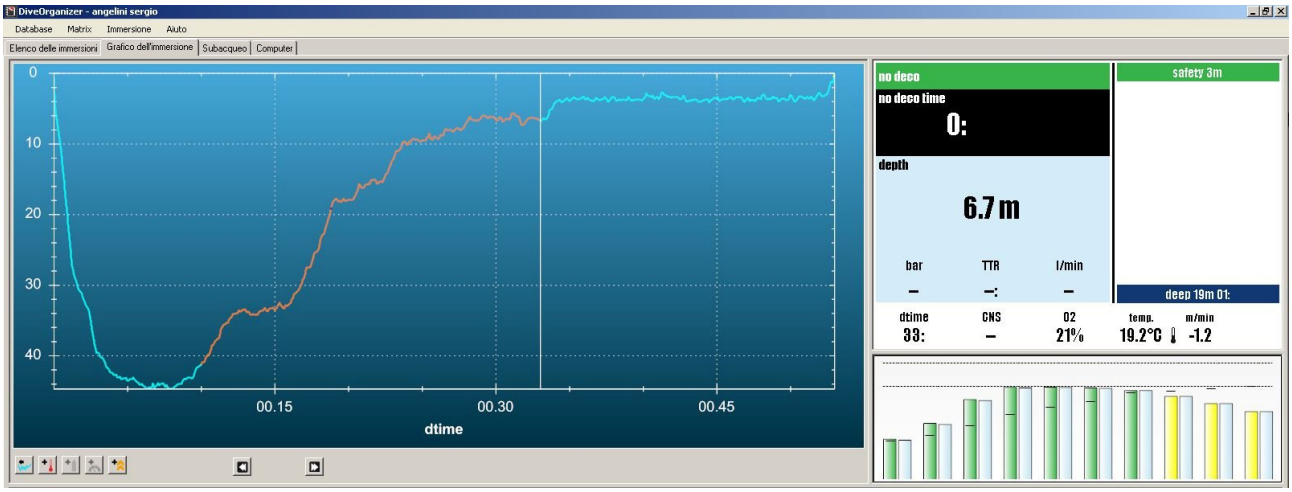


Fig. 12: Tissue status at end of decompression obligation.

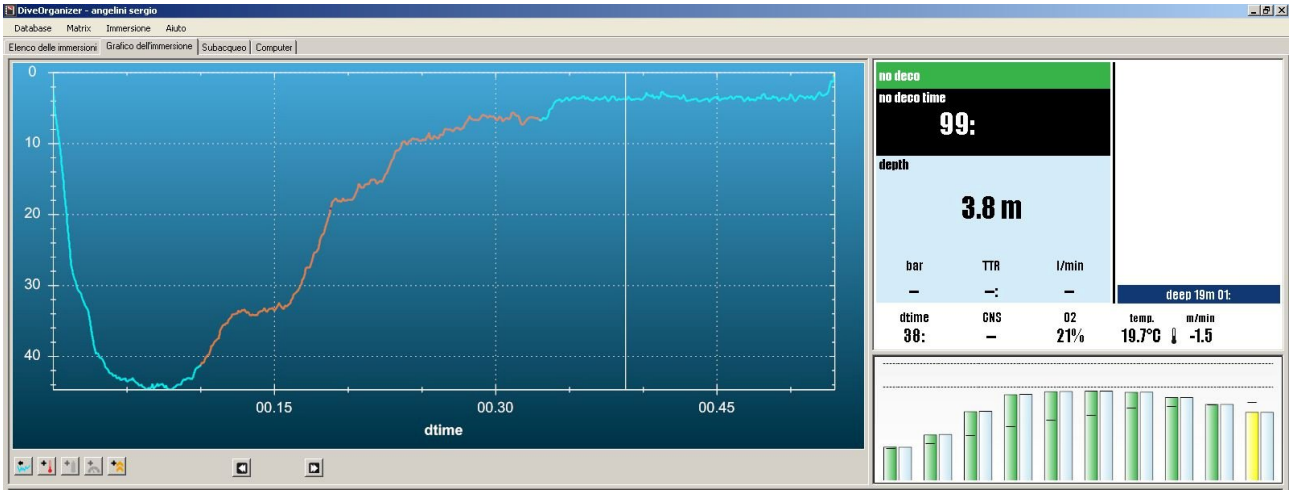


Fig. 13: Tissue status after 5 minutes at 3m beyond the end of decompression obligation.

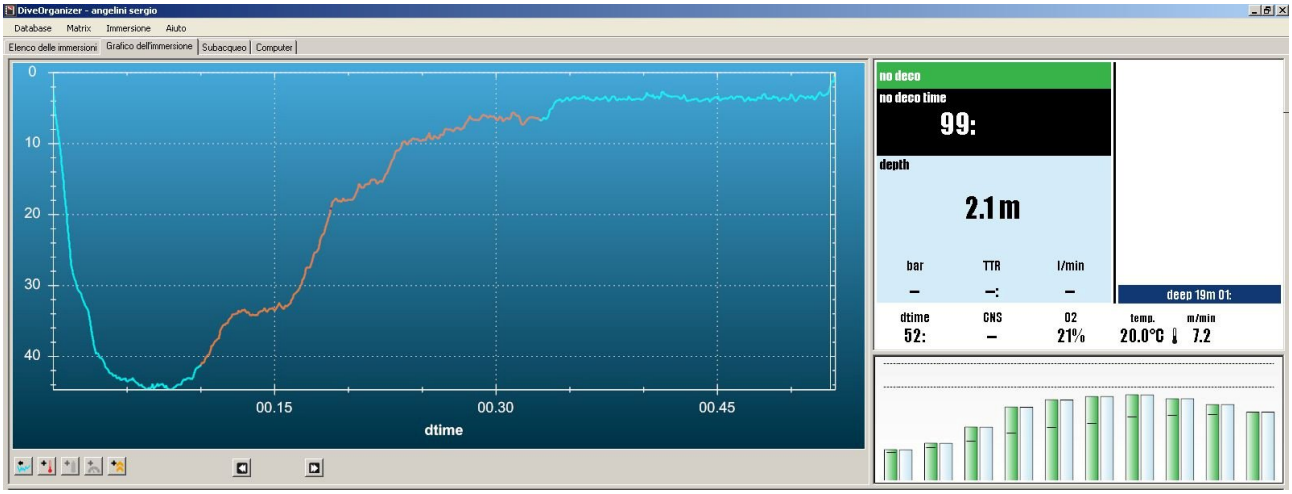


Fig. 13: Tissue status after 19 minutes at 3m beyond the end of decompression obligation.