"High Altitude Diving and Decompression"

By: Richard H. Geyer © 1972

SECTION I

Introduction:

The convenience of travel has made formerly remote inland areas readily accessible to the diving fraternity. Included are environments of "High Altitude." Yet, in the field of diver education "High Altitude Diving and Decompression" is seldom discussed. In the interest of diving safety, for all certification levels, the instructor should include this aspect in his course content.

Diving at any increased elevation greater than 1000 feet presents some very complex problems and added hazards for the uninformed.

Problems arise because physical laws concerning absolute pressures and gas partial pressures are affected. For instance, lower oxygen partial pressure in breathing air at high altitude can result in anoxia, causing unconsciousness, after surfacing from a dive, and, susceptibility to nitrogen narcosis or decompression sickness at unusually shallow depths must be anticipated due to the increased percentage of nitrogen.

I. Presentation:

In a lecture covering "High Altitude Diving" it is wise for the instructor first to point out to his students all areas of the diving technique that require changes to compensate for increased elevation.

Areas to be considered include:

1. Conversion Factor for finding theoretical dive depths and decompression stop depths at altitude.
2. Atmospheric pressure at altitude.
3. Depth of dive.
4. Ascent rates.
5. Decompression stops.
6. "No Decompression Limits" and Repetitive Dives.
7. Compressor Output Adjustment for surface supplied diving.
8. Flying after diving.

Discussion:

1. *Conversion Factor* – The most vital detail necessary for the diver to develop is a workable conversion factor which places all aspects of diving that are influenced by high altitude in their proper perspective.

   Finding a factor for any altitude is rather simple provided the diver knows the atmospheric pressure at sea level (760 mm Hg), which is a constant, by the atmospheric pressure for his atltitude (in mm Hg), the variable.

   eg: For a dive site altitude of 6000 feet the atmospheric pressure is 610 mm Hg.

$$\text{C.F.} = \frac{\text{760 mm Hg @ Sea Level}}{\text{610 mm Hg @ 6000 feet}} = 1.245$$

   Rule: When applying C.F. to find theoretical dive depth, multiply.

   When using C.F. to find atmospheric pressure, ascent rates, and theoretical decompression stop depths, divide.

2. *Atmospheric Pressure* - At 6000 feet the pressure of one atmosphere is 11.8 psi instead of 14.7 psi found at sea level. This is due to the change in partial pressure of oxygen (2.36 pp or 16%) and nitrogen (9.44 pp or 84%).

   One atmosphere of depth in a lake at 6000 feet of altitude would be 27 feet instead of 34 feet found at sea level.

3. *Depth of Dive* - Due to the decreased pressure at altitude, the actual diving depth of a dive must be converted to a theoretical depth for use in the standard decompression tables.

   eg:Diving in a lake at 6000 feet to an actual depth of 110 feet, the theoretical depth would be 137 feet. (110 ft. actual X 1.245 C.F. = 137 ft. Theoretical)

   NOTE: See table ADT-2 for depth conversions.

4. *Ascent Rates* - Especially on decompression dives ascent rates must be changed to correspond with the pressure differential ratio of altitude.

   eg:The rate of ascent from dives at sea level is 60 fpm. By dividing the C.F. 1.245, for 6000 feet of altitude, into 60 fpm, the adjusted rate of ascent is 48 fpm. (60 fpm ÷ 1.245 C.F. = 48 fpm)

REPRINTED WITH PERMISSION OF THE AUTHOR. 29 FEBRUARY 1992

"High Altitude Diving and Decompression"
By: Richard H. Geyer © 1972

5. *Decompression Stops* – Diving at high altitude predisposes the diver to increased partial pressures of nitrogen. If there is a need for decompression the depths of decompression stops will need conversion in order to end the dive safely.

When figuring theoretical diving depth for decompression schedules, the rule of next greater depth still applies.

eg:If the "Tables" require decompression stops at 30 ft., 20 ft., and 10 ft. for a diver at an altitude of 6000 feet, the theoretical decompression stop depths would be at 24 ft., 16 ft., and 8 ft., (Actual stop depths divided by C.F. 1.245)

Note: See table ADT-3 for conversion of stop depths.

6. *"No Decompression Limits and Repetitive Dives"* - Single dives that fall within the "No Decompression Limits" are arrived at by using the theoretical depth of the dive.

When using the repetitive dive schedules, the diver must determine his repetitive group designations from the theoretical depth and residual nitrogen time to be applied to a second dive must be determined based on the theoretical depth of the repetitive dive.

NOTE: Time is not a function of altitude diving, therefore, the "Surface Interval Credit Table" (1-12) remains unchanged.

7. *Compressor Output for Surface Supplied Diving* – Any high altitude environment affects output power on gasoline or diesel motors. Generally, engines will have a decrease in horse power of about 3½% for each 1000 feet above sea level. This power reduction results in a cutback of engine rpm and subsequently lowers the air output from the diver's compressor.

In other words, a diver using surface supplied equipment at high altitude will experience less cfm of free air available to his mask, Hookah, etc., and this could be a determining factor in how deep the diver can perform his work.

When using S. AS. gear for altitude diving, consult the engine compressor manual for the unit involved to get correct details on power reductions caused by altitude.

8. *Flying After Diving* If it is necessary to use air transportation within 12 hours after diving at high altitude, the diver must plan his dive(s) in advance as though the dive(s) is at an altitude equal to the airplane cabin's pressurized altitude.

If the plane does not have a pressurized cabin. then the dive(s) must be based on the highest altitude the airplane will reach.

Individual air lines can inform the diver of the altitude and pressure differential that their cabins will be pressurized to in flight.

NOTE: See Sec. III, Additional Notes and Cautions, A-2.

SECTION II

Example Dives (Use Tables ADT-1, ADT-2, ADT-3 for this section):

Example A – Single Dive

The day's diving will be in a lake at an elevation of 4800 ft. above sea level. A recovery job requires that the diver goes to an actual depth of 93 ft. for 18 min. bottom time.

1. Go to next highest altitude -5000 ft.
   Atm. Press. @ 5000 ft. = 633 mm Hg (from Table ADT-1)
2. Conversion Factor = 1.20 (from Table ADT-1)
3. Ascent Rate = 50 fpm – (60 fpm : 1.20 = 50 fpm)

Actual Dive	Theoretical Dive
93 ft - 18 min.	120 ft. – 18 min. (from Table ADT-2)
No Decompression Required	Decompress 2 min. @ 8 ft. (Table ADT-3)

NOTE: Make certain that the ascent rate from depth to the 8 foot decompression stop is 50 fpm.

"High Altitude Diving and Decompression"
By: Richard H. Geyer © 1972

Example B – Repetitive Dive

The first dive of the day will be to a depth of 80 ft. for 18 min. at an altitude site of 8000 ft. Following this dive there is a surface interval of 2 hours 43 min. in order to re-arrange topside equipment. Then a repetitive dive is carried out at a depth of 82 ft. for 18 min. bottom time.

1. Atm. Press. @ 8000 ft. = 565 mm Hg.
2. C.F. = 1.345.
3. Ascent Rate = 45 fpm.

Actual Dive
80 ft – 18 min. (E)
S.I. = 2.43 (C)
82 ft. - 18 min.
+ - 11 min. N_2
82 ft - 29 min. Total B.T.

No Decompression Required

Theoretical Dive
108 ft. – 18 min. (G)
S.I. = 2:43 (D)
121 ft. – 18 min.
+ 11 min. N_2
121 ft. - 29 min. Total B.T.
Decompression Required:
3 min. @ 15 ft. and 18 min. @ 7 ft.

Note: Check rate of ascent at 45 fpm to the first stop.

Example C – First dive at altitude, repeat dive at sea level. A diver makes his first dive at an altitude of 4000 feet, to a depth of 90 feet, bottom time 35 minutes. After a surface interval of 2 hours 19 minutes, during which time the diver travels to sea level, he makes a repetitive dive to a depth of 60 feet for 10 minutes in the ocean.

1. Theoretical Depth @ 4000 ft. = 104 ft.
2. C.F. = 1.155.
3. Ascent Rate = 51 fpm.

Actual Dive
60 ft. –10 min.
+ 44 min. N_2
54 min. Total B.T.
No decompression required for repetitive dive.

Theoretical Dive
104 ft. - 35 min. Decompress 2 min. @ 17 ft. and 21 min. @ 9 ft. (L)
S.I. = 2:19 (G)
Note: Check rate of ascent at 51 fpm to the 17 ft. stop.

Example D – First dive at sea level, repetitive dive at altitude. The diver makes his first dive at sea level to a depth of 74 feet for 20 minutes. *Following the dive, it takes him 3 hours to fill his tanks and pack all the necessary gear for a dive trip to a mountain lake at an altitude of 4300 feet (Surface interval @ sea level). The diver then drives to the dive site in 2 hours 8 minutes and begins his dive to 66 feet for 25 minutes.

1. Theoretical Depth @ 5000 ft. = 84 ft.
2. C.F. = 1.20.
3. Ascent Rate = 50 fpm.

Actual Dive
74 ft. - 20 min. (E) No decompression required.
96 ft. - 20 min. (F)
S.I. = 5.18

Theoretical Dive
84 ft. - 25 min.
+ 7 min. N_2
84 ft. - 32 min. Total B.T. Decompress 7 min. @ 8 ft.

NOTE: Check rate of ascent at 50 fpm to the 8 ft. stop.

*Surface Interval at sea level must be a minimum of 2 hrs. before traveling to any altitude dive site. See Sec. III, Additional Notes and Cautions, A-2.

"High Altitude Diving and Decompression"
By: Richard H. Geyer © 1972

SECTION III

Additional Notes and Cautions:

A. There may be some occasions when a diver will need to make a dive at some high altitude and then return to sea level for a repetitive dive within a 12-hour period, or, make his first dive at sea level followed by a repetitive dive in a lake at high altitude.

1. For a single dive or repetitive dives made at high altitude, the diver will follow the procedure of planning that considers theoretical dive depth and any decompression for his dive. After his trip to sea level (Surface Interval) he may assume the previous dive(s) and any decompression was made to actual sea level depths.

2. If the diver makes his first dive or repetitive dives at sea level and then travels to some high altitude for subsequent dives he must assume that the sea level dive(s) was made at the altitude of his new dive site.

NOTE: *Based on a research report authored by Edel, Carroll, Honaker, and Beckman published in "Aerospace Medicine," October 1969, it is advised by this author that the surface interval following a "No Decompression" dive(s) at sea level should be a minimum of 2 hours, at sea level, before attempting trips to dive sites at high altitude.*

It is further recommended that a diver who exceeds the "No Decompression Limits," for a dive(s) regardless of decompression carried out, must allow a surface interval of 24 hours, at sea level, prior to traveling to high altitude for other dives.

The above cautions are to be followed when considering airline travel as well, even in planes with pressurized cabins.

B. Two cautionary notes on maladies peculiar to high altitude environments are included for divers who may be considering dive trips to elevations greater than 7000 feet.

The following remarks are reproduced from a personal communication written by W. Brandon Wright, Research Medical Officer at the U.S. Navy's Experimental Diving Unit for that activity's archives.

Acute Mountain Sickness

Altitudes greater than 7,000 - 9,000 feet have decreased partial pressures of oxygen which cause arterial hypoxemia. In response to hypoxic stimulation, hyperventilation occurs with secondary lowering of arterial CO_2 and production of alkalosis. The newcomer to high altitude typically experiences dyspnea (shortness of breath), rapid heart rate, headache, insomnia, and general malaise. These symptoms usually disappear within 3 to 10 days and general graded exercise may hasten acclimatization. Acclimatization is lost within a week at lower altitudes.

Altitude Pulmonary Edema

Pulmonary edema can occur in non-acclimatized persons who travel within a day or two to altitudes greater than 9,000 feet. Symptoms usually appear 6 to 36 hours after arrival and consist of dry cough, dyspnea and a feeling of pain in the chest. Treatment includes transportation to lower altitude, hospitalization with bed rest, oxygen and diuretic therapy. Prevention consists of taking adequate time for altitude ascent, and upon reaching altitude avoid over-exertion which can cause pulmonary edema even in well acclimatized individuals.

Diving is strenuous and should not be done at high altitude without adequate acclimatization. This might require as much as three months of graded increasing exercise programs at altitude.

Increasing the oxygen partial pressure in the diver's gas supply to account for the decreased atmospheric pressure may be helpful. However, the exertion of a dive may precipitate pulmonary edema which could severely interfere with respiration while diving and afterwards as well. The symptoms may be indistinguishable from the chokes type of decompression sickness. Recompression with oxygen therapy would probably relieve the symptoms during treatment but they might well recur following therapy.

The pulmonary edema of altitude exposure can be a serious, even fatal illness. No one should dive who has the slightest evidence of shortness of breath, cough, or tightness in the chest. Anyone who has obvious symptoms of this altitude disease should receive 100% oxygen to breathe and be rapidly transported to a hospital for prompt vigorous therapy.

ALTITUDE DIVING TABLES

Table ADT - 1
Atmospheric Pressures (in mm Hg) and conversion Factors
for altitudes to 10,000 feet

	1,000	2,000	3,000	4,000	5,000	6,000	7,000	8,000	9,000	10,000
mm Hg	734	708	681	658	633	610	589	565	543	524
C.F.	1.035	1.073	1.116	1.155	1.200	1.245	1.292	1.345	1.396	1.450

Table ADT - 2
Theoretical Depth at Various Altitudes (FFW)

Actual Depth	1,000	2,000	3,000	4,000	5,000	6,000	7,000	8,000	9,000	10,000
0	0	0	0	0	0	0	0	0	0	0
10	10	11	11	12	12	12	13	13	14	15
20	21	21	22	23	24	25	26	27	28	29
30	31	32	33	35	36	37	39	40	42	44
40	41	43	45	46	48	50	52	54	56	58
50	52	54	56	58	60	62	65	67	70	73
60	62	64	67	69	72	75	78	81	84	87
70	72	75	78	81	84	87	91	94	98	102
80	83	86	89	92	96	100	103	108	112	116
90	93	97	100	104	108	112	116	121	126	131
100	103	107	111	116	120	124	129	134	140	145
110	114	118	122	127	132	137	142	148	153	160
120	124	129	134	139	144	149	155	161	167	174
130	135	140	145	150	156	162	168	175	181	189
140	145	150	156	162	168	174	181	188	195	203
150	155	161	167	173	180	187	194	202	209	218
160	166	172	178	185	192	199	207	215	223	232
170	176	182	189	196	204	212	220	228	237	247
180	186	193	200	208	216	224	233	242	251	261
190	197	204	212	220	228	237	246	255	265	276
200	207	215	223	231	240	249	259	269	279	290
210	217	225	234	243	252	261	272	282	293	305
220	228	236	245	254	264	274	234	296	307	319
230	238	247	256	266	276	286	297	309	321	334
240	248	258	267	277	288	299	310	323	335	348
250	259	268	278	289	300	311	323	336	349	363

Richard H. Geyer © 1972 Not to be reproduced in any way without express written permission from the author.

Instructions for ADT - 2: Table ADT - 2 lists theoretical dive depths at altitudes to 10,000 feet for actual dive depth to 250 feet of fresh water (FFW). To use this table, enter the left column (actual diving depth) to the actual, or next greater, depth for the dive. At the top of the depth column find the altitude of the dive site, or the next highest altitude if altitude falls between those listed. The figure given in the selected altitude column for the actual depth is the theoretical dive depth for that altitude.

Table ADT - 3
Theoretical Depth of Decompression Stop (FFW)

Prescribed Depth	1,000	2,000	3,000	4,000	5,000	6,000	7,000	8,000	9,000	10,000
0	0	0	0	0	0	0	0	0	0	0
10	10	9	9	9	8	8	8	7	7	7
20	19	19	18	17	17	16	15	15	14	14
30	29	28	27	26	25	24	23	22	22	21
40	39	37	36	35	33	32	31	30	29	28

Table ADT - 4
Changes in Ascent Rates (in FPM)
for altitudes to 10,000 feet.

Sea Level	1,000	2,000	3,000	4,000	5,000	6,000	7,000	8,000	9,000	10,000
60 fpm	58	56	54	52	50	48	46	45	43	41

Richard H. Geyer © 1972 Not to be reproduced in any way without express written permission from the author.

SELECTED BIBLIOGRAPHY

1. Anonymous, Special Notice to Aviation Personnel Who Engage in Scuba Diving, Naval Medicine Newsletter 39: 16 1962.
2. Edel, P.O. Decompression Risks in Successive Hyperbaric-Hypobaric Exposures. Report to Manned Spacecraft Center (Houston, Texas). Under Contract Number T-77550, March, 1969.
3. Edel, P. O., J.J. Carroll, R.W. Honaker, and E.L. Beckman. Interval at Sea Level Pressure Required to Prevent Decompression Sickness in Humans Who Fly in Commercial Aircraft After Diving. Aerospace Medicine 40:1105-1110, 1969.
4. Edel, P.O. Surface Interval Providing Safety Against Decompression Sickness in Hyperbaric-Hypobaric Exposures. National Aeronautics and Space Administration (Houston, Texas). Under Contract Number NAS 9-9036, March 1970.
5. Ferris, E. B., and G.L. Engel. The Clinical Nature of High Altitude Decompression Sickness. In: Decompression Sickness, edited by J.F. Fulton, Philadelphia: W.B. Saunders, 1951.
6. Gramenitsky, P. M., and Savich, A.A. Methods of Inducing Bends in Animals. Vol. 3: "Functions of the Organism Under Conditions of an Altered Gas Environment." Published by the Institute of Evolutionary Physiology. Academy of Sciences USSR: pp 35-42, 1964.
7. Miner, A.D. Scuba Hazards to Aircrews. Business Pilot's Safety Bulletin 61 – 204. Flight Safety Foundation New York, 1961.