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# Health and safety for heavy duty work at extreme altitude

## Construction of the Fred Young Telescope at 5700m

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11th European Hypoxia Symposium
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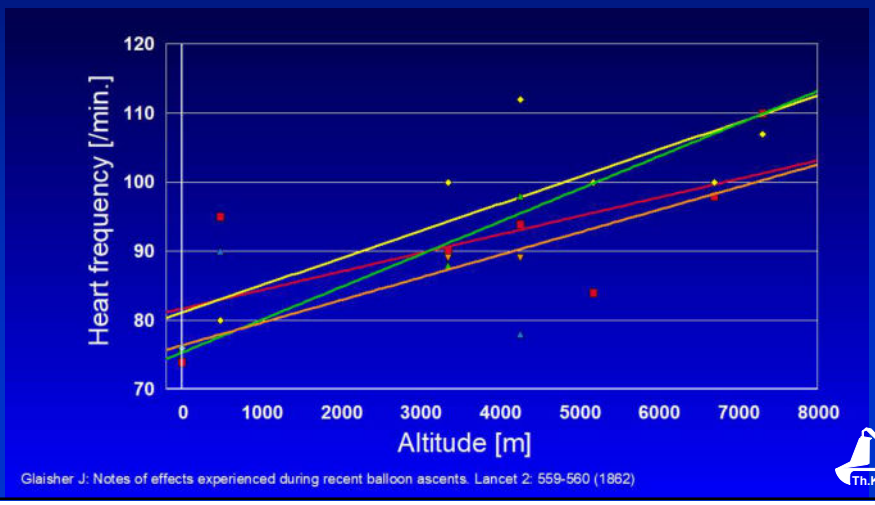
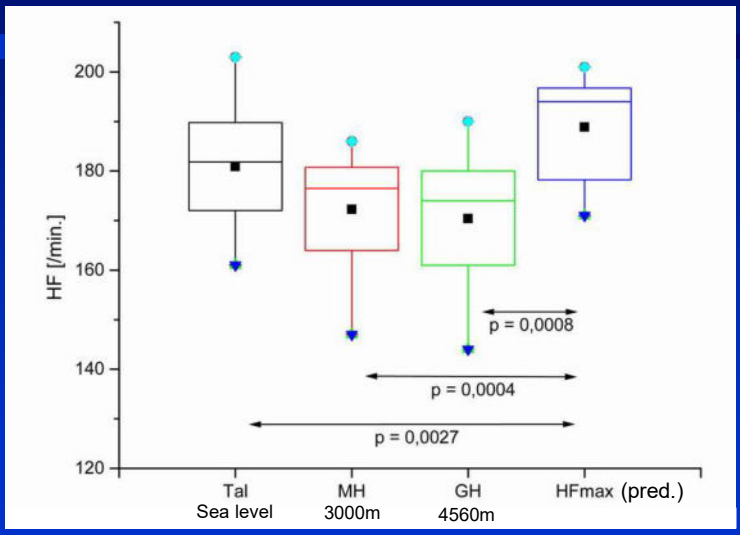
# HR at rest at altitude



# HFmax at altitude



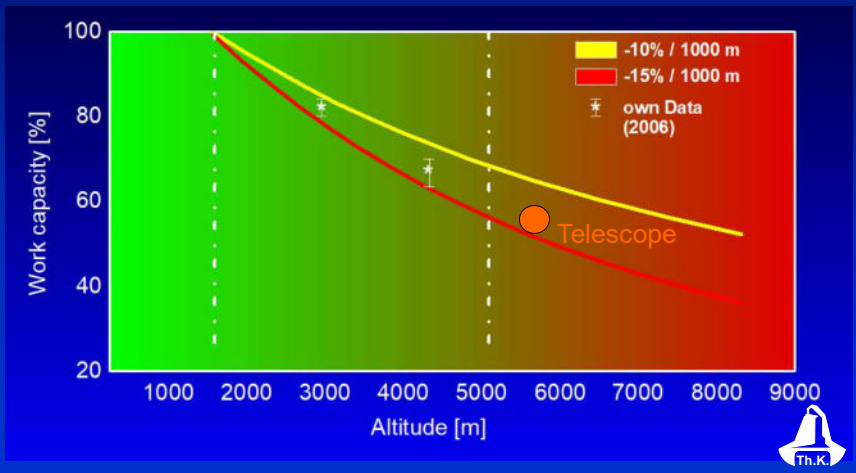

Küpper T. Workload and professional requirements for alpine rescue. Professoral thesis, 2006

# Consequences of the circulatory system's response

1. HF at rest increased
2. HFmax reduced

This limits the range of workload capacity ($\Delta VO_{2max}$).

# Decrease of endurance capacity with altitude

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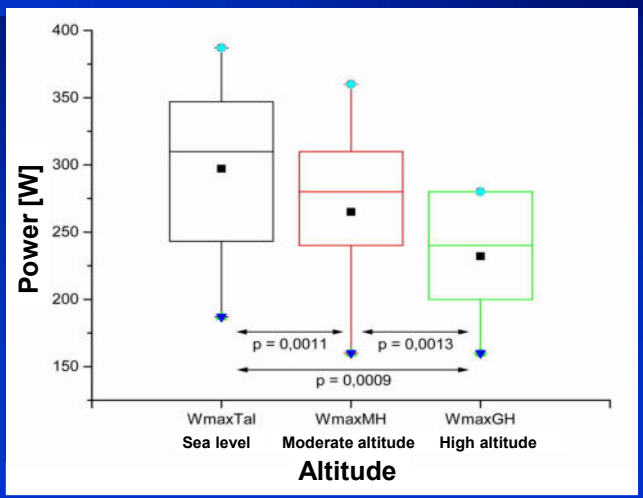
# Decrease of endurance capacity with altitude

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# Spurious arguments by sceptics

1. „Anything below 19.5% is life-threatening“ (OSHA)
   - Equivalent altitude: ≈800m
     - Long distance flight: 8000 ft / 2500m, ≈15,5%
2. Accidents caused by hypoxia-induced mental impairment
3. Altitude diseases
   - AMS, HAPE, HACE
4. Acute incidences of pre-existing diseases


# Altitude & Hypoxia

## or: Oddities in occupational safety

- OSHA (U.S.): „…anything below 19.5% oxygen is potentially life-threatening!“
- Consequence when considering $\%O_2$:
  - According to OSHA, Americans may be catapulted into the stratosphere (21% $O_2$!) without further measures
- Consequences when considering $p_iO_2$:
  - Americans should never fly (equivalent altitude 2500m = 15,5% isobaric)
  - The Midwest and the entire Rocky Mountains would have to be evacuated (~18,0 – 12,5% $O_2$ isobaric)
  - Skiing, trekking, etc. is only possible for Americans with supplemental oxygen

# Physiological statements

Hypoxia management is a completely normal, vital process

Without hypoxia tolerance, we would not be able to survive even for a short period of time

In the life sciences, $\%O_2$ is uninteresting; living organisms need a minimum level of $pO_2$

# Factors of risk management

- Level/extent of isobaric hypoxia
- Duration of exposure
- Acclimatisation status
- Required level of exertion
- Serious/severe pre-existing conditions?
- Retreat/escape routes (duration/distance)
- Local infrastructure (first aid measures, equipment, etc.)

# Factors of risk management

## - Mental limitations -

Typical altitude of work

Construction site of the Fred Young Telescope

| Altitude | $\%O_2$-isobaric conditions | Atmospheric pressure | | $pO_2$ | | Time of useful consciousness |
|---|---|---|---|---|---|---|
| [m] | | [mmHg] | [hPa] | [mmHg] | [hPa] | |
| 0 | 20.9 | 760.0 | 1013.2 | 158.8 | 211.7 | |
| 500 | 19.7 | 716.0 | 954.6 | 149.6 | 199.5 | |
| 1000 | 18.5 | 673.8 | 898.3 | 140.8 | 187.7 | |
| 1500 | 17.4 | 634.0 | 845.3 | 132.5 | 176.7 | |
| 2000 | 16.4 | 596.0 | 794.6 | 124.6 | 166.1 | |
| 2500 | 15.4 | 560.0 | 746.6 | 117.0 | 156.0 | No limitation |
| 3000 | 14.5 | 525.8 | 701.0 | 109.9 | 146.5 | |
| 3500 | 13.6 | 493.0 | 657.3 | 103.0 | 137.3 | |
| 4000 | 12.7 | 462.0 | 616.0 | 96.6 | 128.8 | |
| 4500 | 11.9 | 432.6 | 576.8 | 90.4 | 120.5 | |
| 5000 | 11.1 | 404.8 | 539.7 | 84.6 | 112.8 | |
| 5500 | 10.4 | 378.6 | 504.8 | 79.1 | 105.5 | >30 min. |
| 6000 | 9.7 | 353.6 | 471.4 | 73.9 | 98.5 | |
| 6500 | 9.1 | 330.0 | 440.0 | 69.0 | 92.0 | |
| 7000 | 8.5 | 307.8 | 410.4 | 64.3 | 87.7 | 3-5 min. |
| 10500 | 5.0 | 183.0 | 244.0 | 38.2 | 50.9 | ca. 1 min. |
| 12900 | 3.4 | 123.5 | 164.7 | 25.8 | 34.4 | 15-30 sec. |

But hypoxia can make you euphoric (risk management?)

Küpper T et al. (2012) Recommendation of the Medical Committee of the UIAA No.15: Work in hypoxic conditions. https://theuiaa.org/documents/mountainmedicine/German_UIAA-MedCom-Empfehlung-Nr-15-Arbeit-in-Hypoxie-2012-V2-15.pdf

Th.K.

# Factors of risk management

## - Latency until altitude-related symptoms occur -

| Disease | Latency | Typical altitude |
|---|---|---|
| AMS (acute mountain sickness) | (4-) 6 hrs | >2500m |
| HAPE (High altitude pulmonary edema) | 12-24 hrs | >4000m |
| HACE (High altitude cerbral edema) | 24-72 (-96) hrs | >5000m |
| CMS (Chronic altitude disease) | Months to years | >3500m ? |

Risk management:

- If you can sleep at an altitude of less than 2500 metres, you will never suffer from dangerous altitude sicknesses!
- A prolonged stay requires acclimatisation!

Th.K.

# Factors of risk management

## - Pre-existing diseases -

- Serious / advanced diseases of the cardiopulmonary system can be a problem.
  - Not at stage NYHA 1-2 and ≥15% $O_2$ / <2500m
- No work at high altitude during acute infections of bronchi or lung (heart)
- No work at high altitude with uncontrolled hypertension
  - BP should be at least <160sy bzw. <100 dia [mm Hg]
- Pregnancy
  - No problem at low and moderate altitudes (e.g. supervisory duties) up to 3000 metres (USA: 4000 metres) in uncomplicated pregnancy
  - Any exerise strictly aerobic


# Aptitude test for working at high altitude?

- All procedures to predict altitude tolerance have limited predictive value!
  - For short exposure the hypoxic ventilatory drive (HVD) should work best
  - The person‘s history shows the highest predictive value! If ste Aussagekraft! Anyone who has successfully endured similar exposure to the planned exposure will also tolerate this one
- Altitude (hypoxia) tolerance (in the sense of no symptoms) and fitness at altitude must be considered strictly separately

# Aptitude test for working at high altitude?

- Every consultation requires a precise analysis of the altitude profile!
- Pre-existing acclimatization?

In contrast to all other exposures that are considered from an occupational health perspective, more frequent /higher exposure is a protective factor due to (partial) acclimatisation!

## Situation 1: Construction of a power plant in Tibet

- Lin Zhou Valley, Tibetisches Plateau, 4050m -


High-altitude medical problem: no escape from high altitude

# Construction of a power plant in Tibet

15.62m tunnel boring machine
(with courtesy Herrenknecht / Germany)

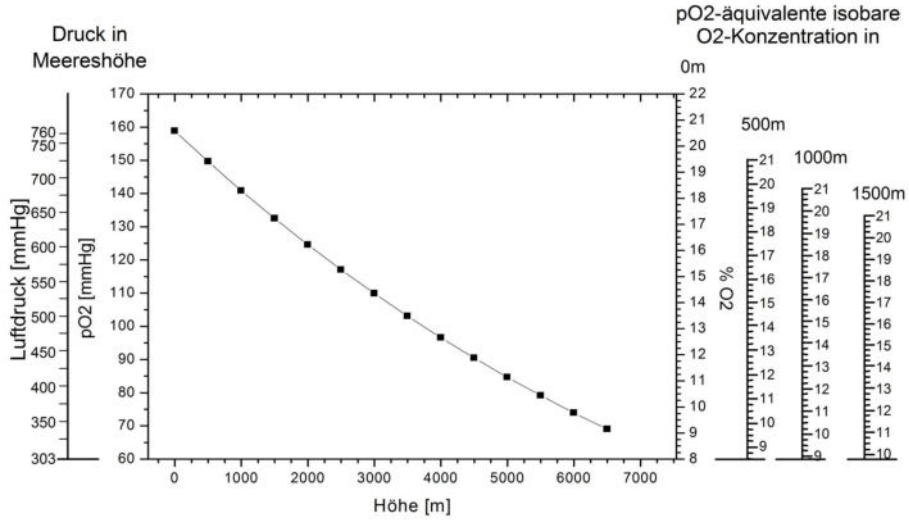
- High-altitude medical problems:
  - Altitude: 4050m
  - Approach in 1 ½ days from 40m
  - No adequate acclimatization
  - No medical infrastructure
  - No realistic escape route to lower altitude
  - Chinese problems
    - Satellite phones forbidden
    - No rescue helicoper
    - Next hospital at „survival level“ and via 400 km track
    - No patient transport crossing borders (e.g. to Nepal)


# Construction of a power plant in Tibet

- How to solve the problem:
  - Combination of Preacclimatization and akklimatisation
    - Sleep at home for 4 nights in isobaric hypoxia corresponding to an altitude of 2500m, 3000m, 2x 3500m
    - 1 acclimatization day during travel at 3500m
  - Medical equipment
    - Dexamethasone, Nifedipine, oxygen, Flow chart for diagnosis and treatment of AMS, HAPE and HACE
  - Pre-departure training to diagnose and to treat altitude diseases
  - Chance to communicate with a physician trained in altitude medicine (Occupational Medicine) at home

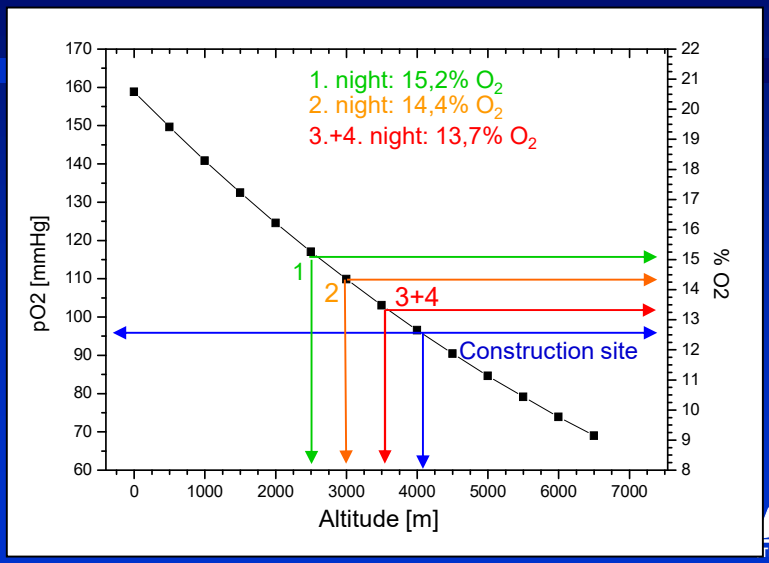
Sleeping in isobaric atmosphere

# Altitude, air pressure, and $O_2$




Küpper T et al. (2015) Recommendation of the Medical Committee of the UIAA No.15: Work in hypoxic conditions. www.theuiaa.org/medical_advice.html

# Altitude, air pressure, and $O_2$



# Construction of a power plant in Tibet

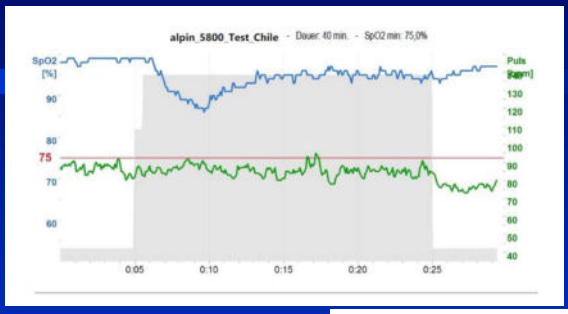
Schlafen in isobarer Hypoxie

- Consequences:
  - 21/23 PAX without symptoms
    - 1 PAX mild headache, was able to work as usual
  - The only person who did not follow the advices developed a severe HAPE after arrival
    - $O_2$ supplies were exhausted
    - Transport problems
    - Finally evacuated and survived by incidence

# Hypoxia tolerance test (Burtscher)

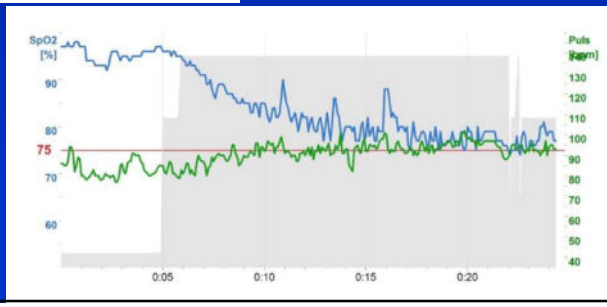
- Sitting position at rest
- 5 min. initial values
- 20 min. hypoxia
  - Here: 10% isobaric (5800m)
- Messurement of HF, $HF_{max}$ and $SaO_2$

# Hypoxia tolerance test (Burtscher)



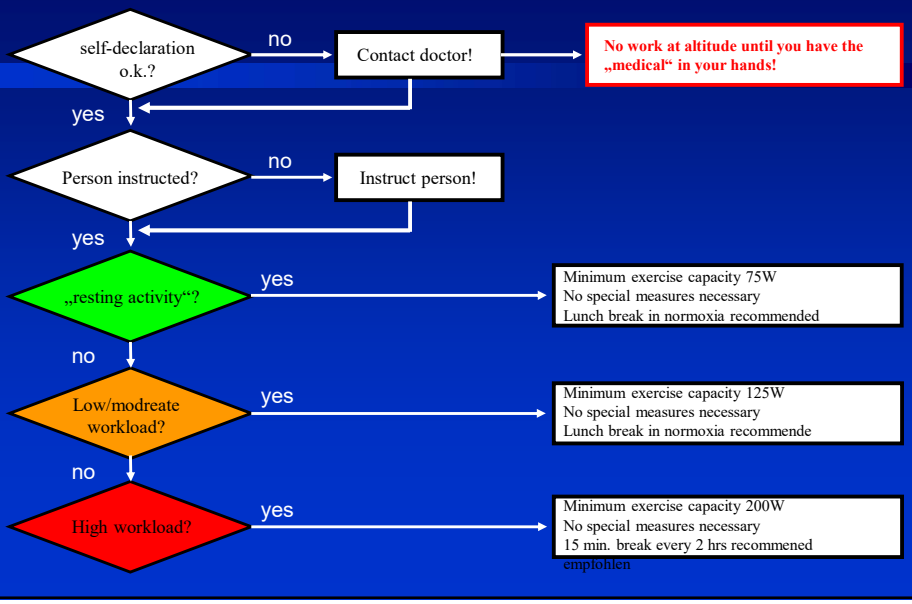

- Good counter-regulation after 10 min.
- Stabilization of the parameters
- Suitable without further restrictions when following the $O_2$ requirement above 5000 m

- No sufficient conter-regulation
- No stabilization of the parameters
- Additional requirement: $O_2$ use above 4000m

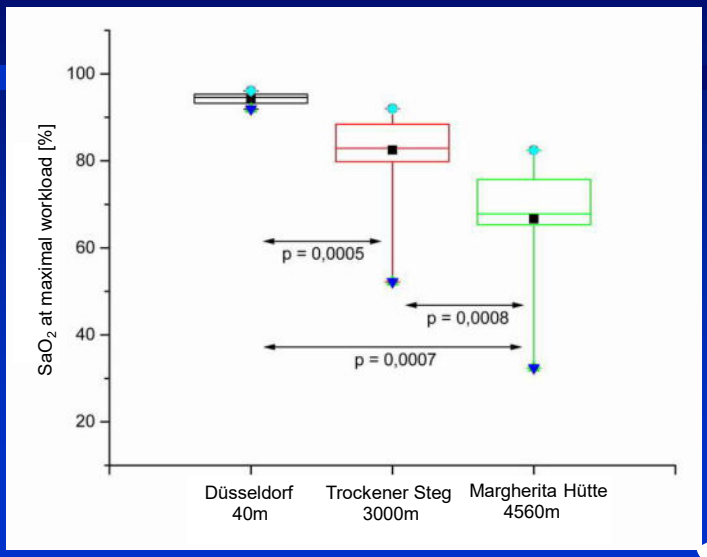



## Occupational health procedure according to UIAA standard

**„Class 2“: 16,9 – 14,8% / 1700 - 2800m**



# $SaO_2$ at $W_{max}$ at 4560m




Küpper T: Körperliche und fachliche Anforderungen bei der Rettung aus alpinen Notlagen. Habilitationsschrift an der RWTH Aachen University, 2006

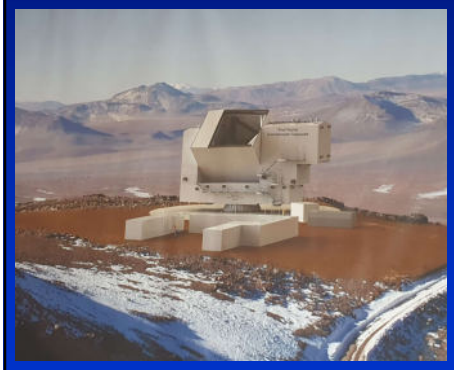
# Situation 2: Astronomers at the European South Observatory

- Cajnantor Plateau, Atacama Desert, 5041m -

„Time of useful consciousness“ at 5040m unlimited

# Construction of the Fred Young Telescope

- Cerro Cajnantor, 5650m -

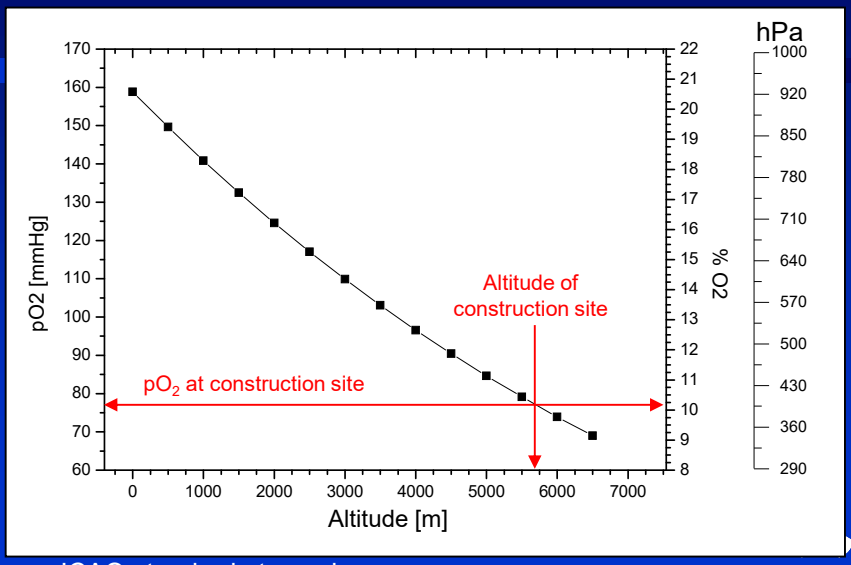


…when construction will be completed…

- High-altitude medical problems:
  - Altitude 5650 m
  - $p_iO_2$ ~78 mmHg (10,3% isobaric)
  - Time of useful consciousness ca. 35-40 min. only
  - Aerobic endurance ~50%
  - No medical infrastructure
  - Approach from 2400m by 4WD in 2 hrs

Th.K.

# Altitude, air pressure and $pO_2$




ICAO standard atmosphere

# Construction of the Fred Young Telescope

- Cerro Cajnantor, 5650m -


- How to solve the problem:
  - Supplemental oxygen obligatoric above 5000 m
    - Demand system
    - 2 l bottle
  - Instruction how to use supplemental $O_2$
  - Exposure at day 1 <4h, at day 2 <6h

# Heavy Duty Work at 5650m

Moving beams weighting several tons
Shovelling and transporting rubble

Loads 35 - >50 kg

# Work at 5650m


# Work at 5650m

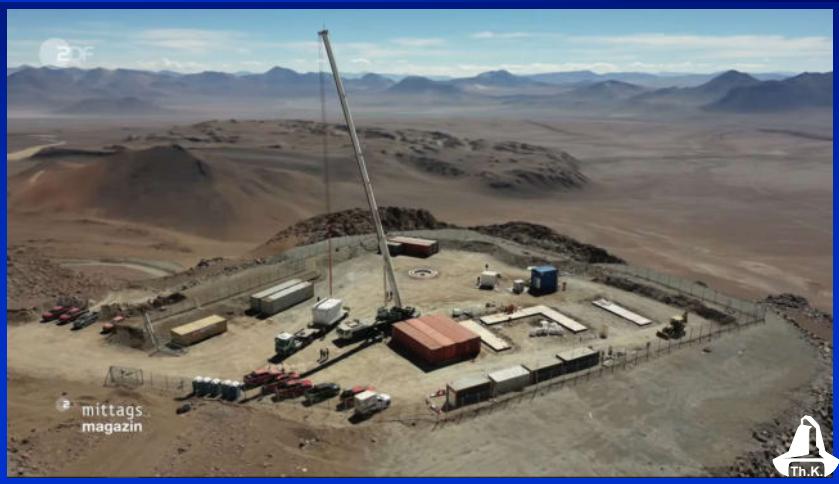
- 250 tons traveling -

# Work at 5650m

- 250 tons traveling -


# Work at 5650m

- Construction site -



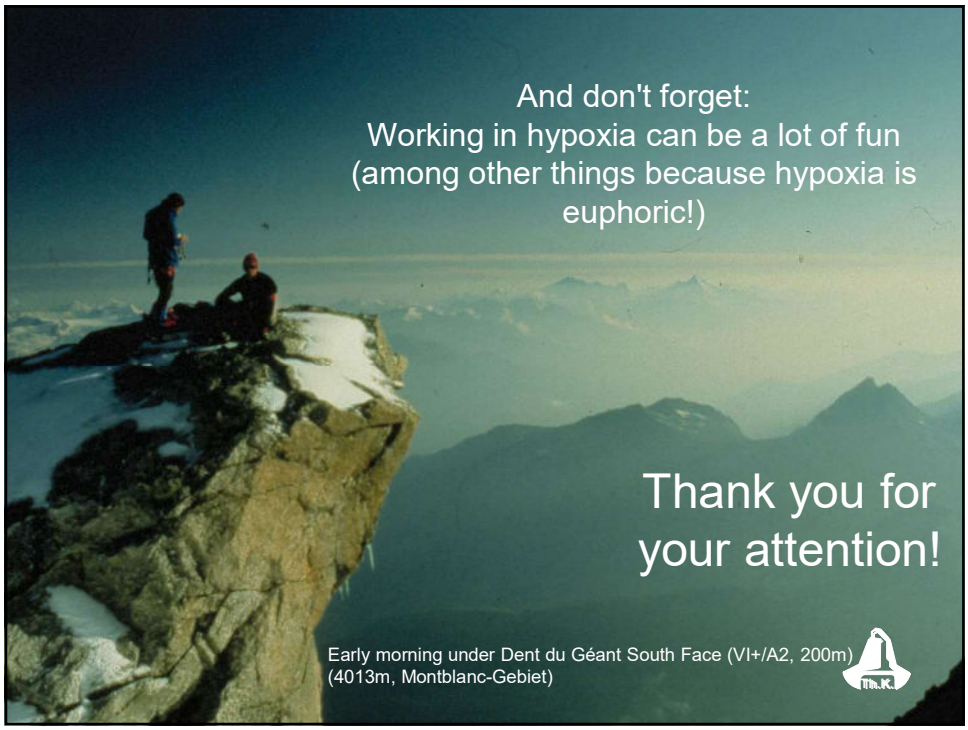
# Work at 5650m

- 80 mm nuts! -


## …last but not least:

- Please don‘t forget:
  - At high altitudes, it is often bitterly cold, very windy, with high radiation intensity and frequently bad weather – in short, the environmental conditions are generally very harsh!

So don't limit work at altitude to hypoxia!


And don't forget:
Working in hypoxia can be a lot of fun
(among other things because hypoxia is euphoric!)
Thank you for your attention!
Early morning under Dent du Géant South Face (VI+/A2, 200m)
(4013m, Montblanc-Gebiet)