Acclimatisation to High Altitude 高地適應

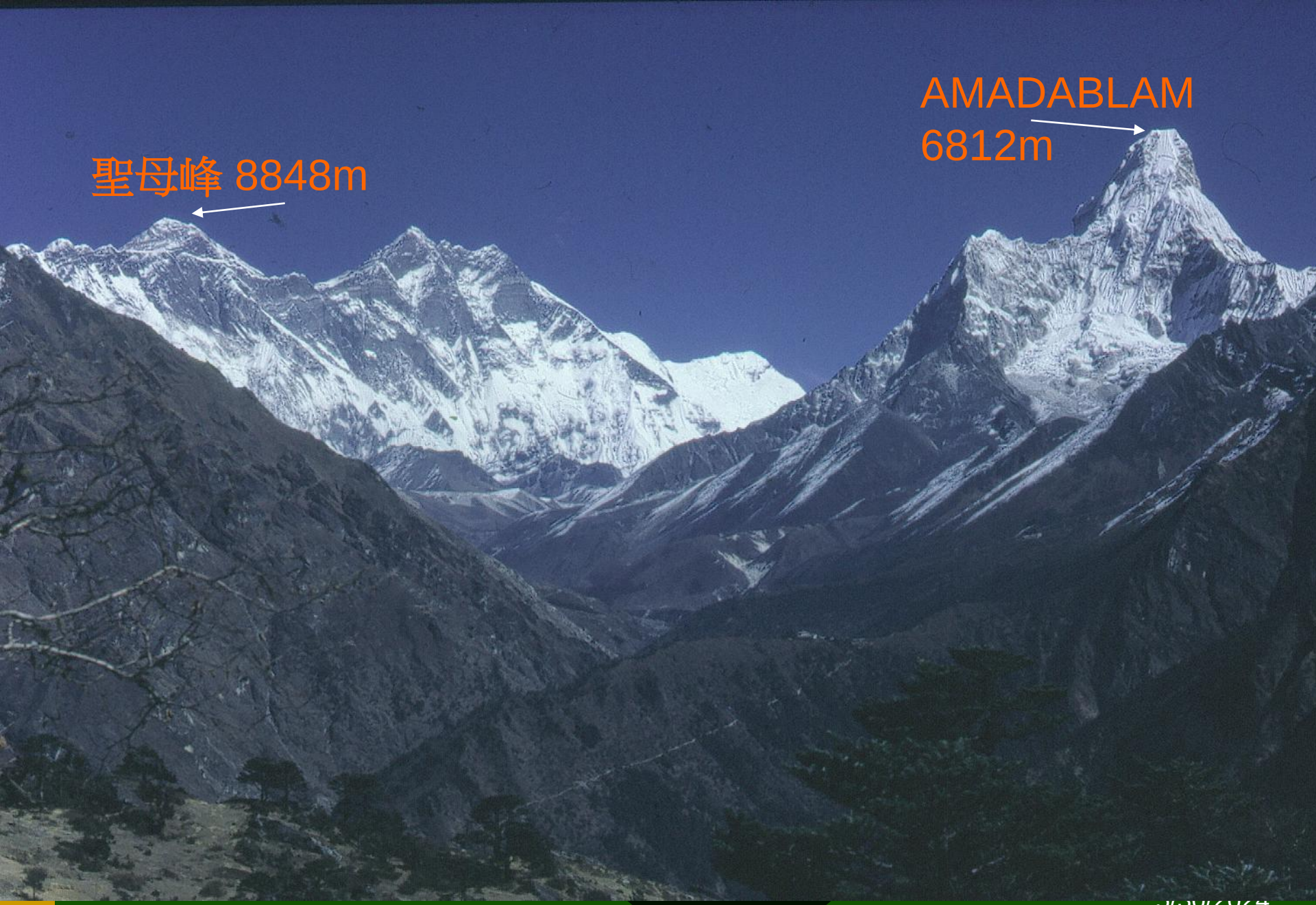
Dr Jim Milledge

Hon. Prof. University College London

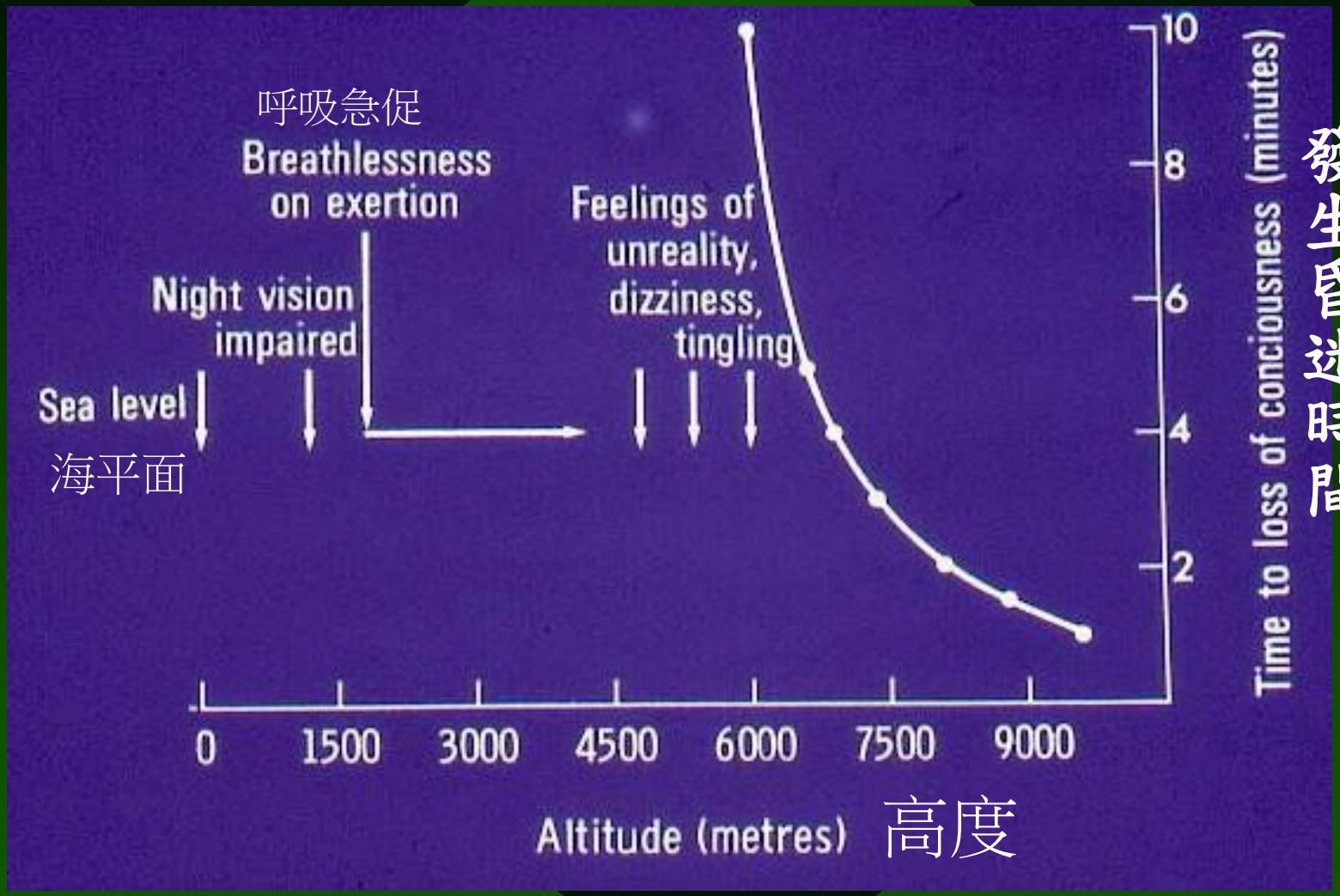
Lecture to conference on Mountain Medicine, Taiwan March 2008

台灣高山醫學研討會演講資料

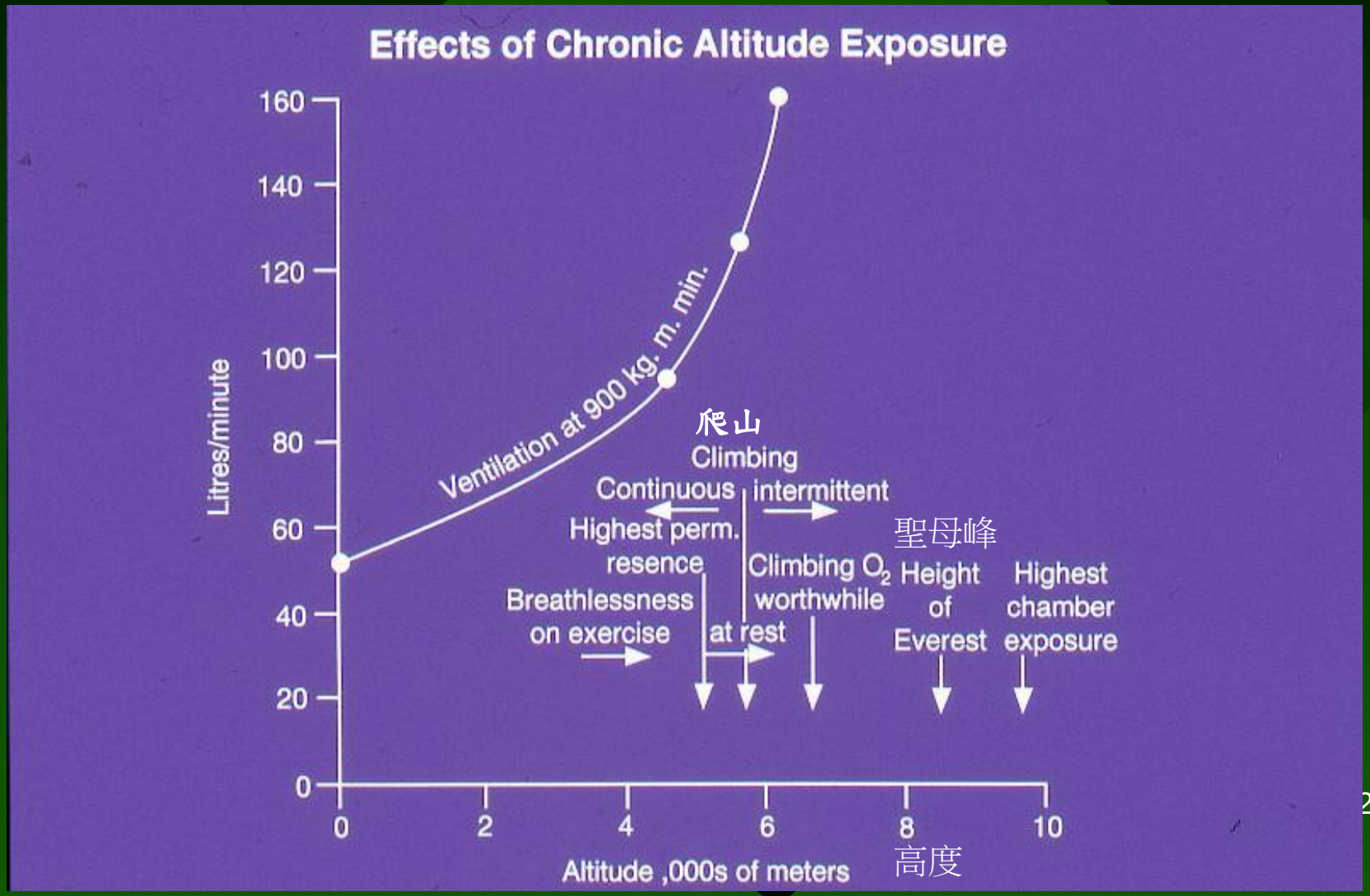
2008年3月


AMADABLAM
6812m
聖母峰 8848m

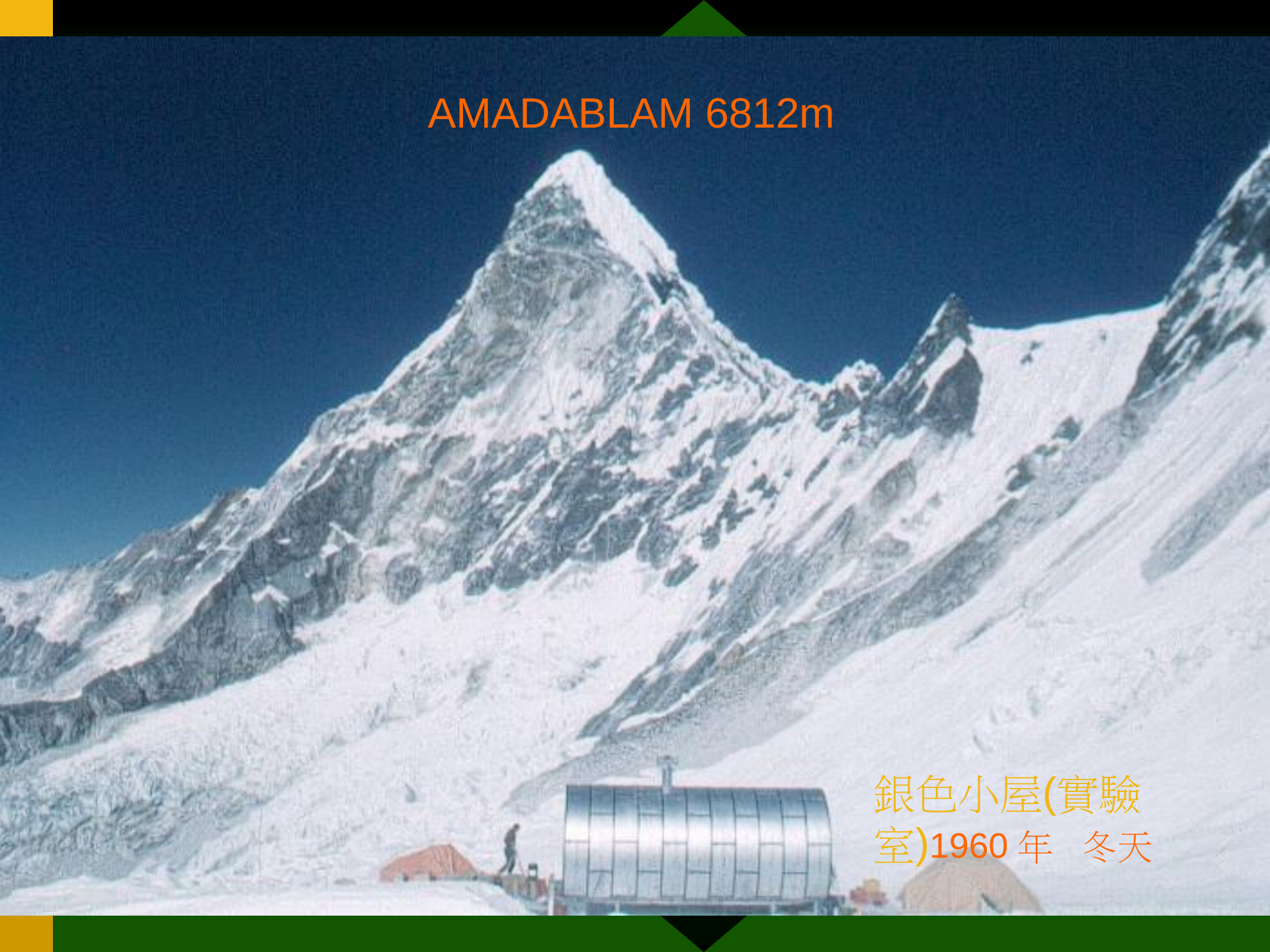
Symptoms of sudden hypoxia
突然缺氧症狀



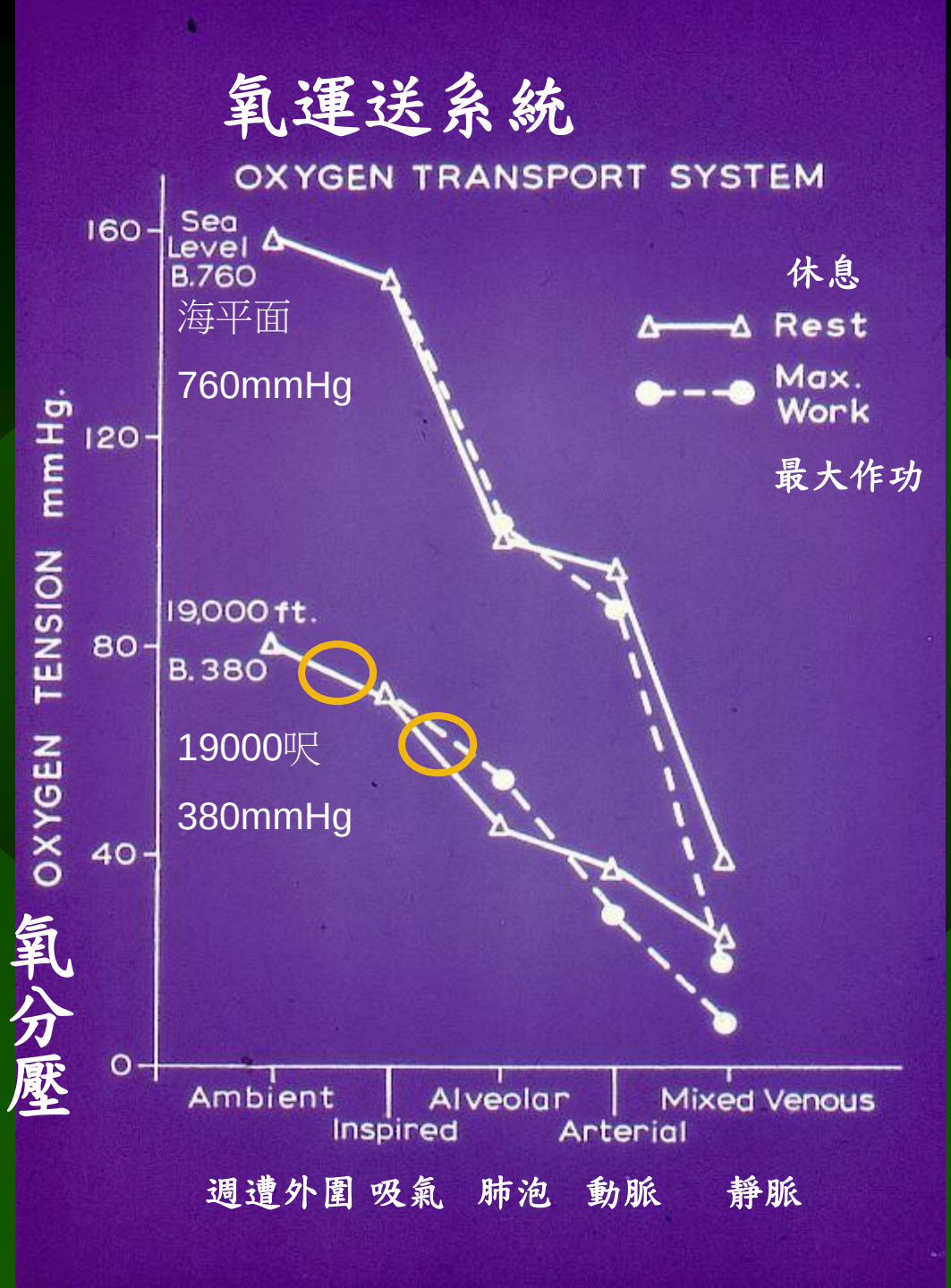
Effect of Chronic altitude exposure
慢性高地暴露之效應



SILVER HUT @ AMADABLAM 5800公尺處建立銀色小屋(實驗室)


AMADABLAM 6812m
銀色小屋(實驗室)1960 年　冬天

氧運送系統

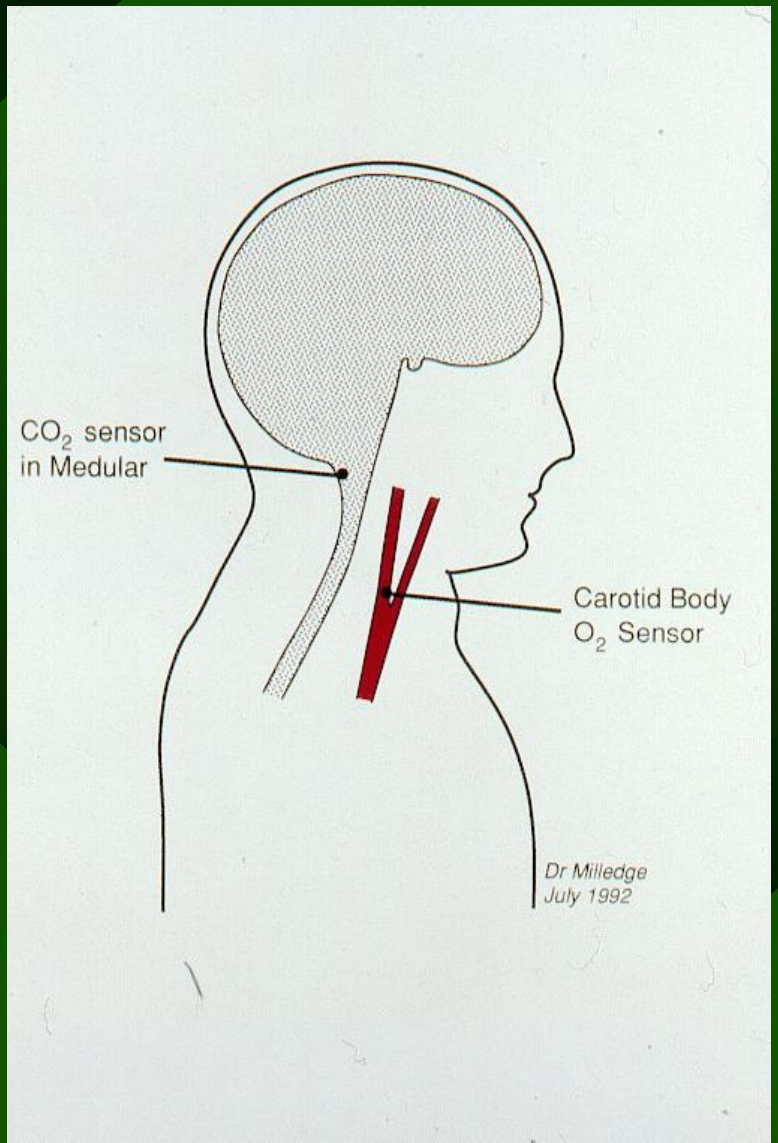

OXYGEN TRANSPORT SYSTEM
OXYGEN TENSION mmHg.
160
120
80
40
0
Sea Level B.760
海平面
760mmHg
19,000ft.
B.380
19000呎
380mmHg
休息
Rest
Max. Work
最大作功
Ambient
Inspired
Alveolar
Arterial
Mixed Venous
週遭外圍 吸氣 肺泡 動脈 靜脈

氧分壓

Respiratory Acclimatisation
呼吸適應

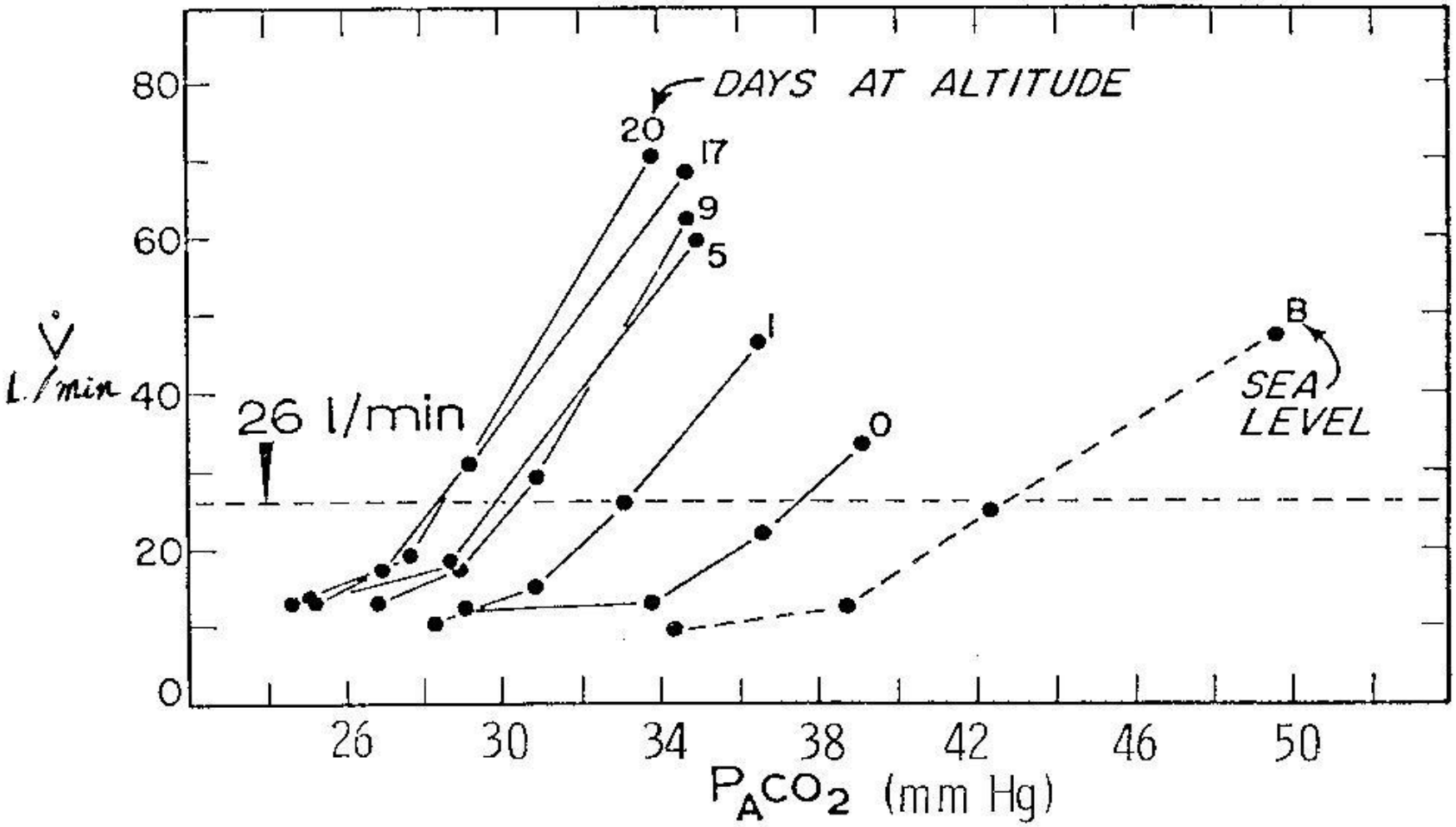
- The earliest and most important defence against altitude hypoxia is an increase in minute ventilation.
  增加每分鐘通氣量是人體最早也是最重要之防禦機制
- There is an increase in both depth and rate of breathing.
  增加通氣量亦即增加呼吸深度與呼吸率
- This results in a decrease in P_ACO_2 and an increase in P_AO_2
  增加通氣量造成動脈血氧分壓增加，動脈血二氧化碳分壓降低

Chemoreceptors, central and peripheral
中樞與周邊之化學接受器

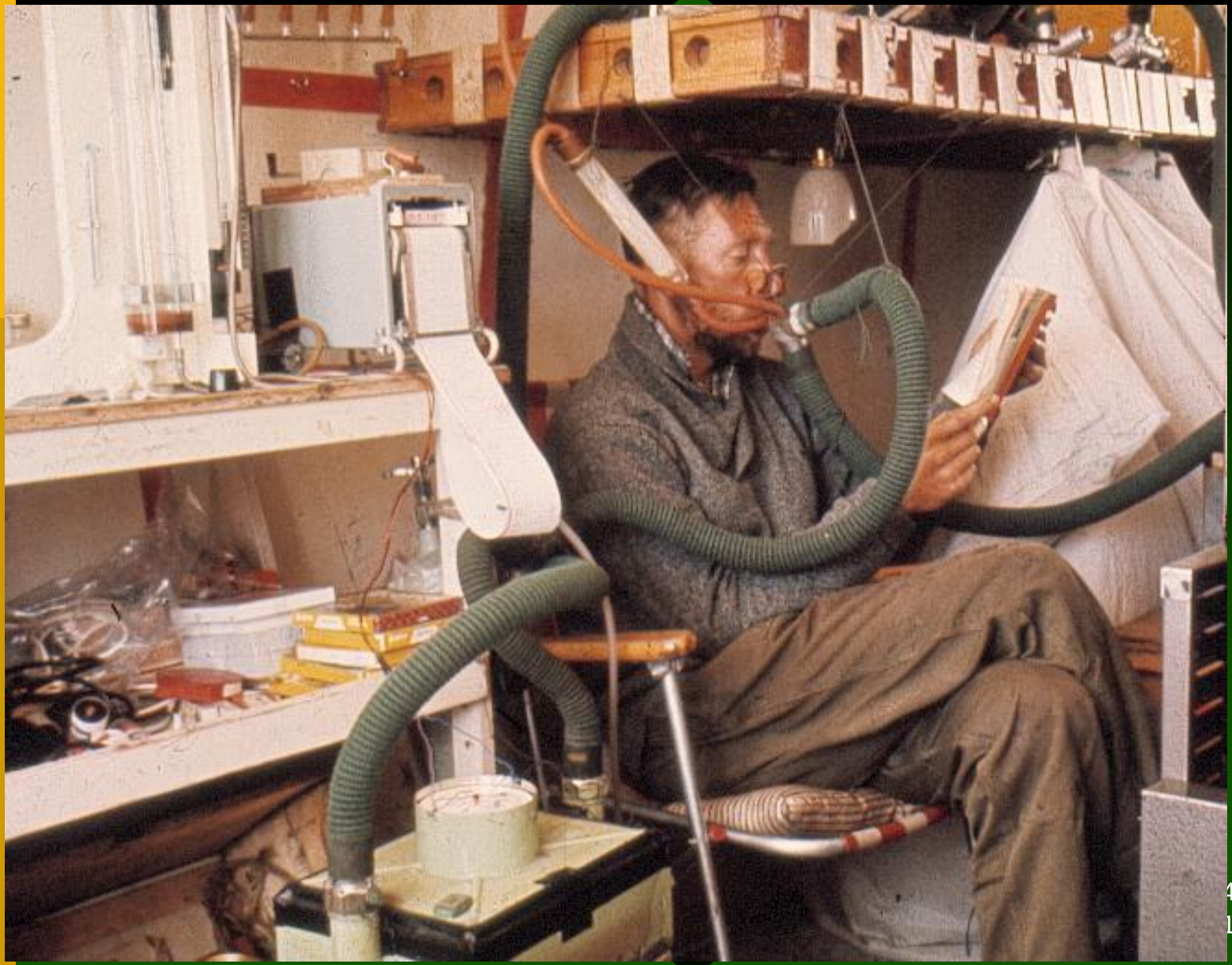


CO_2 Response –Acclimaitzation

適應－二氧化碳之反應



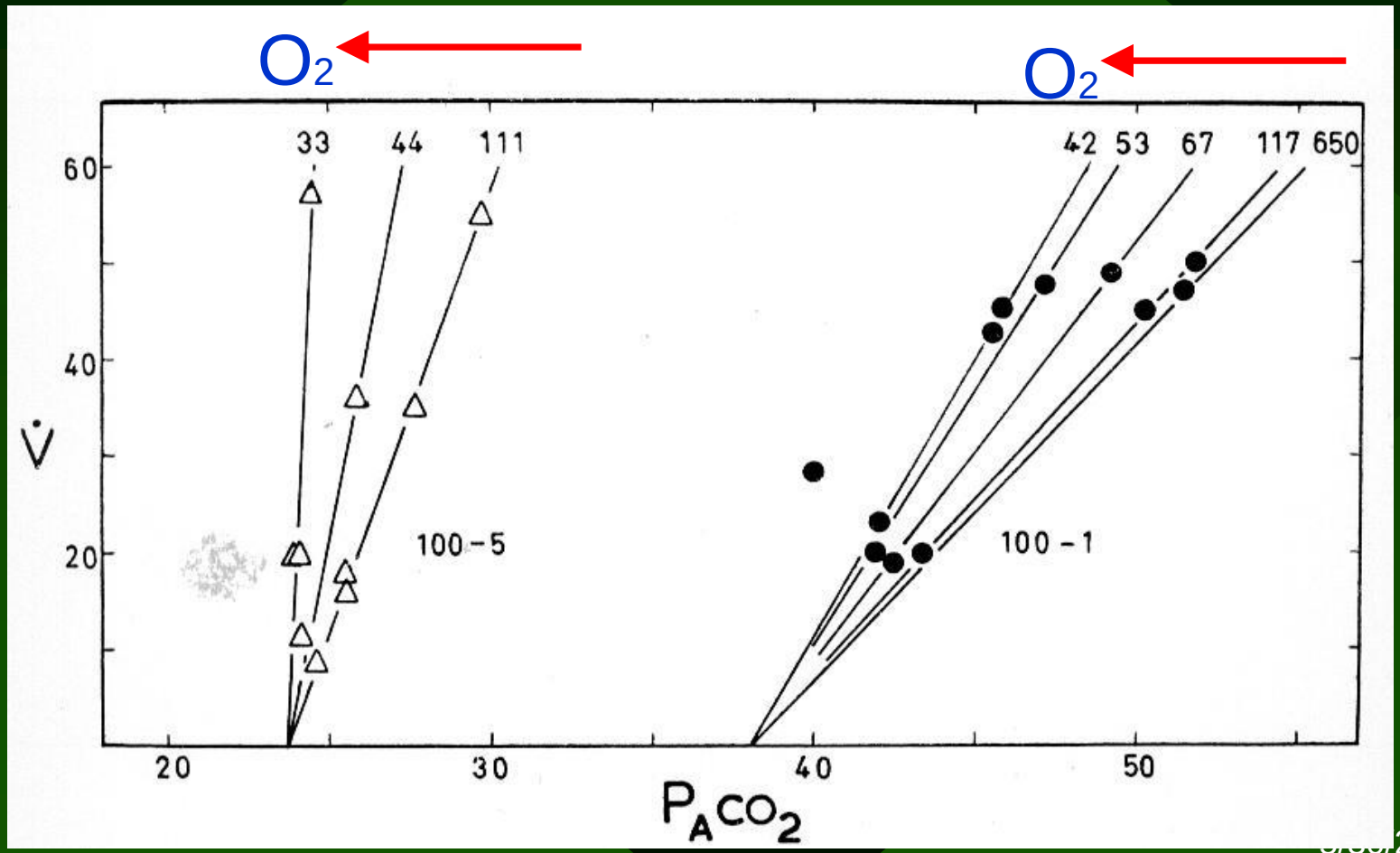
- At 4340m, White Mountain
- Kellogg 1963



1960年銀色小屋(實驗室)建立在Amadablem 5800公尺處

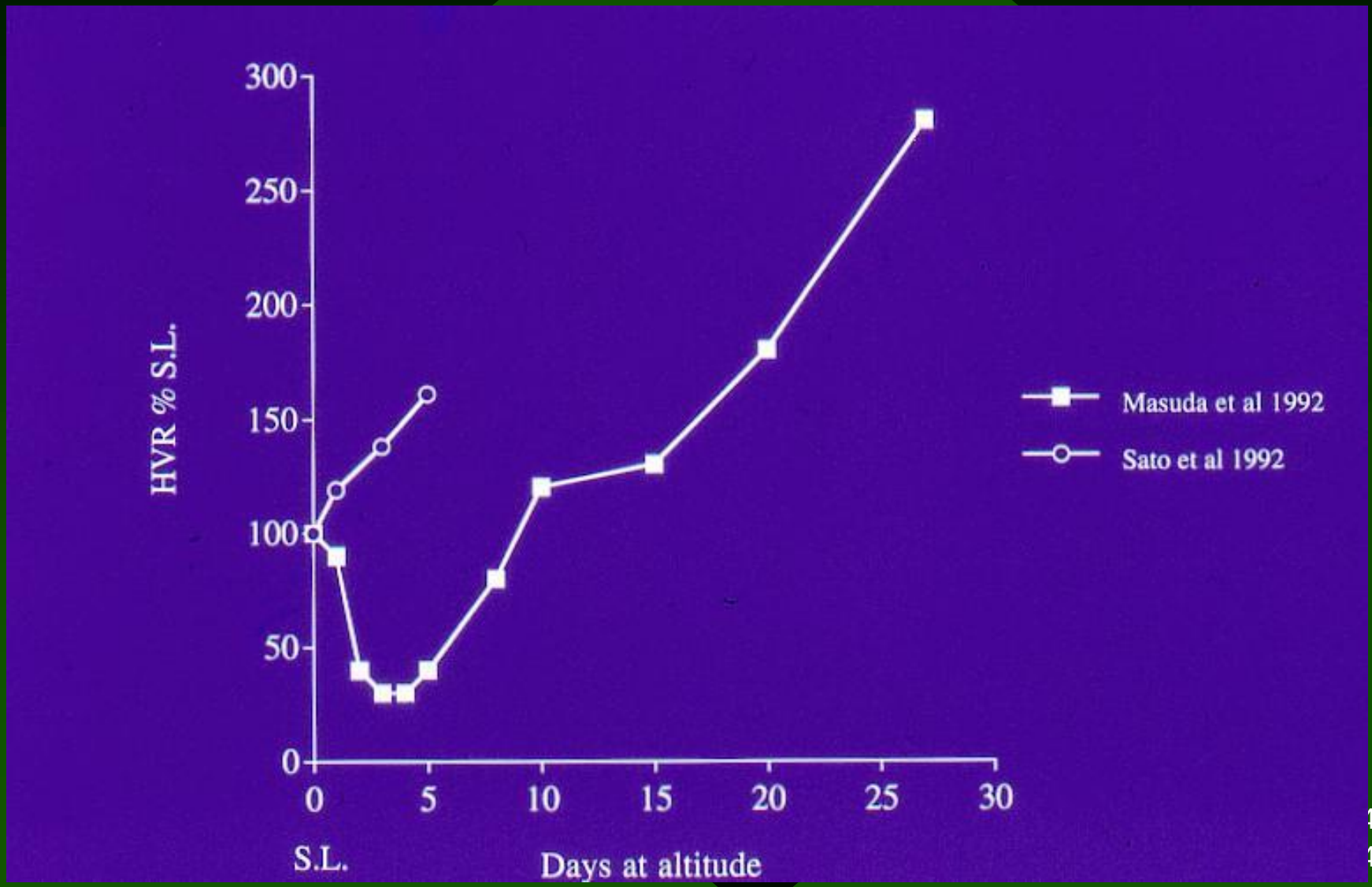
Effect of acclimatisation (left) on CO_2 and Hypoxic Ventilatory Response

二氧化碳適應之效應(左)與低氧通氣反應



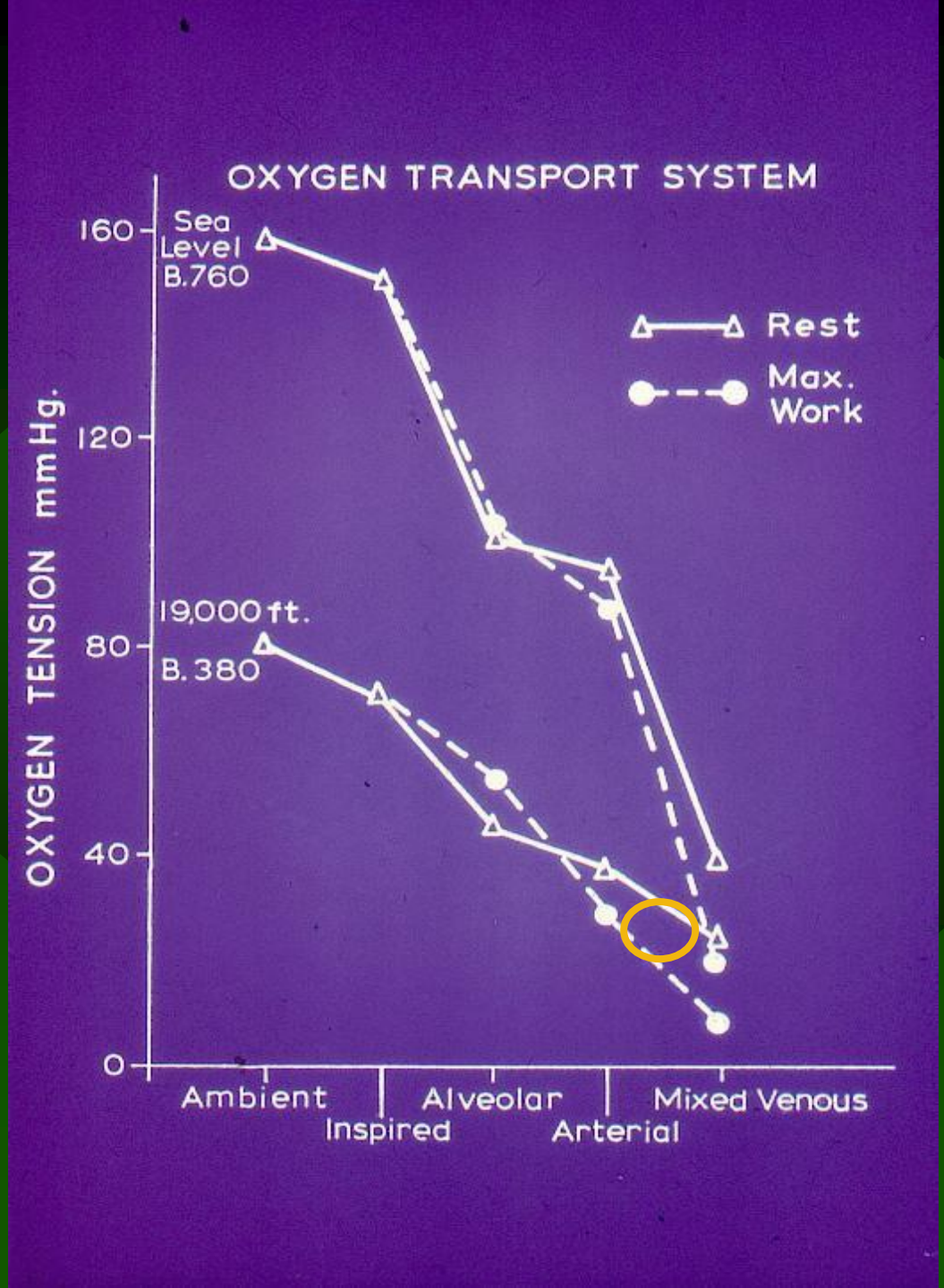
Effect of acclimatisation on HVR

低氧通氣效應之適應



Mechanism of Resp Acclimatization
呼吸適應機制

- Hypoxia – Carotid body – hyperventilation
  低氧－頸動脈體－過度通氣
- Hyperventilation – PCO_2 down
  過度通氣 - 二氧化碳分壓下降
- PCO_2 down – pH alkaline (resp)
  二氧化碳分壓下降－酸鹼值上升（偏鹼性）（呼吸）
- Less hyperventilation 降低過度通氣
- Renal excretion of HCO_3 (Diamox)腎臟過濾出重碳酸根
- pH returned towards normal 酸鹼值(pH) 恢復至正常
- Ventilatory drive restored, further hyperventilation.
  通氣驅使再次循環，回至過度通氣


OXYGEN TRANSPORT SYSTEM
OXYGEN TENSION mm Hg.
160
120
80
40
0
Sea Level B.760
19,000 ft.
B. 380
Rest
Max. Work
Ambient Inspired
Alveolar
Arterial
Mixed Venous

Art. – vein. PO_2 difference
動靜脈氧氧分壓差

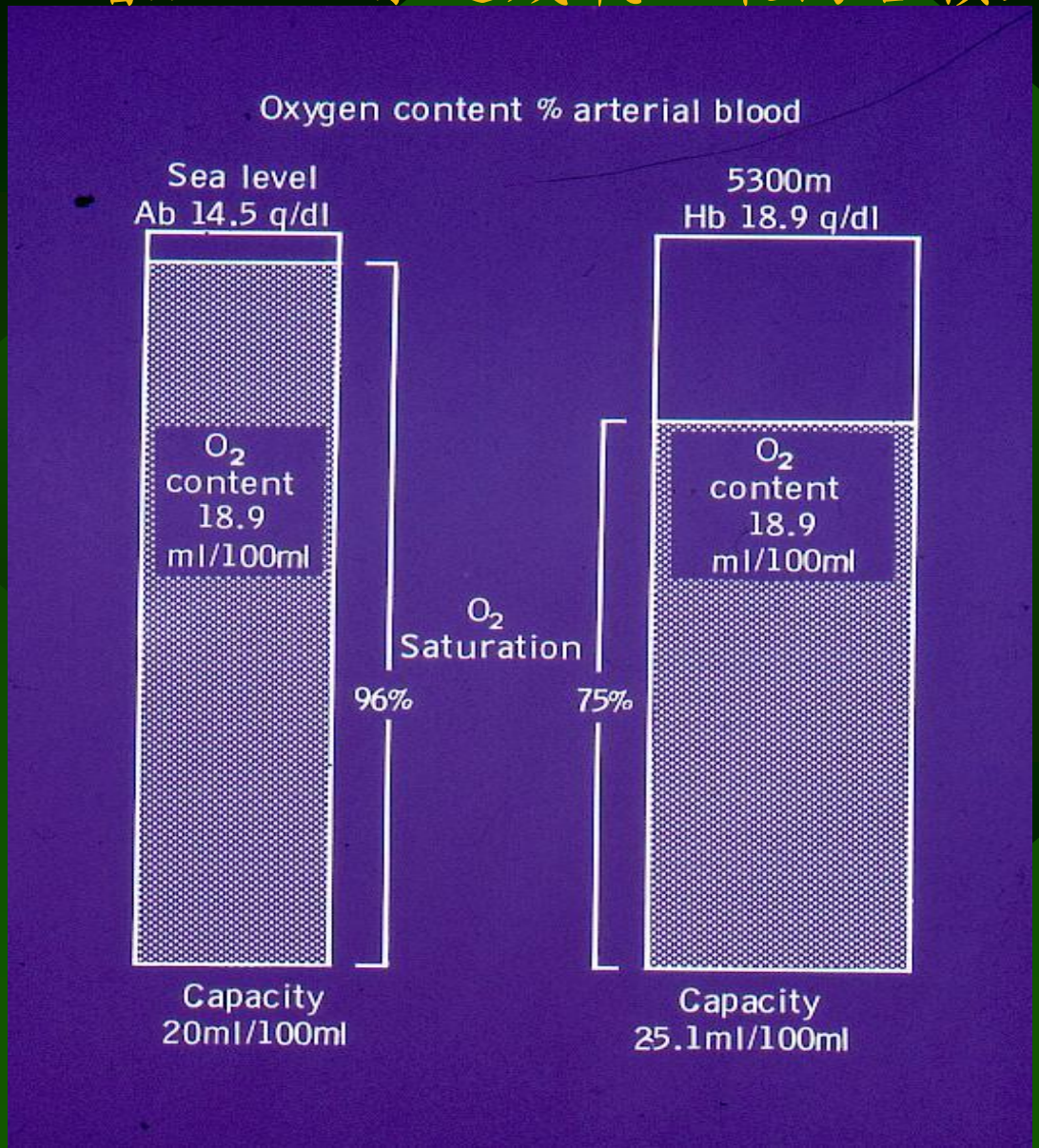
- Depends on 依據: -
  1. Cardiac output 心輸出量
- 2. Hb concentration 血紅素濃度
- 3. Position on O_2 dissociation curve 氧解離曲線之位置

Increase in RBCs at altitude
高地增加紅血球

- Best known physiological effect of Alt.
  目前最著名之高地生理效應
- Paul Bert, *La Pression Barometric* (1878) suggested it might happen
  Paul Bert, *La Pression Barometric* (1878) 認為將會發生
- Was sent samples of blood of animals from La Paz, showed O_2 capacity increased
  La Paz分析動物血液檢體發現氧容積增加
- Viault (1890) found RBC increased in man at (4372m), from 5 to 7.1 million/cu.mm
  Viault (1890)發現在4372公尺高度低樣刺激血液中紅血球增佳

Effect of increased Hb on Oxygen carrying capacity

增加血紅素造成氧之最高容積效應



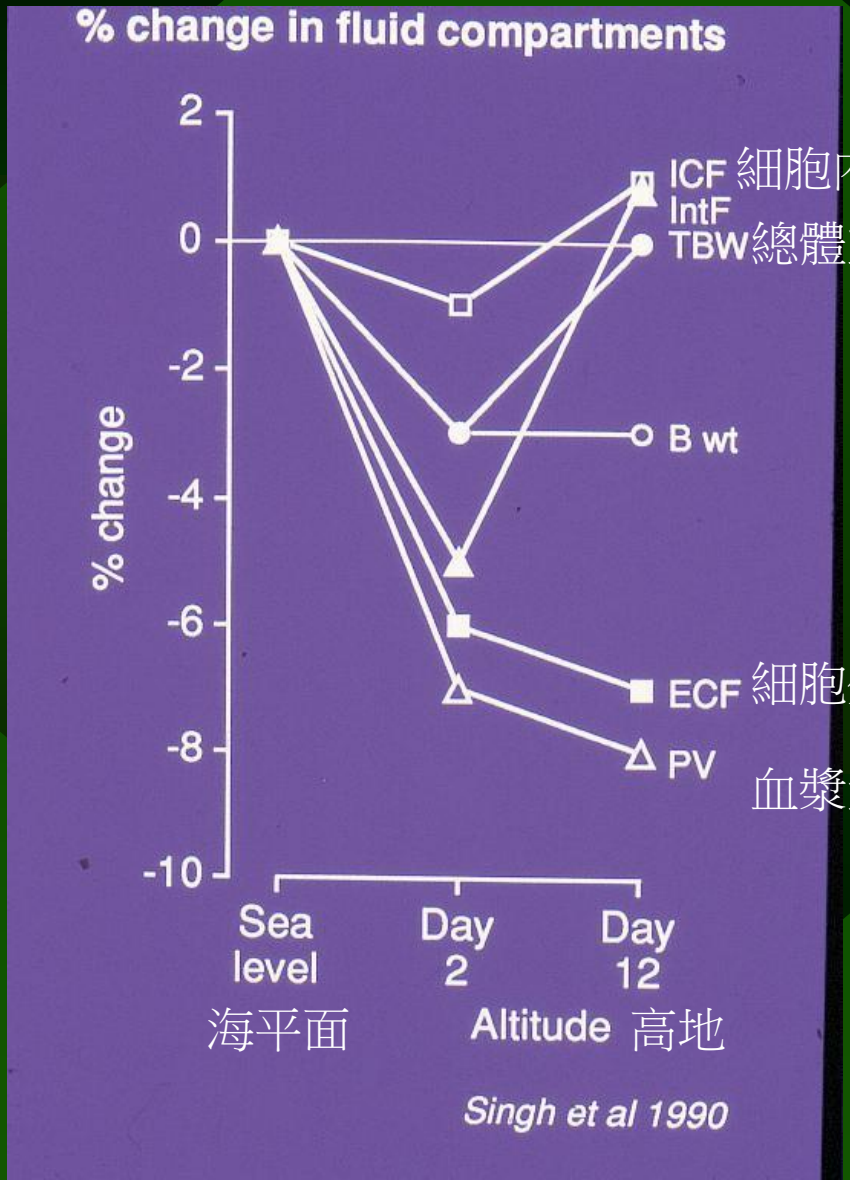
How is [Hb] increased?

血紅素如何增加？

- Possibilities可能是：-
- 1. Decreased Plasma Volume
  減少血漿量
- 2. Increased red cell mass
  增加紅細胞質量

Effect of Alt, 3500m, on fluid compartments of the body

海拔3500公尺對人體體液組成之影響

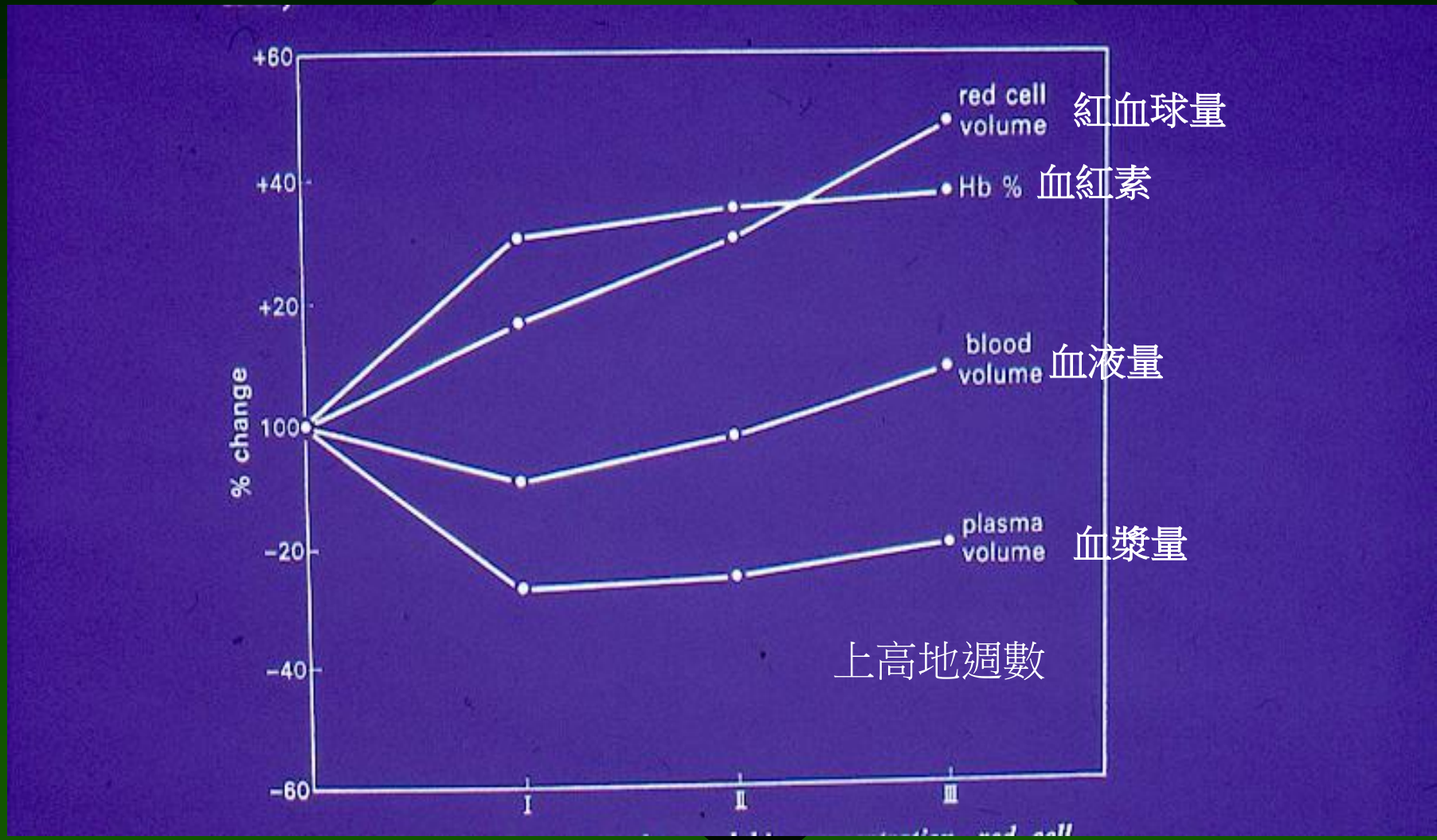


Altitude and plasma volume
高度與血漿量

- Most studies show reduction, 8 – 30%
  大部分研究認為降低8 – 30%
- However exercise can over-ride altitude and result in an increase
  然而運動能超越高度效應而導致血漿量增加
- AMS may cause fluid retention including increase in plasma volume
  急性高山症可造成體液滯留包括增加血漿量
- The effect is seen early in alt. exposure
  此效益在高地暴露早期即發生

Longer-term effect of altitude on PV, Hb, RCM, Blood Vol.

長期高地環境對血漿量、血紅素、紅血球質量、血液量之影響



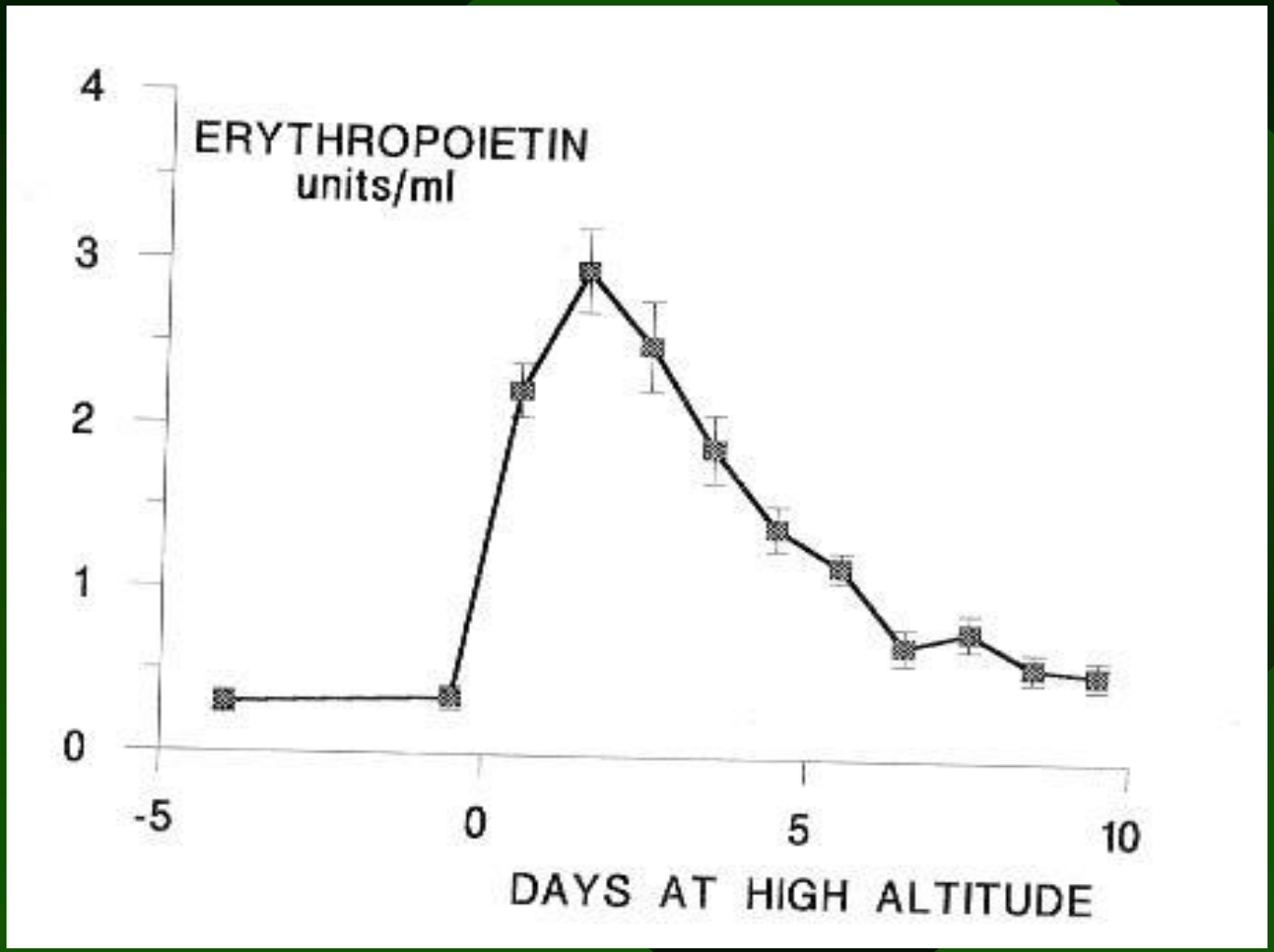
Erythropoietin(EPO)紅血球生成素

- Produced in the kidneys (liver)
  腎肝製造
- Gene switched on by HIF-1
  HIF-1基因啟動
- Rapid response to hypoxia (~2 hrs)
  約2小時之低氧刺激即迅速啟動
- Rapid reduction in blood levels (~3-5 days)
  約3-5 天持續低氧刺激，血中快速生成紅血球生成素速率減緩
- Low increased levels but may be increased production and utilization in bone marrow
  因紅血球生成素作用，造成骨髓製造紅血球量增加

Erythropoietin and red cell mass
紅血球生成素與紅血球質量

- Erythropoietin (EPO) stimulates bone marrow
  紅血球生成素刺激骨隨
- But response of RCM very variable
  但導致紅血球質量反應變異較大
- Depends on iron stores端賴於鐵的儲存
- Subjects with low ferritin levels (women) may show no increase in RCM
  若體內儲鐵量較低（女性）將導致紅血球質量未明顯增加
- Iron supplements help if Fe stores low
  (Stray-Gundersen & Levin 1996)
  若體內儲鐵量較低應補充鐵劑

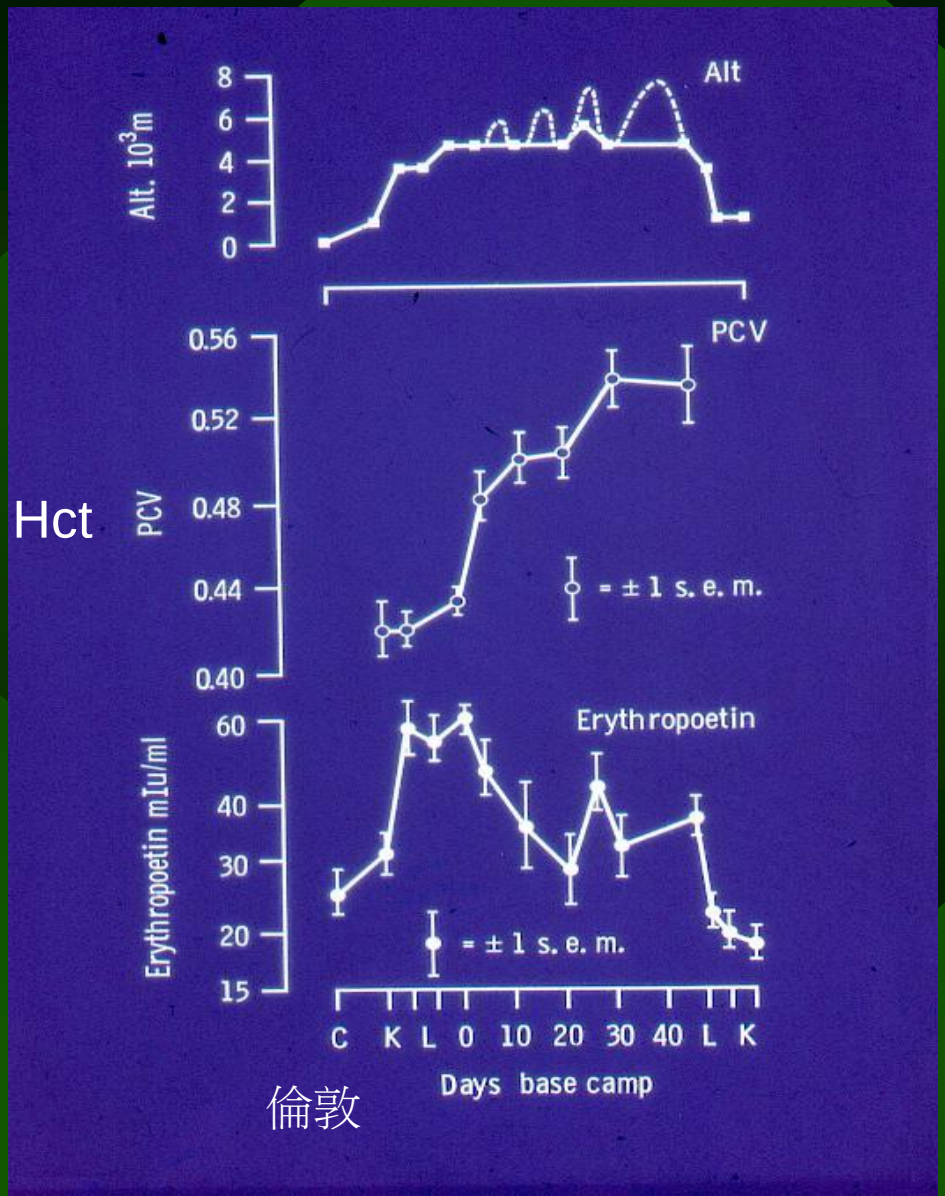
Effect of altitude on serum erythropoietin
高地效應對血清紅血球生成素之影響



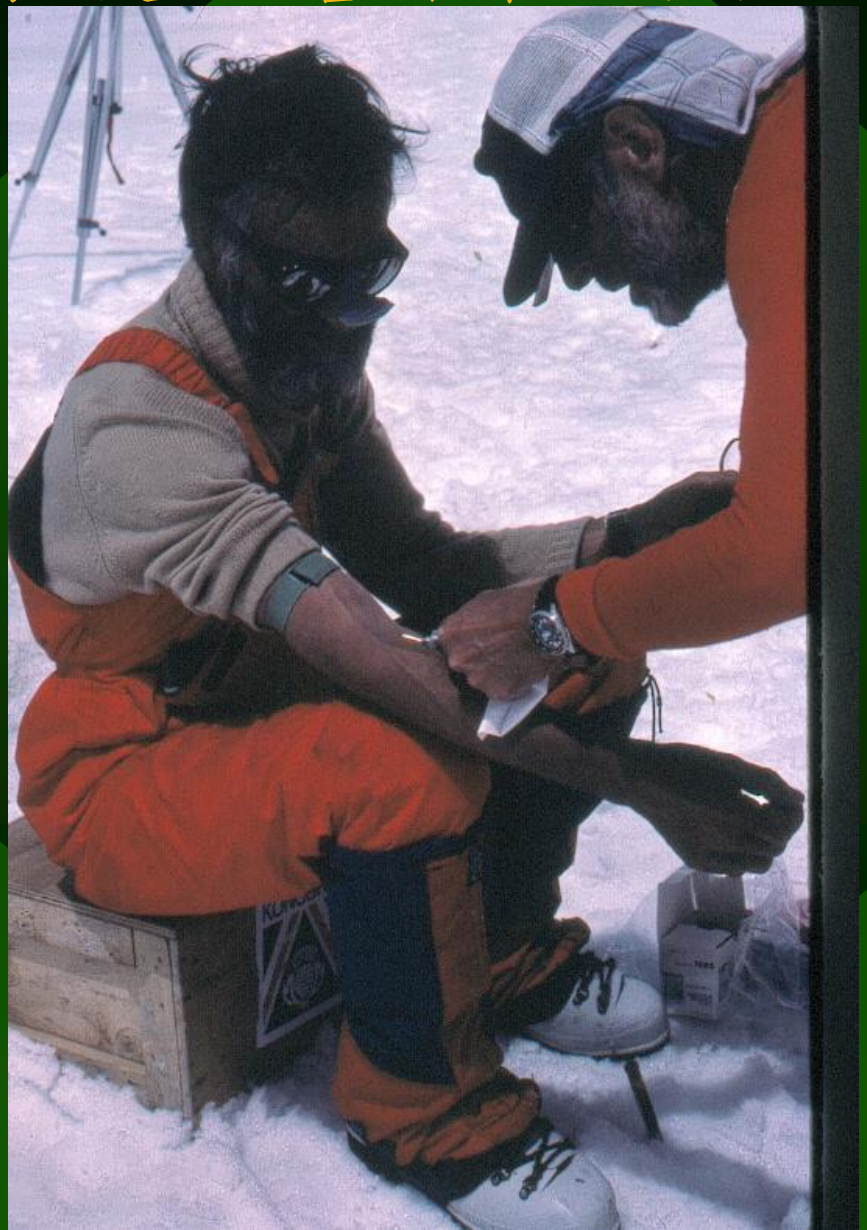
- Weil JV *et al.* 1968

公格山 (Kongur 7719m), 中國新疆

Erythropoietin at altitude
高地作用之紅血球生成素表現

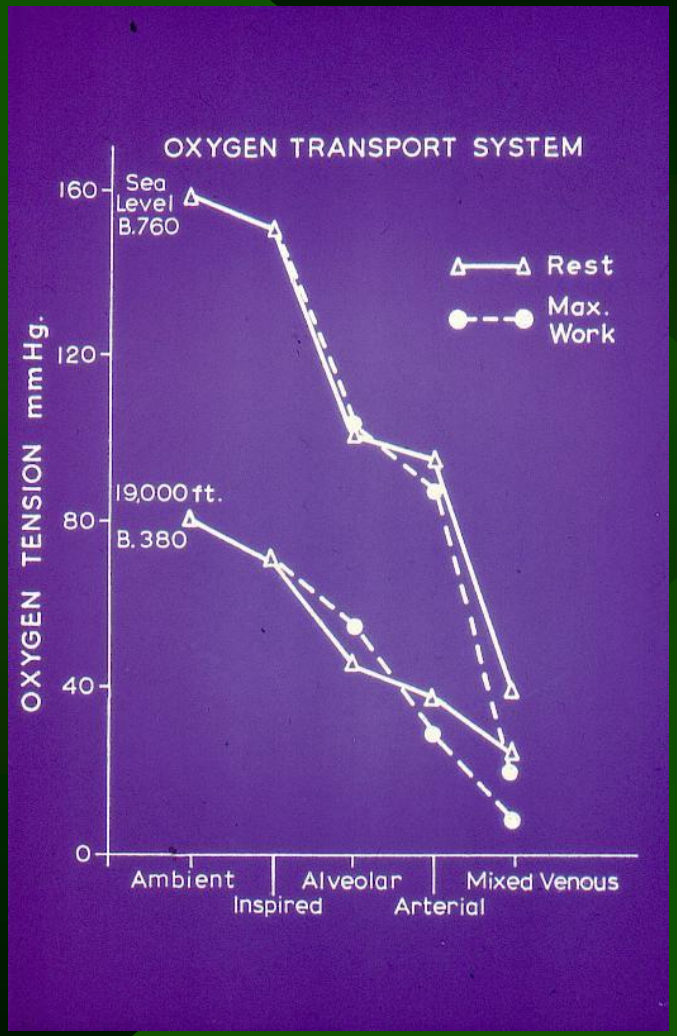


Blood sampling at advanced BC
前進基地營採集血液檢體



Acclimatization – Textbook
適應–教戰守則

- Respiratory acclimatization Most important
  呼吸適應最重要
- [Hb] increase, less important
  血紅素增加較不重要
- So O_2 delivery to tissues is increased
  BUT
  所以氧傳送至組織雖增加
- 但



Awkward Questions:

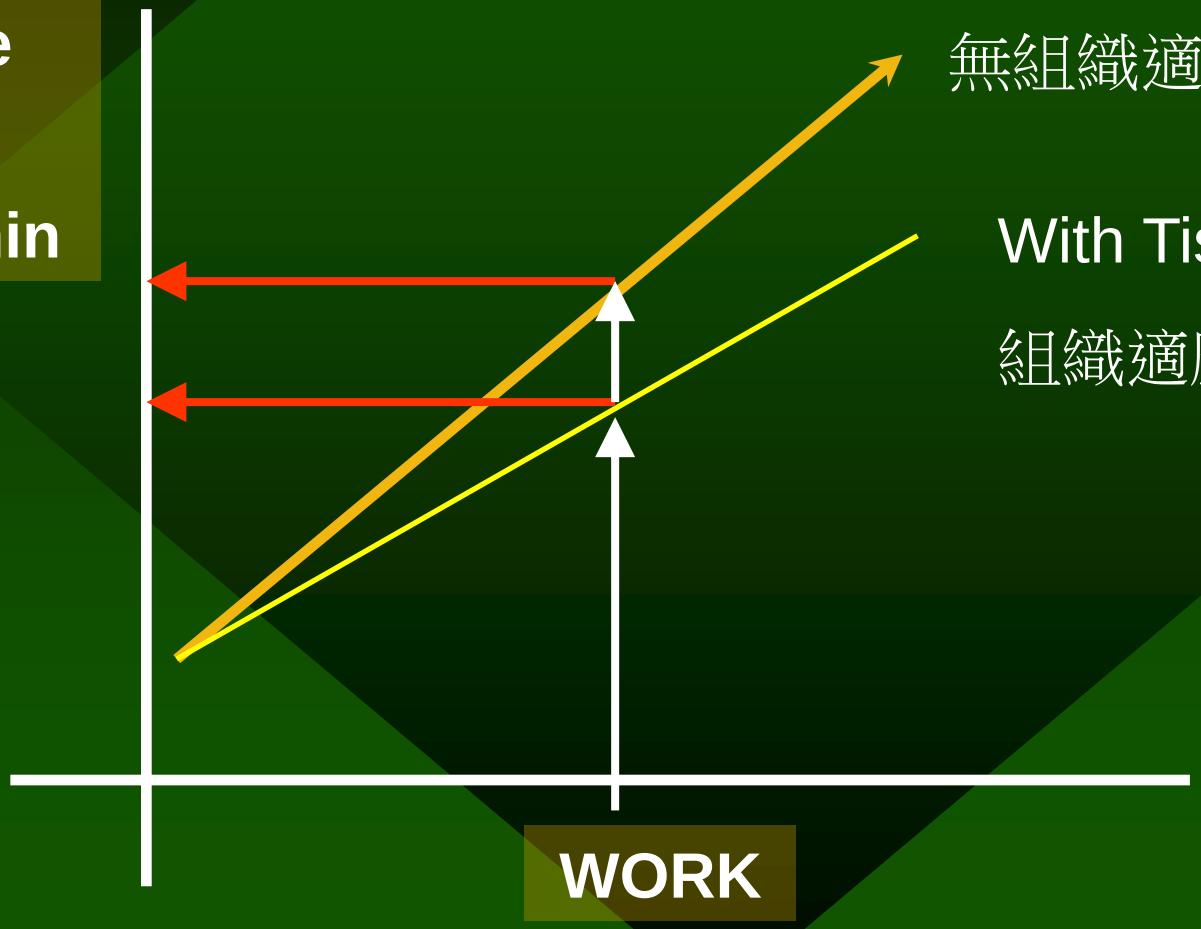
1. Climbers with highest Hb or ventilation do not always do best.
   具有最佳血紅素濃度或通氣量之登山者未必總是最好的
2. Sherpas have lower Hb and ventilation than lowlanders but perform better at altitude.
   雪巴人較一般居住低海拔人士具有較低之血紅素或通氣量，卻能在高地展現較佳運動能力
3. No increase in VO_2 max with acclimatization though oxygen delivery increasing.
   儘管高地適應可增加氧傳送能力，但結果並未造成最大攝氧量增加

Tissue acclimatization ?
組織適應？

Is there more efficient O_2 utilization ?
是否有較高之氧使用效應？

So use less O_2 used for same work done?
較少耗氧是否能完成相同作功量？

Oxygen Economy - ΔVO_2:ΔWR
氧經濟性－耗氧量：作功量



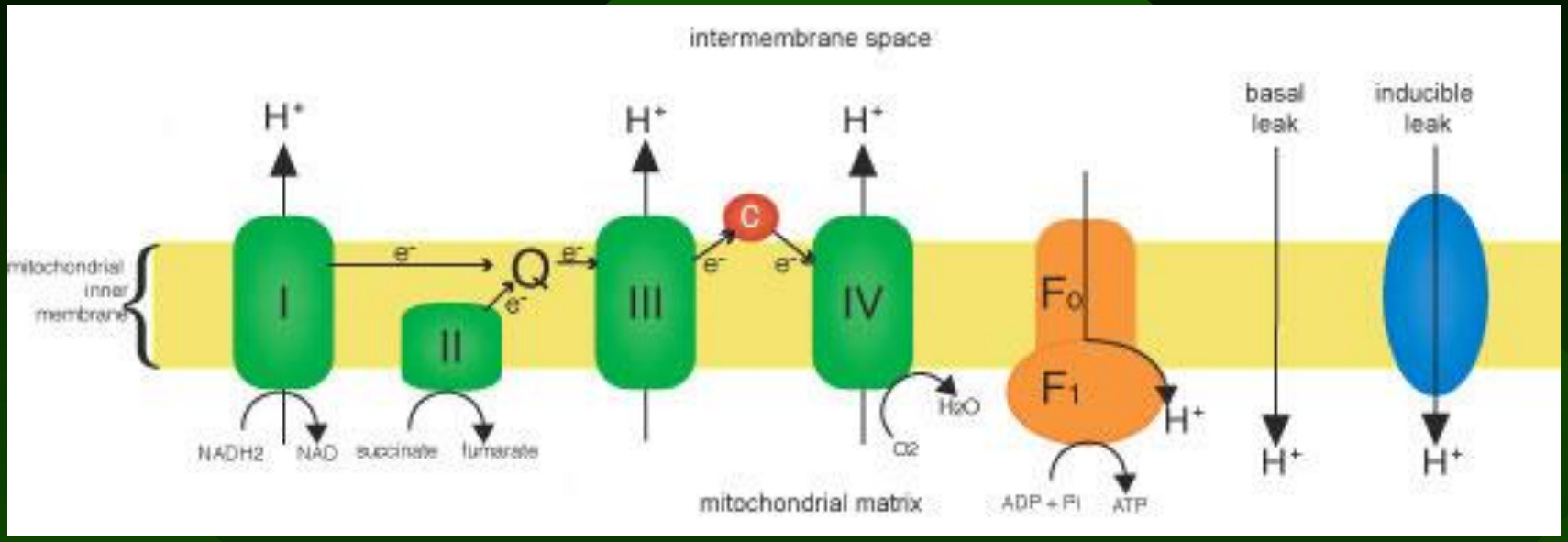
Hypothesis假說

Changes in the efficiency of oxygen utilisation may contribute to differences in performance in hypoxia

在缺氧環境中改變氧使用效率有助於體能提昇

•Slide courtesy of Dr Denny Levertt

Uncoupling Proteins未結合蛋白



- Efficiency regulation效應調節
- Metabolic signalling代謝訊號
- Thermogenesis溫度調節

•Slide courtesy of Dr Denny Levertt