IGU Commission for Water Sustainability - International research-to-practice conference:
WATER SUSTAINABILITY IN THE XXI CENTURY: CHALLENGES AND SOLUTIONS
15-21 Aug. 2017 Istomino (Lake Baikal), Russian Federation

CLIMATIC **CONTROLS ON WATER QUALITY AND HEALTH:**
a case study on natural uranium pollution in the southern Kalahari Desert

92
U
238.03

Frank Winde

NORTH-WEST UNIVERSITY
YUNIBESITI YA BOKONE-BOPHIRIMA
NOORDWES-UNIVERSITEIT

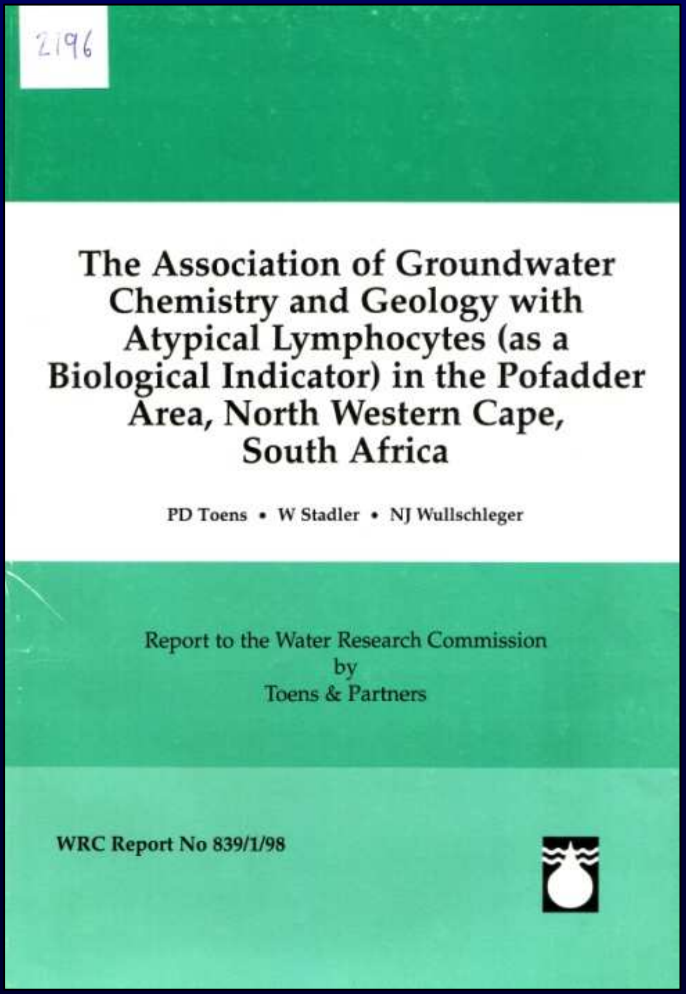
Contents

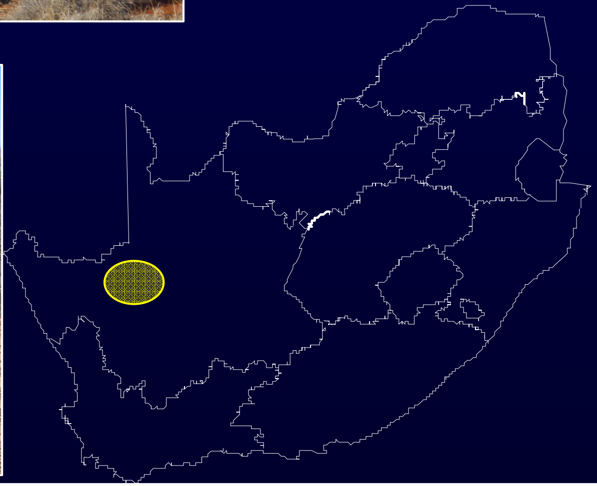
(1)
Background

Motivation for original study

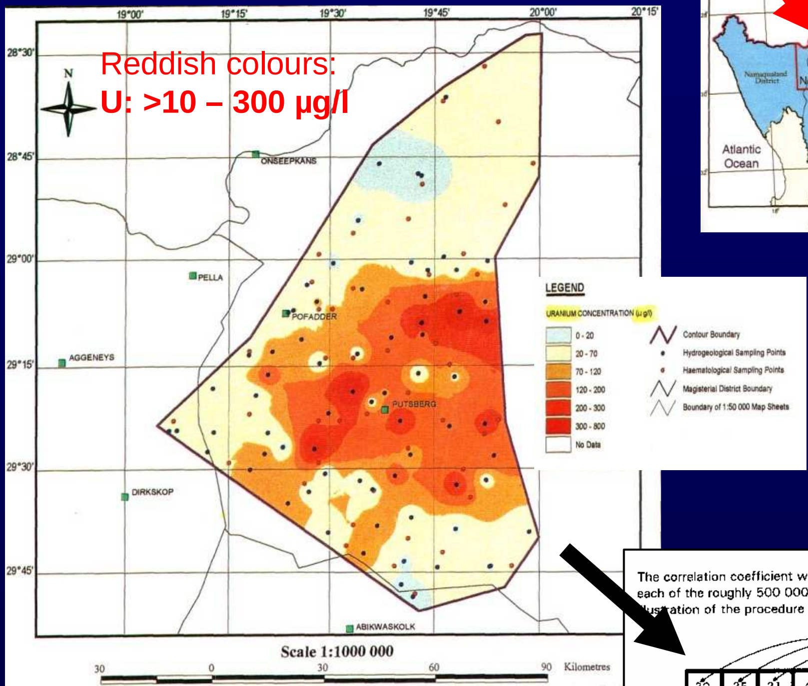
Dr de Villiers (Stellenbosch Univ.): high number of leukaemia patients come from this area

- blood samples of **418 people** from **120 localities** (>16 a of age, 1993)
- water quality: **126 boreholes**, AEC data (early 1980s)

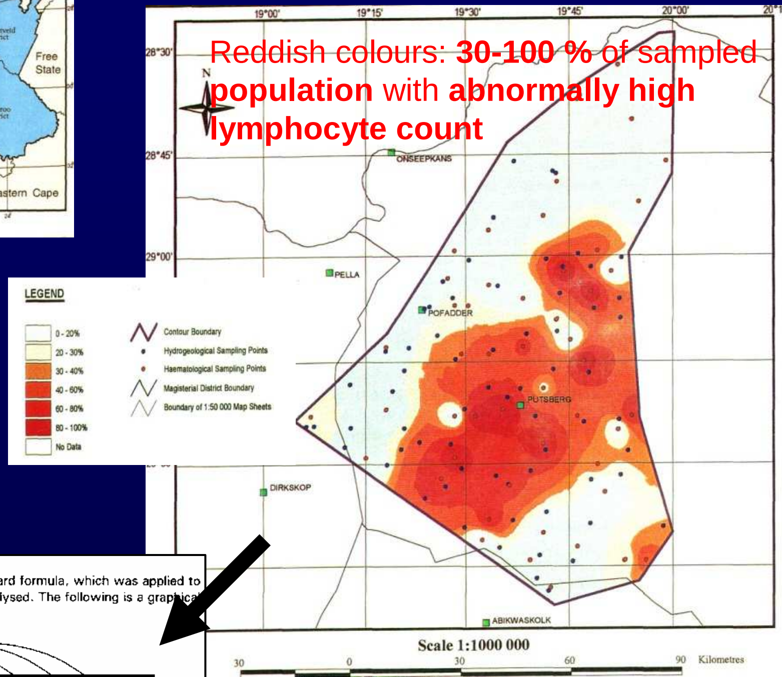


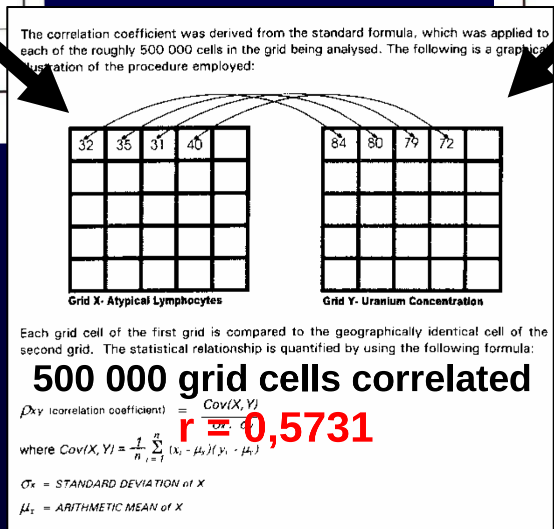


U-levels
(126 boreholes)



abnormal Lymphocyte count
(418 residents from 120 localities)




The correlation coefficient was derived from the standard formula, which was applied to each of the roughly 500 000 cells in the grid being analysed. The following is a graphical illustration of the procedure employed:

Each grid cell of the first grid is compared to the geographically identical cell of the second grid. The statistical relationship is quantified by using the following formula:

500 000 grid cells correlated

ρ_{XY} (correlation coefficient) $= \frac{Cov(X,Y)}{\sigma_X \cdot \sigma_Y}$

r = 0,5731

where $Cov(X,Y) = \frac{1}{n}\sum_{i=1}^{n}(x_i - \mu_x)(y_i - \mu_y)$

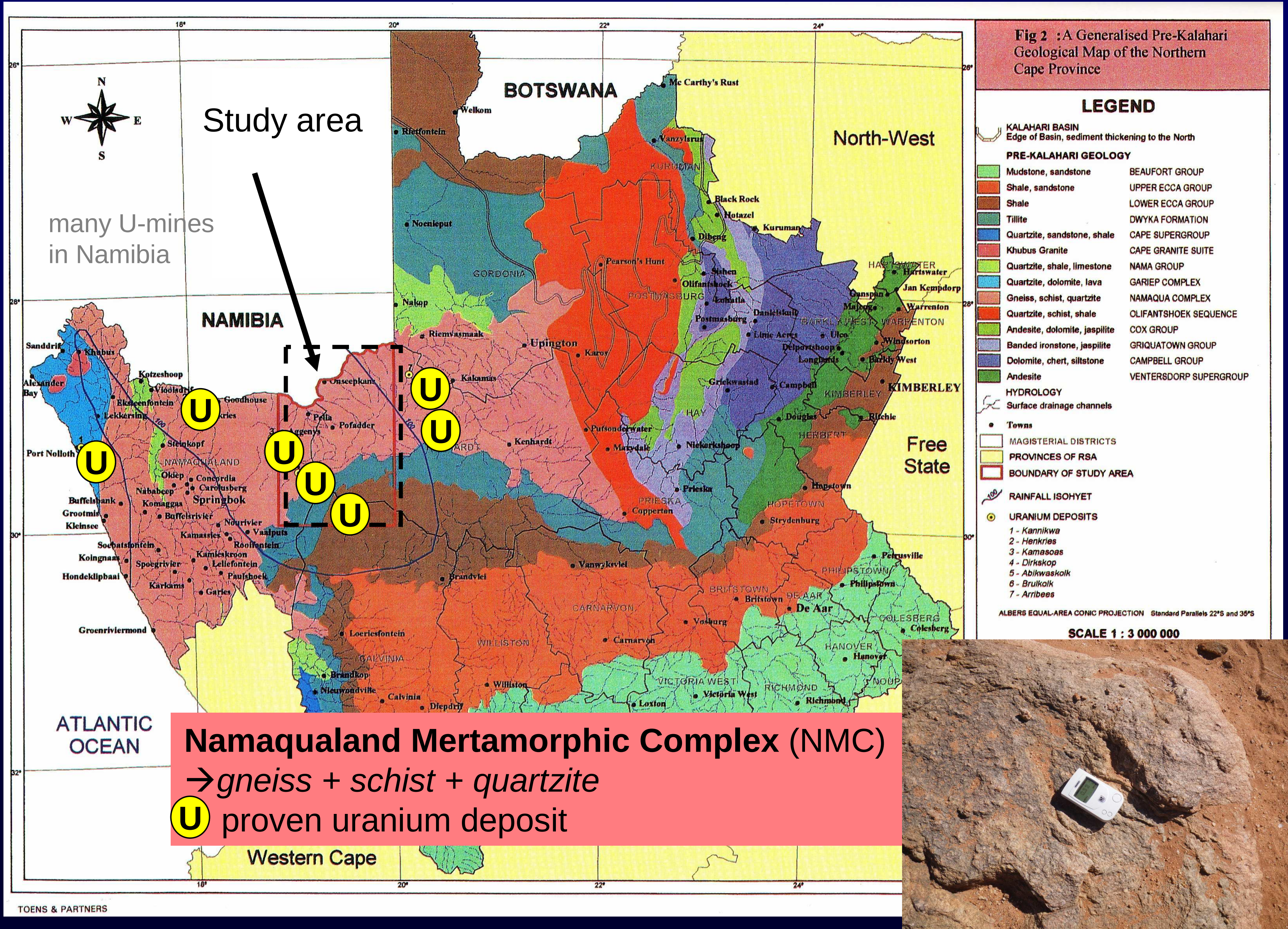
σ_x = STANDARD DEVIATION of X

μ_x = ARITHMETIC MEAN of X

→ 3 x follow-up studies confirmed high U-levels and domestic use of water

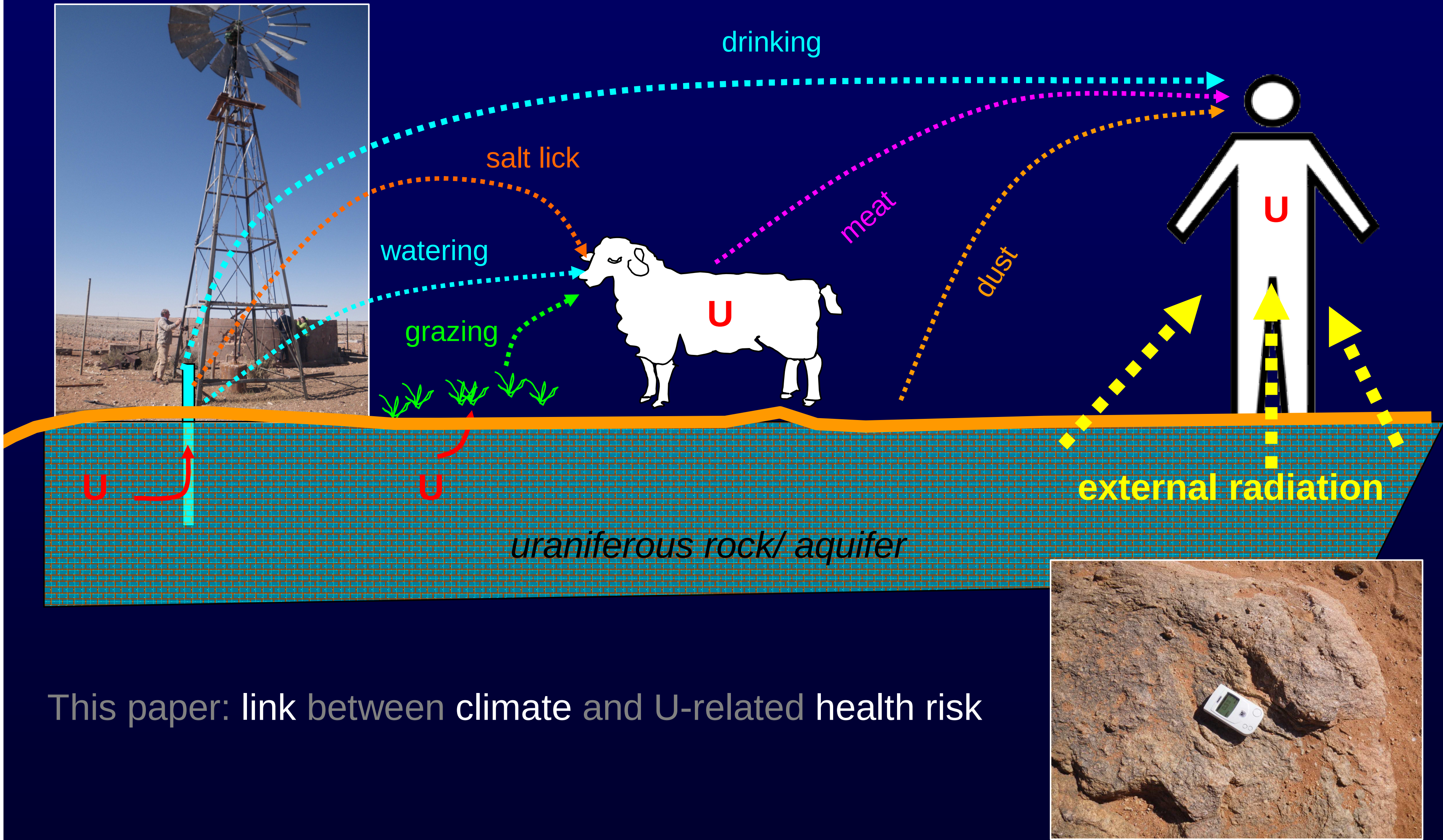
U: radioactive and chemotoxic

not analysed: food chain dust, agro-chemicals etc.



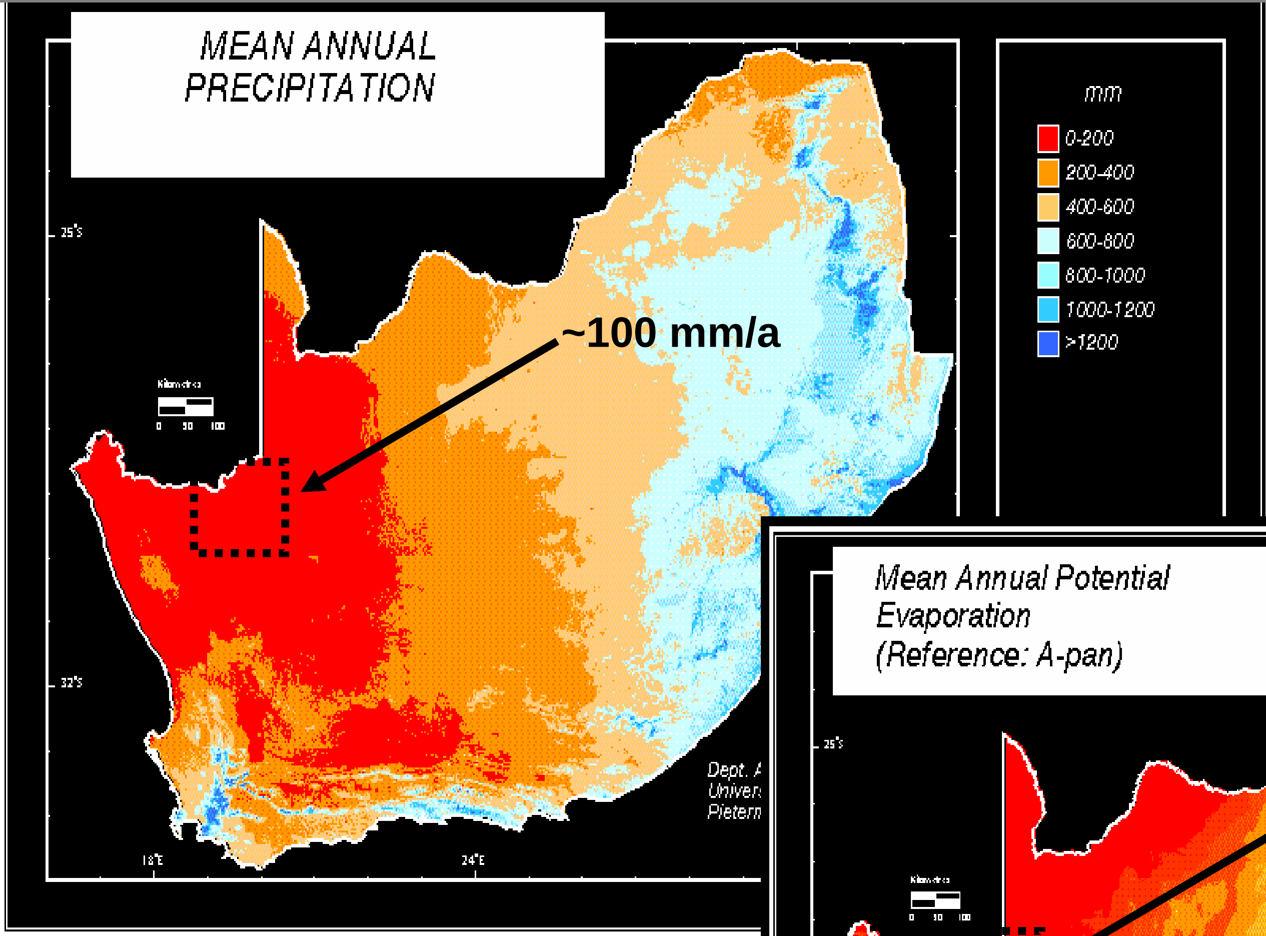
Namaqualand Mertamorphic Complex (NMC)
→*gneiss + schist + quartzite*
U proven uranium deposit

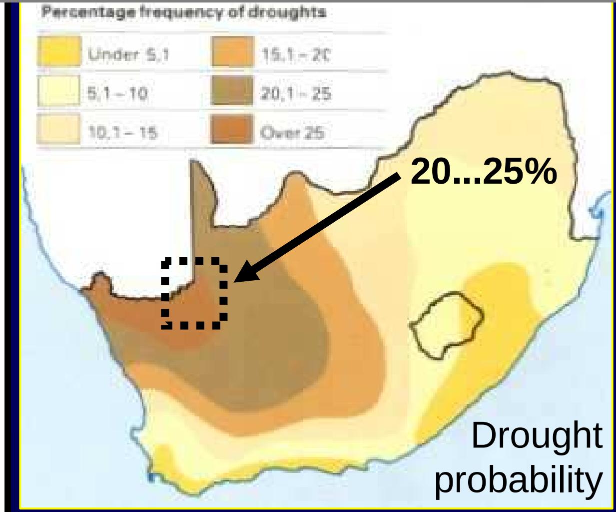
Closing gaps: quantify U-transfer via meat consumption, dust inhalation and external radiation

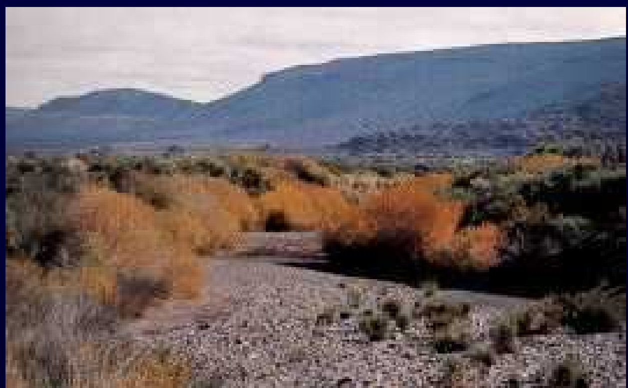


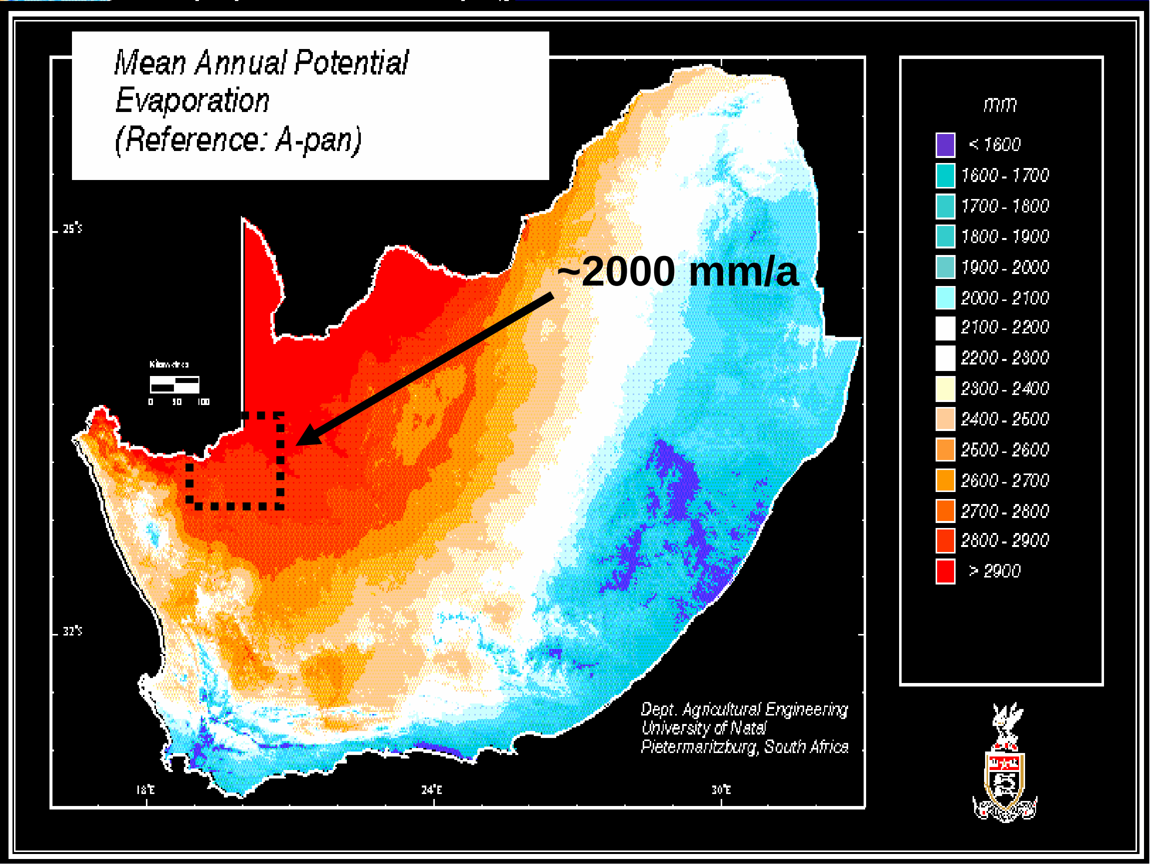
This paper: link between climate and U-related health risk

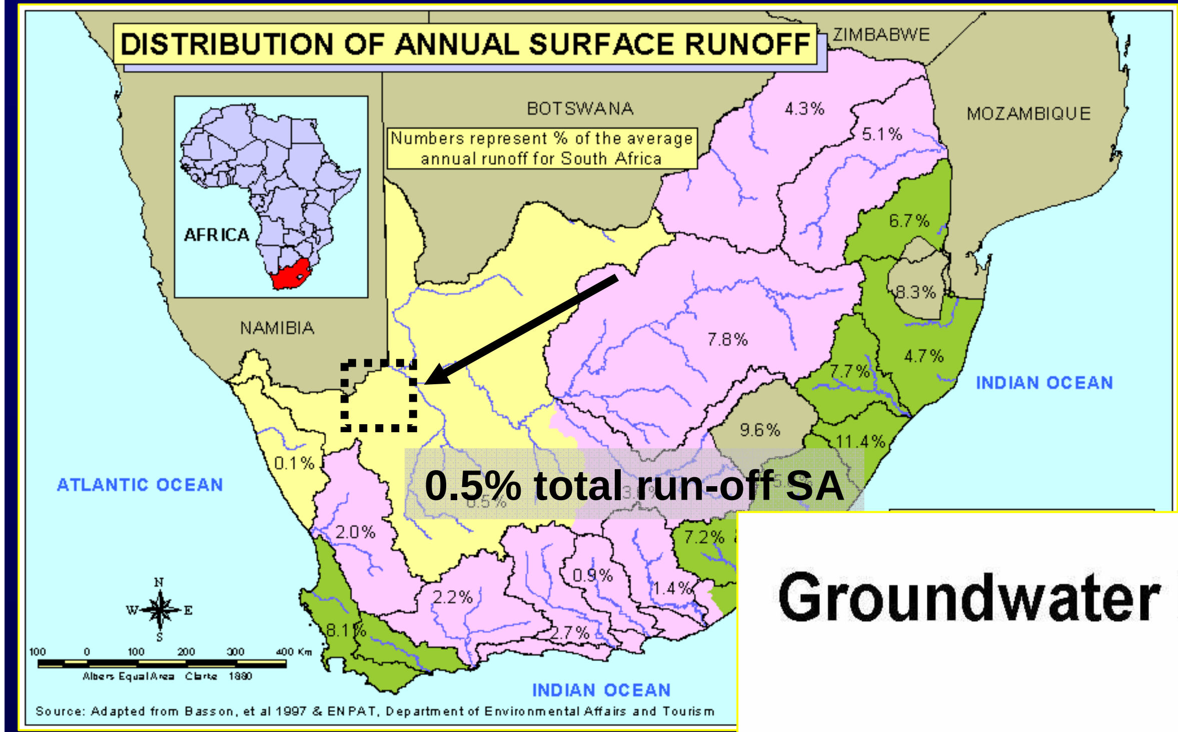
(2)
Climate and water quality

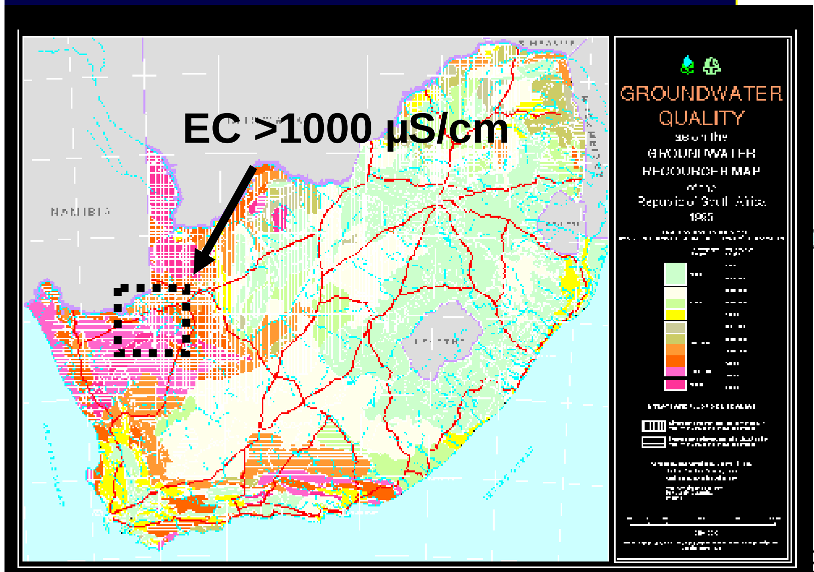

MEAN ANNUAL
PRECIPITATION
mm
0-200
200-400
400-600
600-800
800-1000
1000-1200
>1200
~100 mm/a
25°S
32°S
18°E
24°E

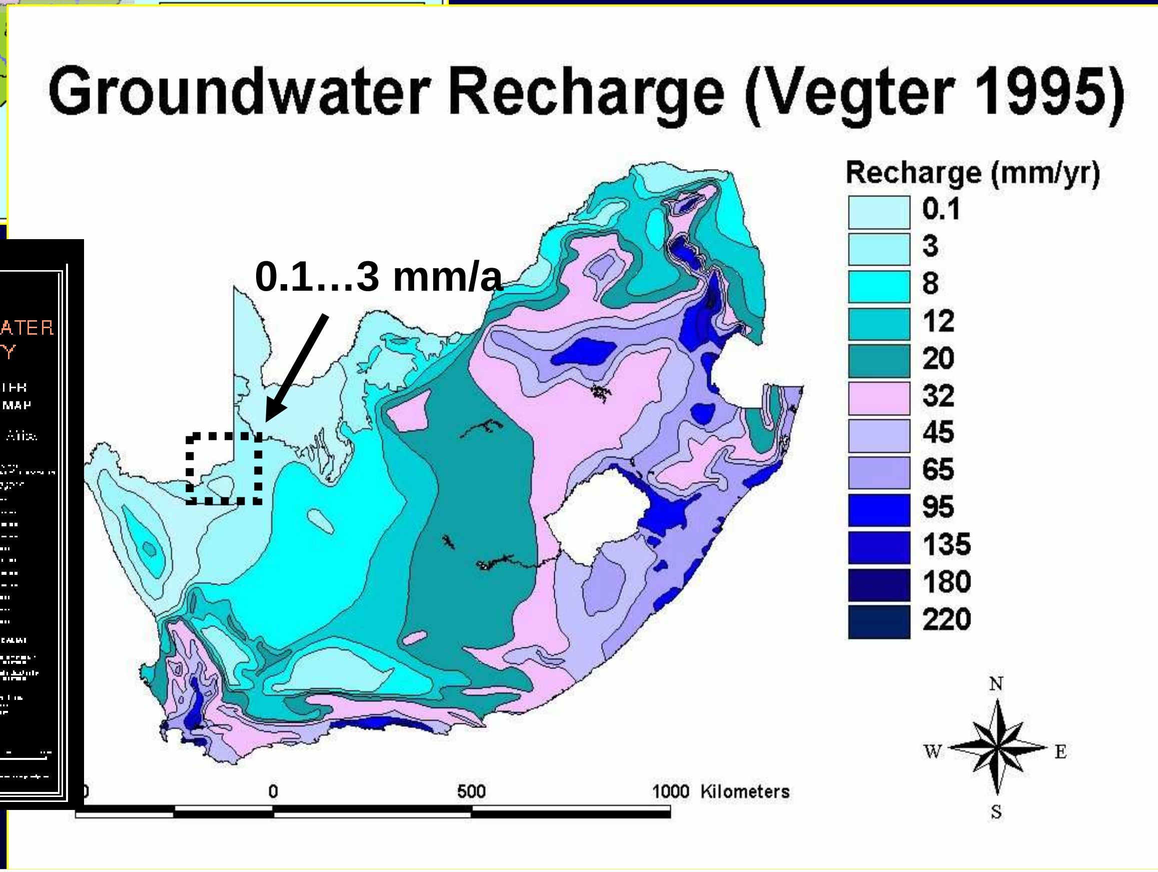

Percentage frequency of droughts
Under 5,1
5,1 – 10
10,1 – 15
15,1 – 20
20,1 – 25
Over 25
20...25%
Drought
probability

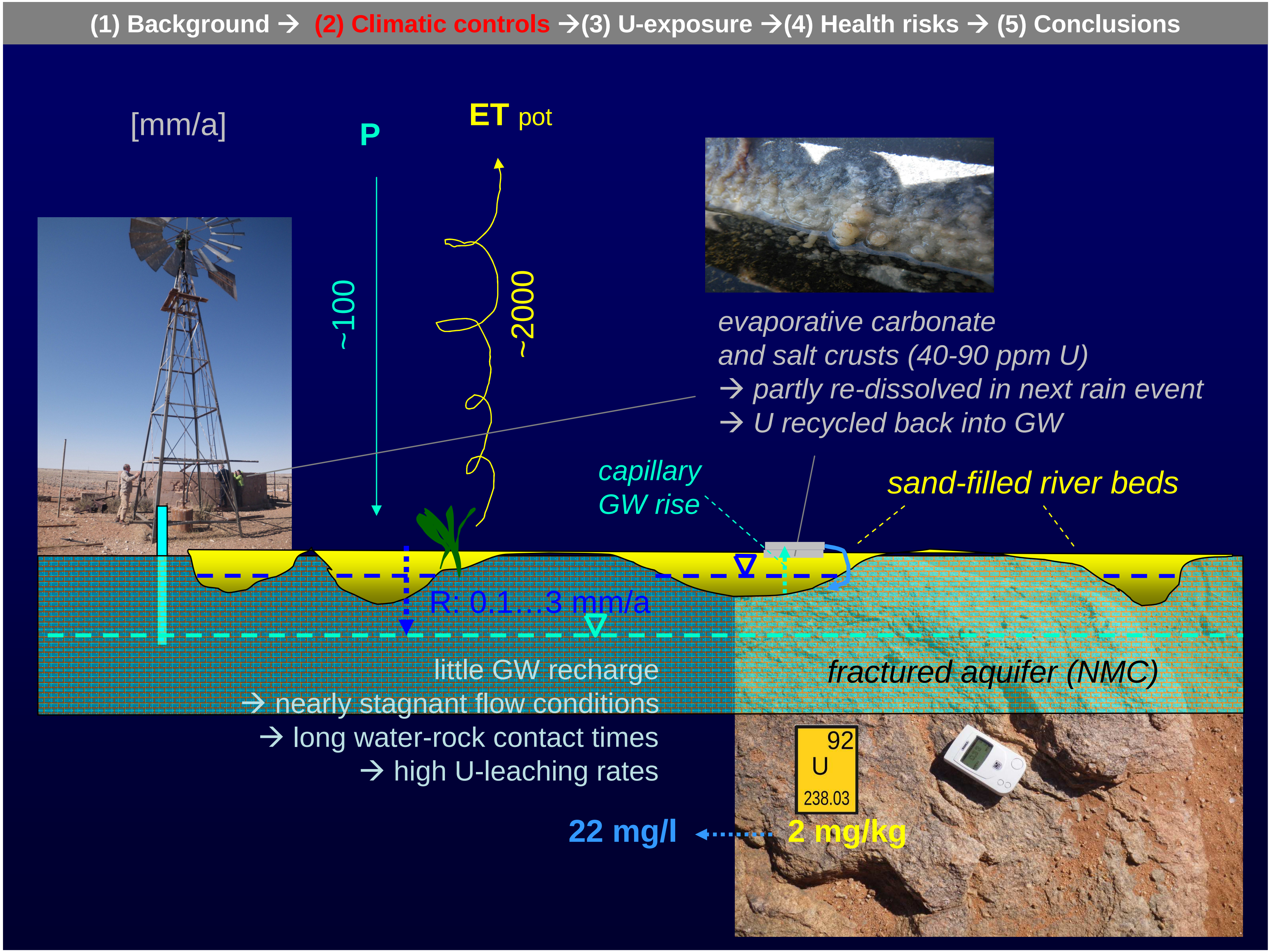



Mean Annual Potential
Evaporation
(Reference: A-pan)
mm
< 1600
1600 - 1700
1700 - 1800
1800 - 1900
1900 - 2000
2000 - 2100
2100 - 2200
2200 - 2300
2300 - 2400
2400 - 2500
2500 - 2600
2600 - 2700
2700 - 2800
2800 - 2900
> 2900
~2000 mm/a
Dept. Agricultural Engineering
University of Natal
Pietermaritzburg, South Africa
25°S
32°S
18°E
24°E
30°E

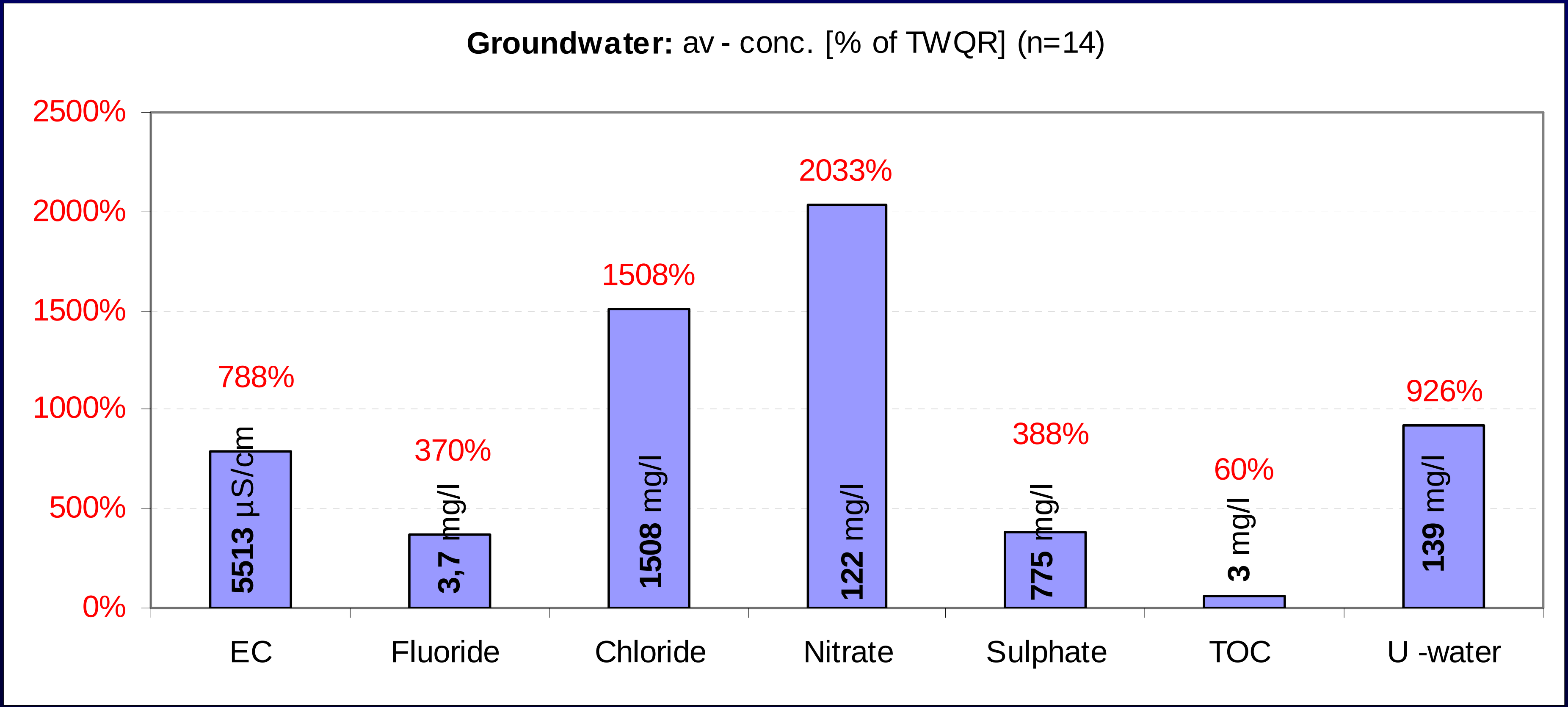

DISTRIBUTION OF ANNUAL SURFACE RUNOFF
Numbers represent % of the average annual runoff for South Africa
ZIMBABWE
BOTSWANA
MOZAMBIQUE
NAMIBIA
AFRICA
ATLANTIC OCEAN
INDIAN OCEAN
INDIAN OCEAN
4.3%
5.1%
6.7%
8.3%
7.8%
4.7%
7.7%
9.6%
11.4%
0.1%
2.0%
7.2%
0.9%
1.4%
2.2%
8.1%
2.7%
0.5% total run-off SA
Albers Equal Area Clarke 1880
Source: Adapted from Basson, et al 1997 & ENPAT, Department of Environmental Affairs and Tourism

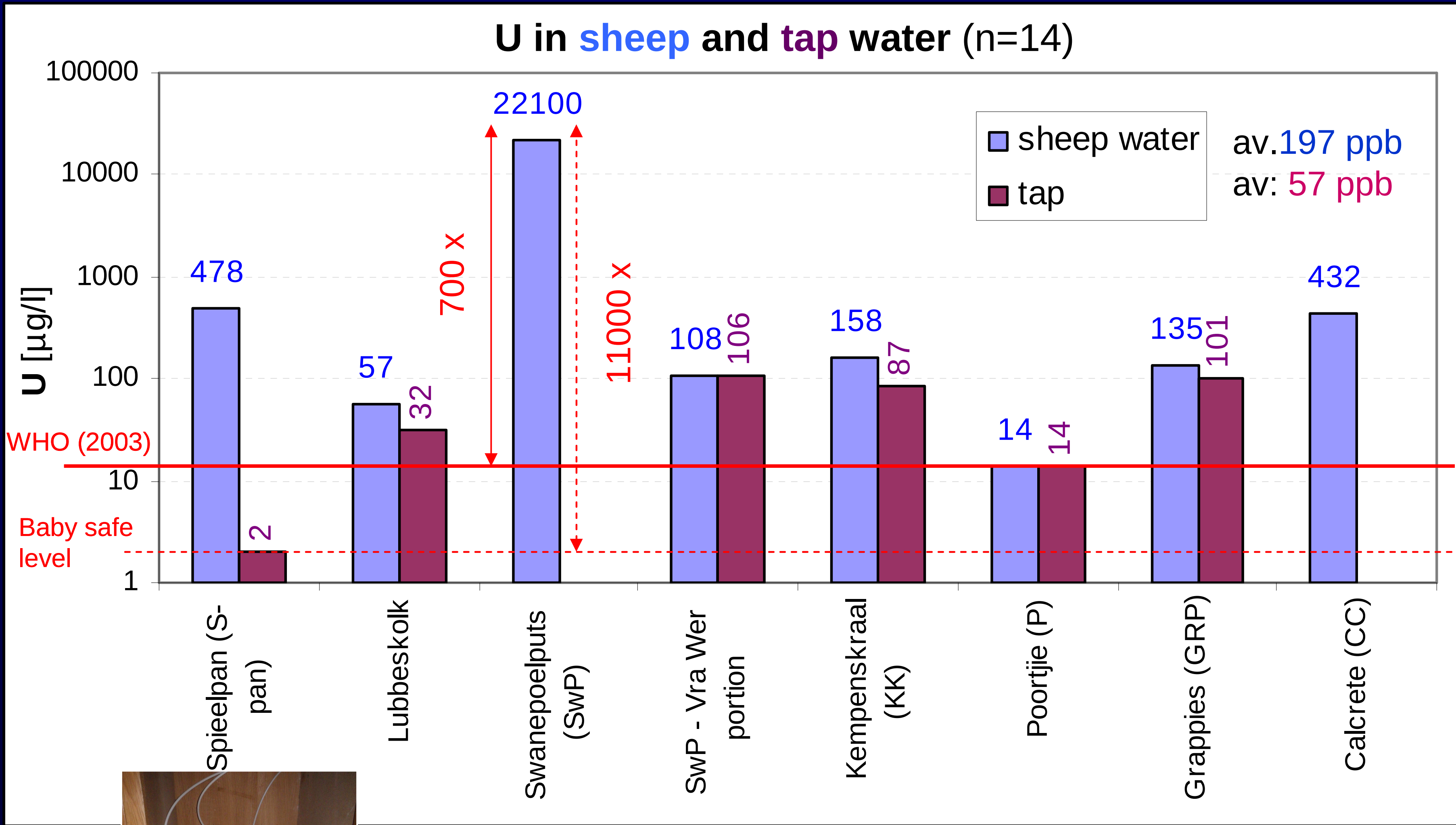

EC >1000 µS/cm
GROUNDWATER QUALITY
NAMIBIA


Groundwater Recharge (Vegter 1995)
0.1…3 mm/a
Recharge (mm/yr)
0.1
3
8
12
20
32
45
65
95
135
180
220
0
500
1000 Kilometers
N
W
E
S

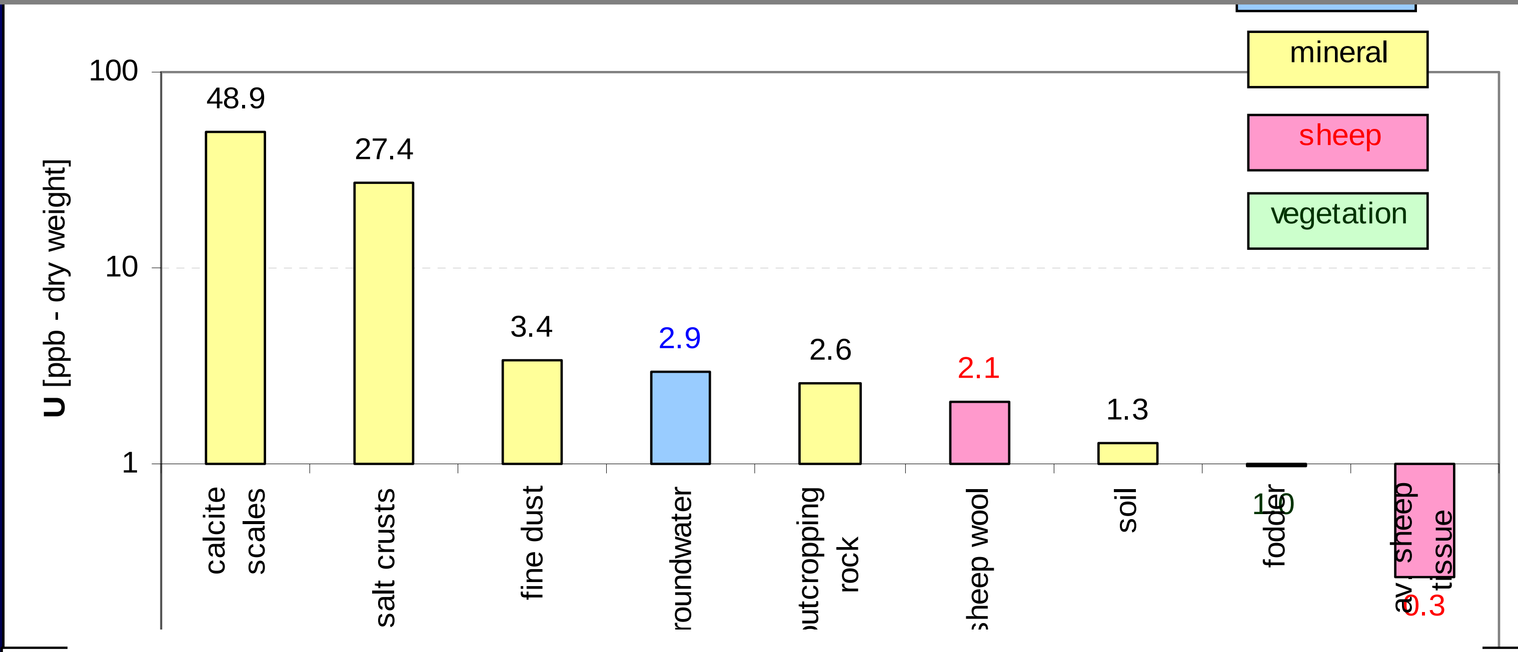

(1) Background → (2) Climatic controls →(3) U-exposure →(4) Health risks → (5) Conclusions
[mm/a]
P
ET pot
~100
~2000
evaporative carbonate
and salt crusts (40-90 ppm U)
→ partly re-dissolved in next rain event
→ U recycled back into GW
capillary
GW rise
sand-filled river beds
R: 0.1…3 mm/a
little GW recharge
→ nearly stagnant flow conditions
→ long water-rock contact times
→ high U-leaching rates
fractured aquifer (NMC)
92
U
238.03
22 mg/l
2 mg/kg

Average exceedance of DWA domestic target water quality limits

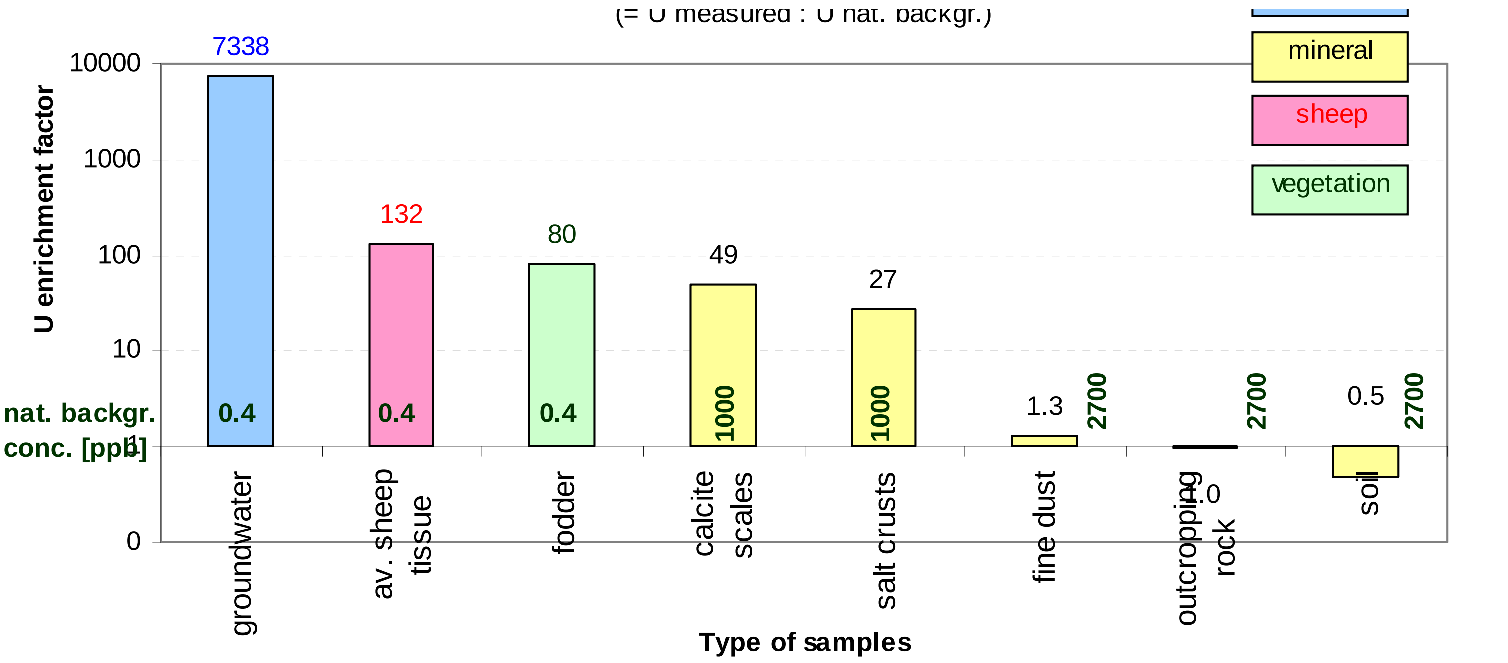




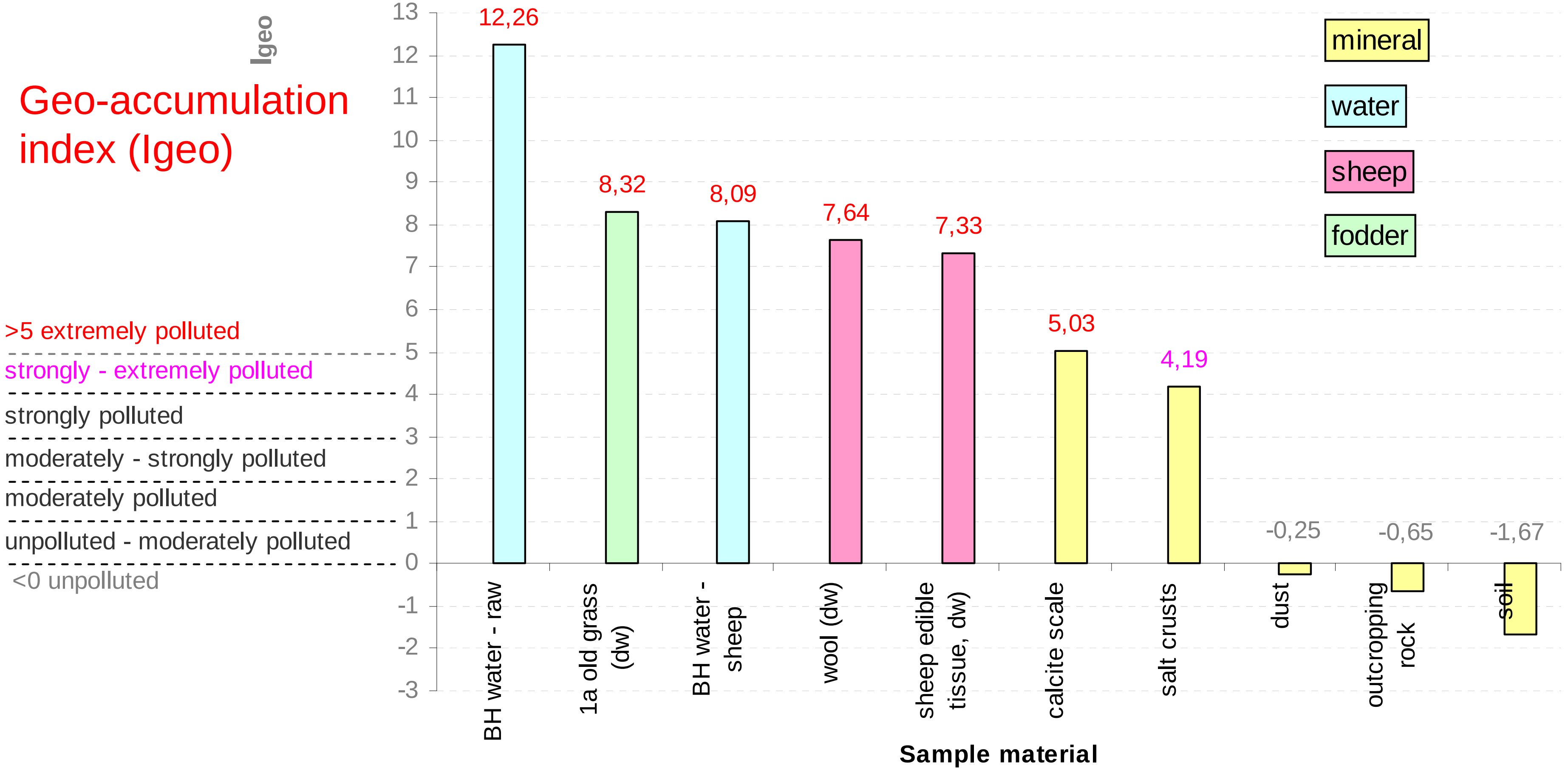
- 7 of 8 GW-samples well above new WHO limit (4…1500 times)
- all GW samples above „baby-safe" U-level (7…11.000 times)
- 'sheep water' partly also consumed by labourers
- commercial tap water filters remove U effectively (99,6%)



U enrichment: GW > sheep > fodder > precipitates > rock



Geo-accumulation index (Igeo)

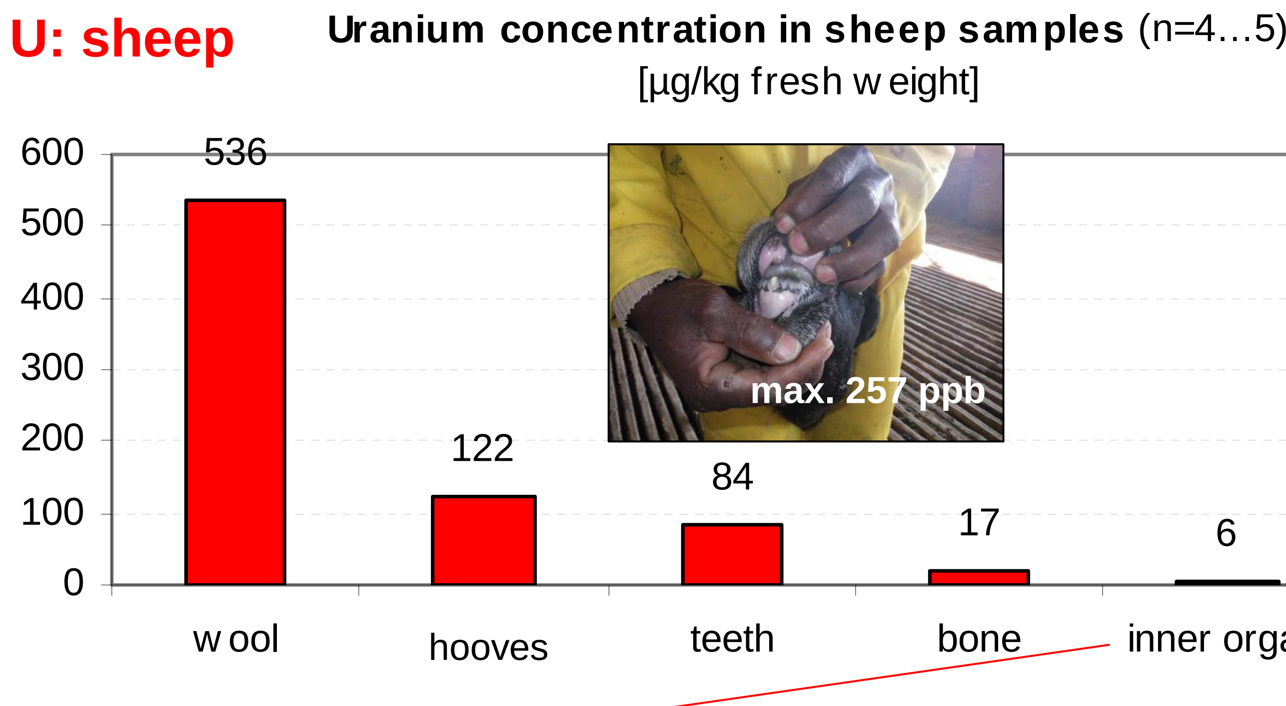


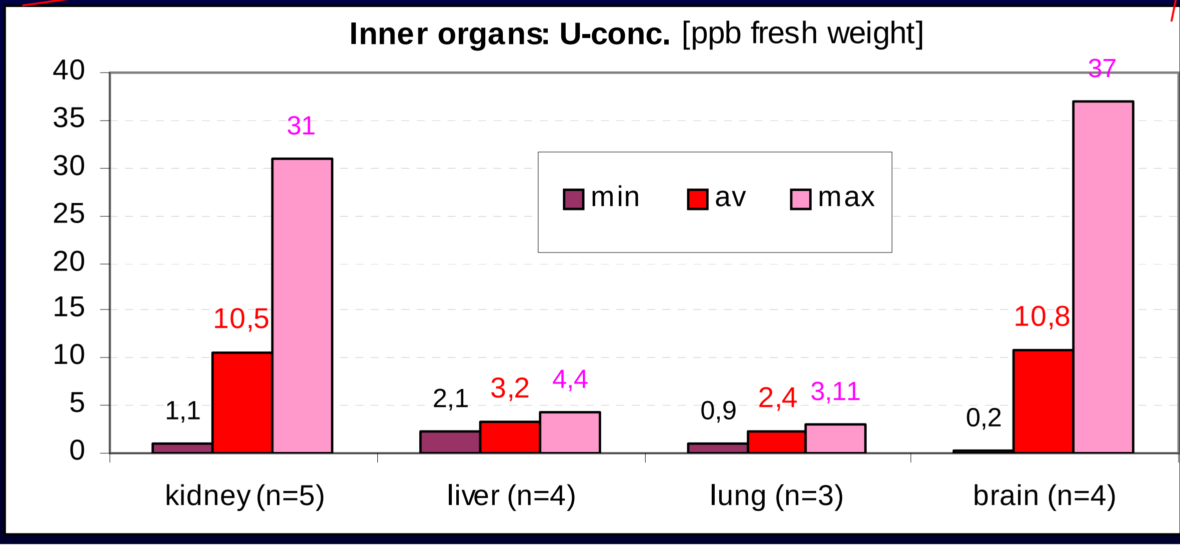
binary logarithm

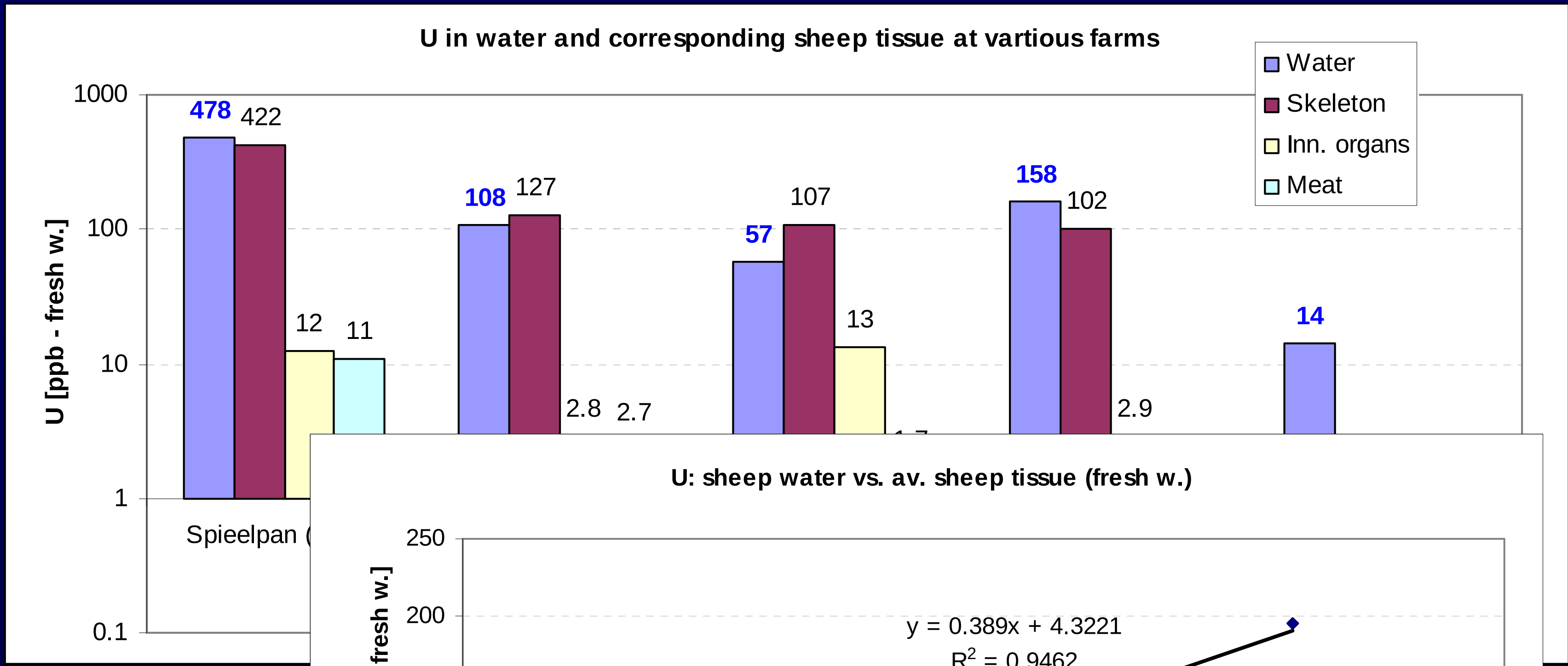
Igeo = log 2 (conc. sample/1.5 background conc.)

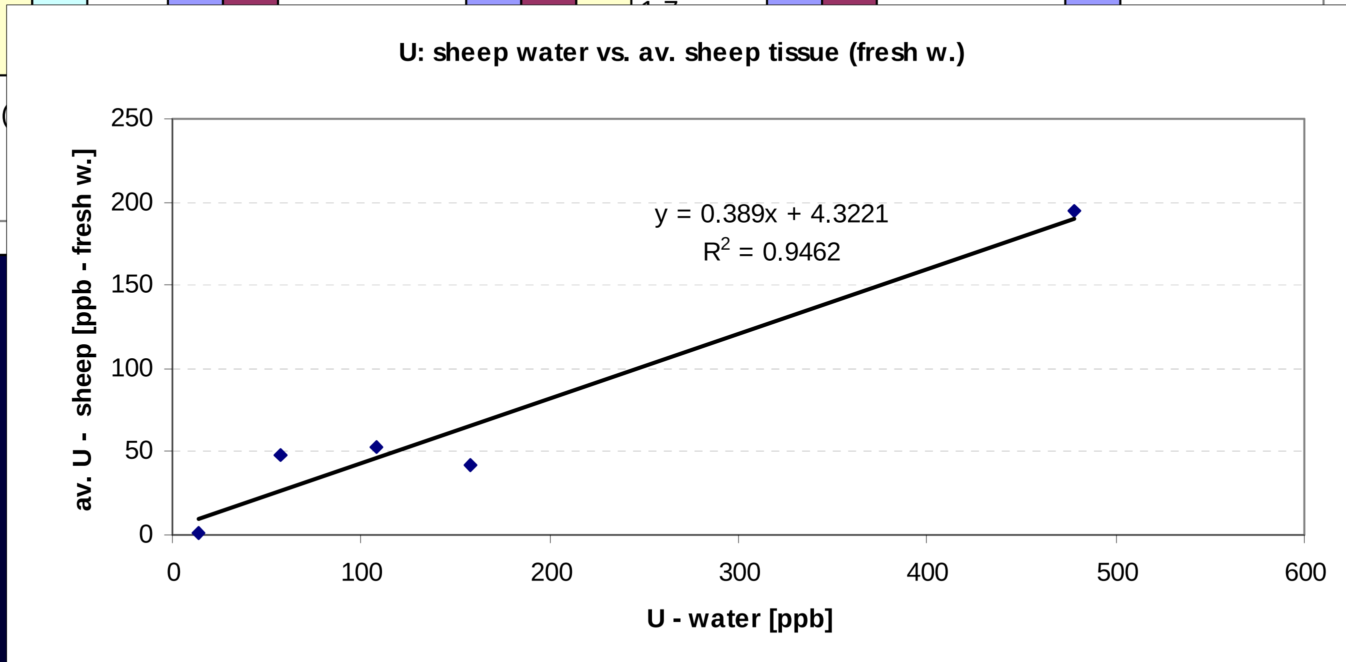
(3)
U-transfer and exposure

U: sheep

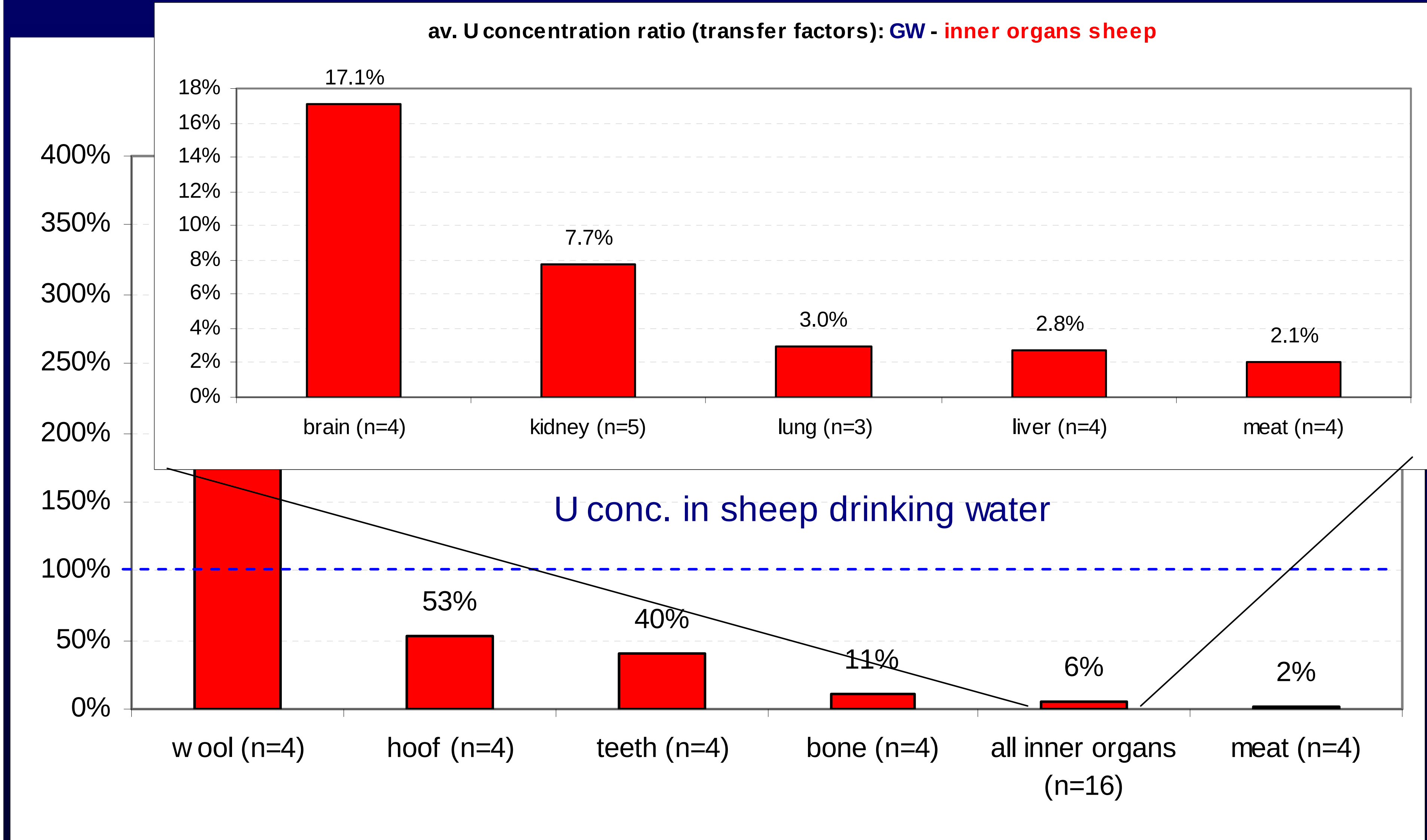

Uranium concentration in sheep samples (n=4…5)
[µg/kg fresh weight]
600
500
400
300
200
100
0
536
122
84
17
6
4
max. 257 ppb
wool
hooves
teeth
bone
inner organs
meat


Inner organs: U-conc. [ppb fresh weight]
40
35
30
25
20
15
10
5
0
min
av
max
1,1
10,5
31
2,1
3,2
4,4
0,9
2,4
3,11
0,2
10,8
37
kidney (n=5)
liver (n=4)
lung (n=3)
brain (n=4)

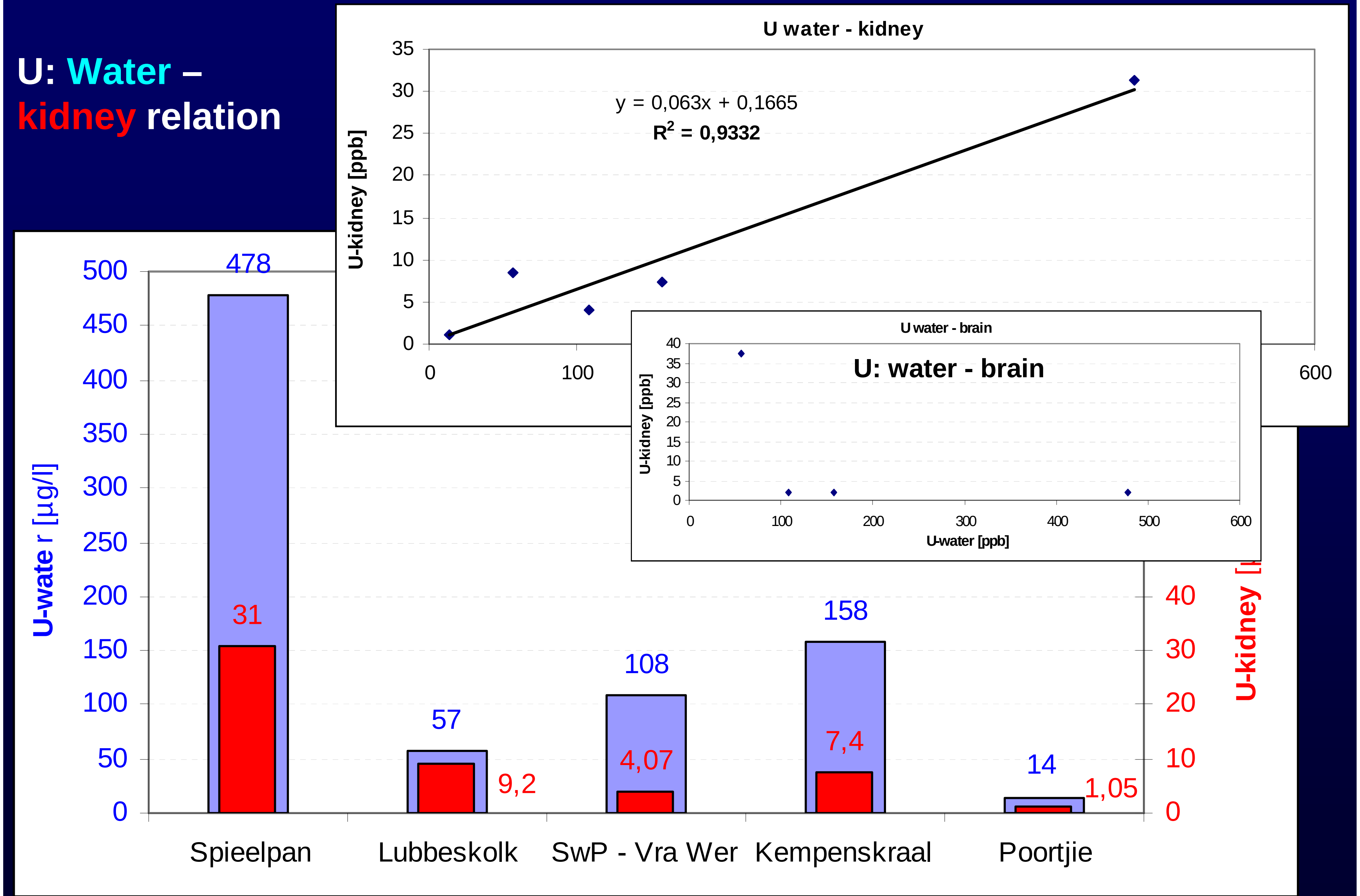


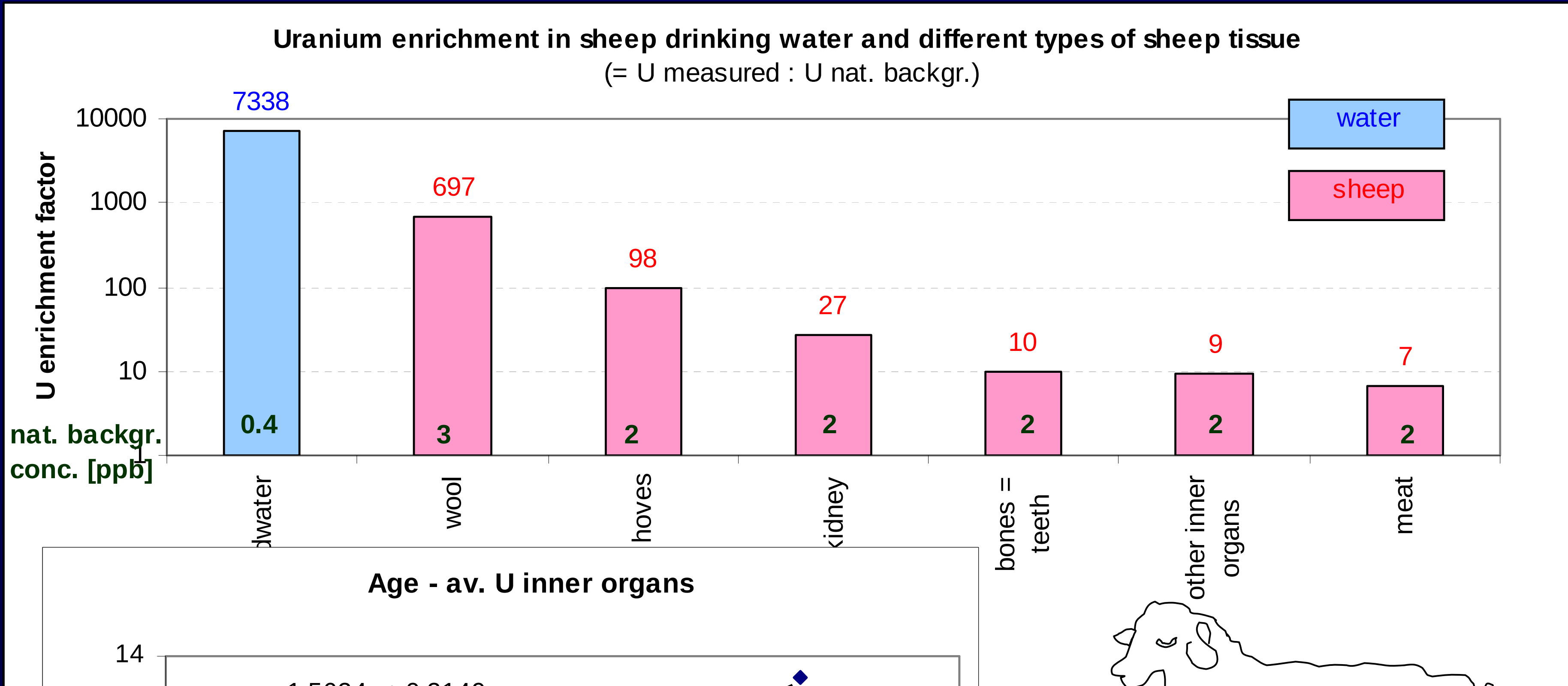


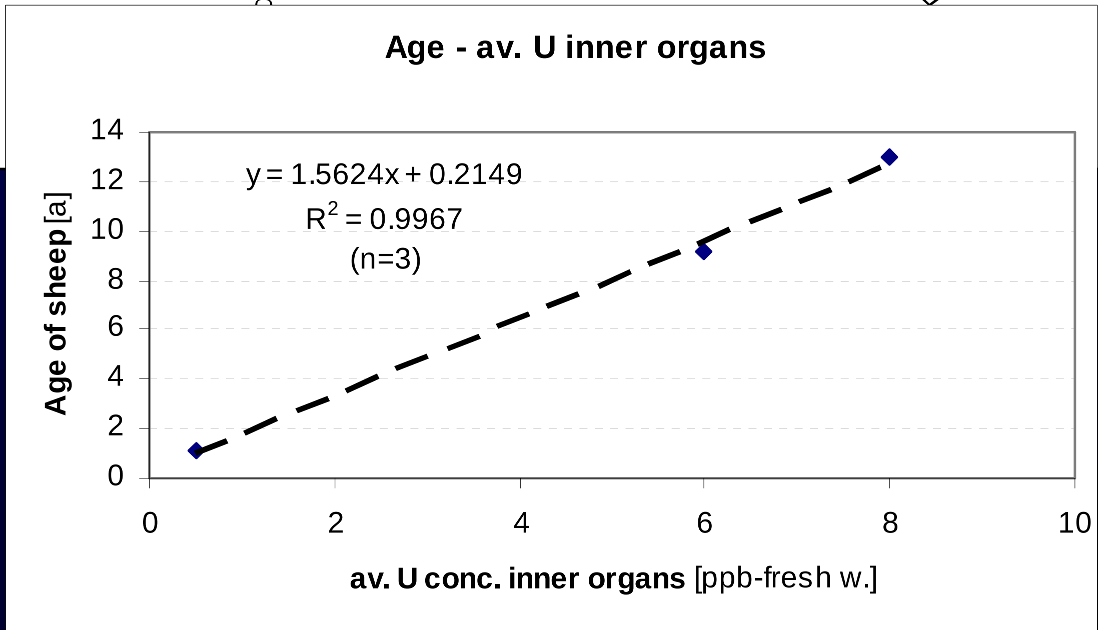
→ suggests that polluted water is main pathway (exaccerbated by fodder and salt crusts indirectly reflecting water quality)

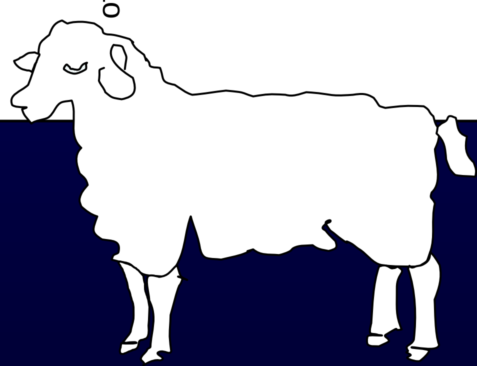

av. U concentration ratio (transfer factors): GW - inner organs sheep
18%
16%
14%
12%
10%
8%
6%
4%
2%
0%
17.1%
7.7%
3.0%
2.8%
2.1%
brain (n=4)
kidney (n=5)
lung (n=3)
liver (n=4)
meat (n=4)
400%
350%
300%
250%
200%
150%
100%
50%
0%
U conc. in sheep drinking water
53%
40%
11%
6%
2%
wool (n=4)
hoof (n=4)
teeth (n=4)
bone (n=4)
all inner organs (n=16)
meat (n=4)

U: Water – kidney relation





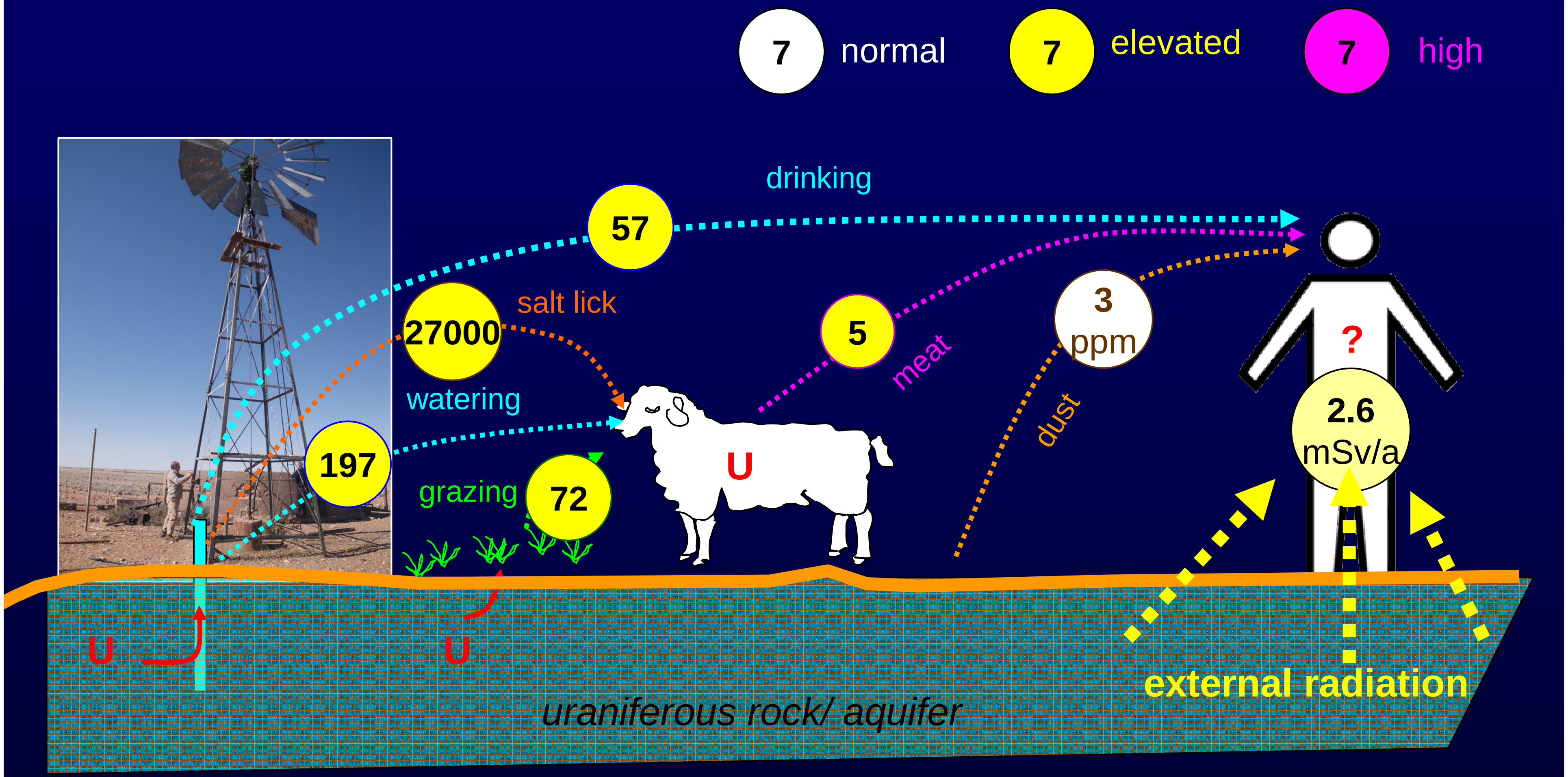


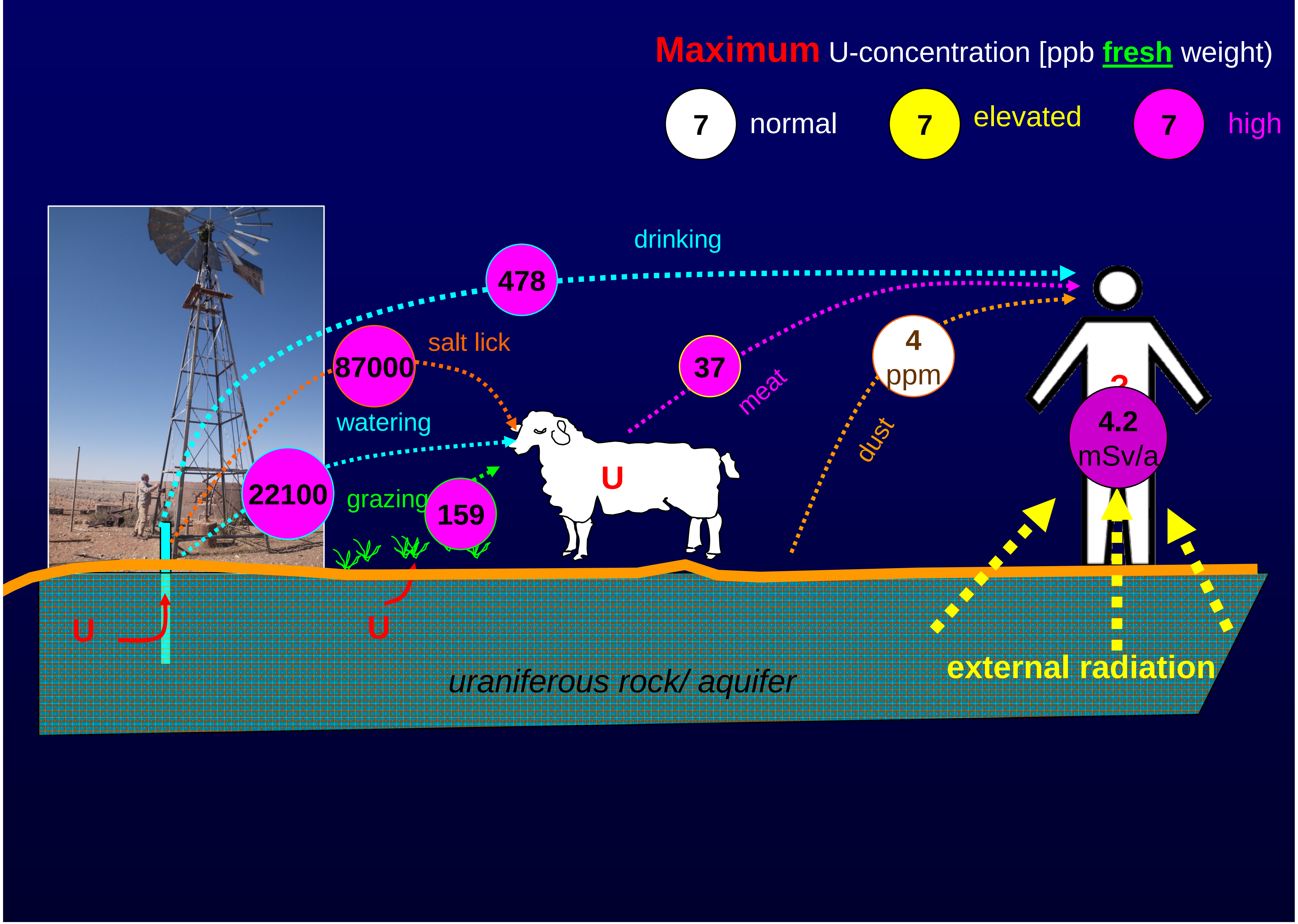


Lamb meat as main market product less affected

(4)
Health risks

Average U-concentration [µg/l **fresh** weight)




Maximum U-concentration [ppb fresh weight)
7 normal
7 elevated
7 high
drinking
478
salt lick
87000
watering
22100
grazing
159
37
meat
4 ppm
dust
U
4.2 mSv/a
U
U
uraniferous rock/ aquifer
external radiation

Risk assessment: External radiation

Range (gamma radiation): **1,2 … 4,2** mSv/a
control site: **1.4** mSv/a
ICRP limit anthropogenic sources: **1,0** mSv/a

→ maximum measured directly on gneiss outcrop
- most sites 1.2…1.4, max. in-house: 2.2 mSv/a
→ generally of lesser concern

Radiation measuring device (Radex)

Dust storm in the study area

Dust inhalation

U in soil + dust close to natural background
→ dust generally 2-3 times higher U-levels than soils
→ associated U-inhalation unlikely to be of concern as U-levels are not higher than background
→ generally of no concern

Risk assessment: Meat consumption

Radiotoxic U-risk (ICRP limit): max. (brain): 37 ppb (WISE calculator)

Uranium Radiation Age-specific Dose Calculator
http://www.wise-uranium.org/rdcua.html
ICRP 72
max. U-conc. Inner organs : **37** µg/kg fresh wt. (brain)

Age	meat consumpti	Dose rate **	[% IAEA limit]***
3 months		)21	2,1%
1 year		)07	0,7%
5 years		)04	0,4%
10 years		)03	0,3%
15 years		)03	0,3%
Adult		)01	0,1%

0,1…2 %
of annual dose limit
→ **no risk**

* StrlSchV 2001 (Germany)
*** 1 mSv/a
** calculated by Uranium Radiation Age-specific Dose Calculator (WISE 2013)

Chemotoxic U-risk (WHO-TDI)

max (brain): **37** ppb | **av.** organs:**6** ppb | **max.** meat:**18** ppb | **av.** meat:**4** ppb

Exposed humans Age	Corresponding body weight	Average meat consumption*	Associated U-ingestion sheep inner organs max U-conc. [µg/k **37**		av. U-conc. [µg/kg fr **5,9** [µ		sheep muscle meat max U-conc. [µ **18** µg/kg bw		av. U-conc. [µg **4,1**	
<1		0,(		34%			0,1			4%
1		0,(		23%			0,(			2%
2		0,1		34%			0,1			4%
7		0,2		32%			0,(			4%
12 - 17 a	50	0,274	0,20	34%	0,03	5%	0,10	16%	0,02	4%
>17 a	60	0,274	0,17	28%	0,03	4%	0,08	14%	0,02	3%

23…34 % of TDI-value → **no risk**

4…5 % of TDI-value → **no risk**

11…16 % of TDI-value → **no risk**

2…4 % of TDI-value → **no risk**

* based on annual consumption of meat for different age groups as given in NECSA (2007a)

Risk assessment: Drinking water

Radiologic U-risk (ICRP dose limit) – WISE calculator

max. GW: 22 100 ppb

max. U-conc. water : 22100 µg/l (U nat with progeny)

Age	[% IAEA limit]***
3 mon	1265%
1 year	391%
5 year	216%
10 year	159%
15 year	150%
Adult	70%

* StrlSchV 2001 (Ger

** calculated by Uranium Radiation Age-specific Dose Calculator (WISE 2013)

…13 times
of annual dose limit
→**high risk for babies + children**
→(water not used as drinking water)

max. tap water: 106 ppb

max. U-conc.tap water: 106 µg/l (U nat with progeny)

Age	water cons	Dose rate **	% IAEA limit]***
3 mon			6,7%
1 year			1,9%
5 years			1,0%
10 years			0,8%
15 years	200	0,007	0,7%
Adult	350	0,004	0,4%

* StrlSchV 2001 (Germany) *** 1 mSv/a

** calculated by Uranium Radiation Age-specific Dose Calculator (WISE 2013)

0.4…7 %
of annual dose limit
→ **no risk**

Chemotoxic U-risk (WHO-TDI)

max. GW: 22100 ppb | max. tap water: 106 ppb | av. tap water: 57 ppb

Exposed humans Age [a]	Corresponding body weight	Average water consumption*	Associated U-ingestion water [µg/kg bw x d] (max U gw [µg/l] 22100)	[µg/kg bw x d] (max U tap [µg/l] 106)	exc fac TDI (WHO) (0.6 µg U/kg bw x d) (av. U tap [µg/l] 57)
<1				10,60	
1 - 2 a				2,12	
2 - 7 a				1,27	
7 - 12 a				1,59	
12 - 17 a				4,24	
>17 a				3,53	

* based on annual consumption of meat for different age groups as given in NECSA (2007a)

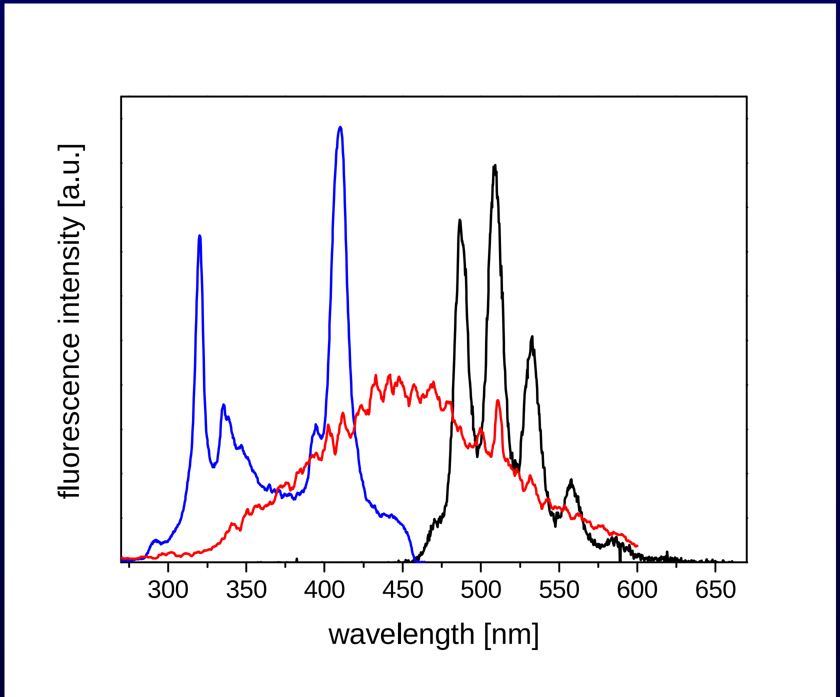
442…3700 times of TDI-value
→**extremely high risk**
for all ages

2…18
times of TDI-value
→**very high risk**
for all ages

1,1…9
times of TDI-value
→**high risk**
for <1a and >12a

U-speciation: $Ca_2UO_2(CO_3)_{3(aq)}$

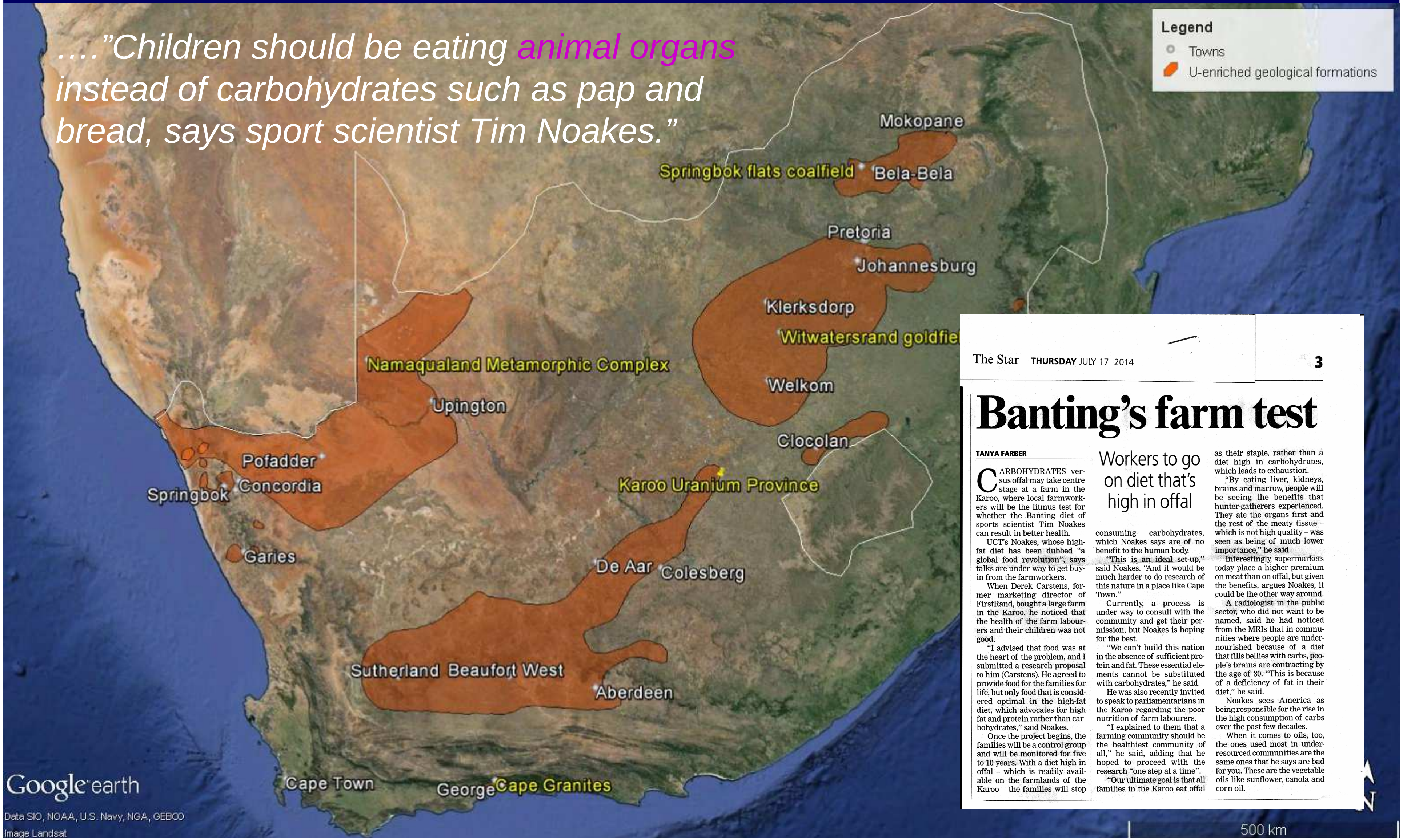
- Ca-uranyle-carbonate: highly soluble (i.e. bio-available) and mobile (neutral charge) but: compared to U-phosphates relatively low toxicity (lower body absorption rate)



Time-resolved Laser Fluorescence Spectroscopy (TRLFS)

HELMHOLTZ ZENTRUM DRESDEN ROSSENDORF

- potential health problems likely to be less obvious because of lack of central reporting point such as Stellenbosch for Bushmanland → pilot study recommended



The Star THURSDAY JULY 17 2014 3

Banting's farm test

TANYA FARBER

Workers to go on diet that's high in offal

CARBOHYDRATES versus offal may take centre stage at a farm in the Karoo, where local farmworkers will be the litmus test for whether the Banting diet of sports scientist Tim Noakes can result in better health.

UCT's Noakes, whose high-fat diet has been dubbed "a global food revolution", says talks are under way to get buy-in from the farmworkers.

When Derek Carstens, former marketing director of FirstRand, bought a large farm in the Karoo, he noticed that the health of the farm labourers and their children was not good.

"I advised that food was at the heart of the problem, and I submitted a research proposal to him (Carstens). He agreed to provide food for the families for life, but only food that is considered optimal in the high-fat diet, which advocates for high fat and protein rather than carbohydrates," said Noakes.

Once the project begins, the families will be a control group and will be monitored for five to 10 years. With a diet high in offal – which is readily available on the farmlands of the Karoo – the families will stop consuming carbohydrates, which Noakes says are of no benefit to the human body.

"This is an ideal set-up," said Noakes. "And it would be much harder to do research of this nature in a place like Cape Town."

Currently, a process is under way to consult with the community and get their permission, but Noakes is hoping for the best.

"We can't build this nation in the absence of sufficient protein and fat. These essential elements cannot be substituted with carbohydrates," he said.

He was also recently invited to speak to parliamentarians in the Karoo regarding the poor nutrition of farm labourers.

"I explained to them that a farming community should be the healthiest community of all," he said, adding that he hoped to proceed with the research "one step at a time".

"Our ultimate goal is that all families in the Karoo eat offal as their staple, rather than a diet high in carbohydrates, which leads to exhaustion.

"By eating liver, kidneys, brains and marrow, people will be seeing the benefits that hunter-gatherers experienced. They ate the organs first and the rest of the meaty tissue – which is not high quality – was seen as being of much lower importance," he said.

Interestingly, supermarkets today place a higher premium on meat than on offal, but given the benefits, argues Noakes, it could be the other way around.

A radiologist in the public sector, who did not want to be named, said he had noticed from the MRIs that in communities where people are undernourished because of a diet that fills bellies with carbs, people's brains are contracting by the age of 30. "This is because of a deficiency of fat in their diet," he said.

Noakes sees America as being responsible for the rise in the high consumption of carbs over the past few decades.

When it comes to oils, too, the ones used most in under-resourced communities are the same ones that he says are bad for you. These are the vegetable oils like sunflower, canola and corn oil.

(5)
Conclusions

(1) Climate increases U–levels in water

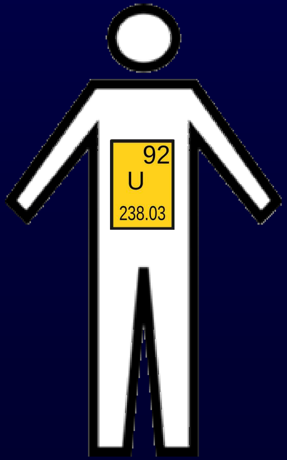
- aridity naturally increases U-levels in water and evaporative crusts despite moderate U-content of source rocks
→ *low dilution + long contact times + U-recycling through evaporation*
→ likely to affect many arid areas world wide

(2) U enriches in sheep

→ water – fodder – salt crusts - (bones)
→ highest in wool (good bio-indicator, mechanisms of U-excretion
→ inner organs (highest polluted edible parts)
- good news: meat and lamb much less affected

(3) U poses chemo- and radiotoxic health risks

→ borehole water most important pathway
→ sheep meat less important
→ chemotoxic + dose-based limits for water intake exceeded
→ local staple food mutton as adds to U-intake
→ household water filters remove U effectively
→ radon + radium need to be monitored (also leukaemia)
→ survey of identified arid areas recommended



Acknowledgement

My colleagues Ewald Erasmus and Emile Hoffmann from the Mine Water Re-Search Group.

Dr. Gehard Geipel from the HZDR for analyzing our samples

The friendly and helpful farming community of the Pofadder area

Thank you !