Mesoscopes for Hydropedology in the Critical Zone

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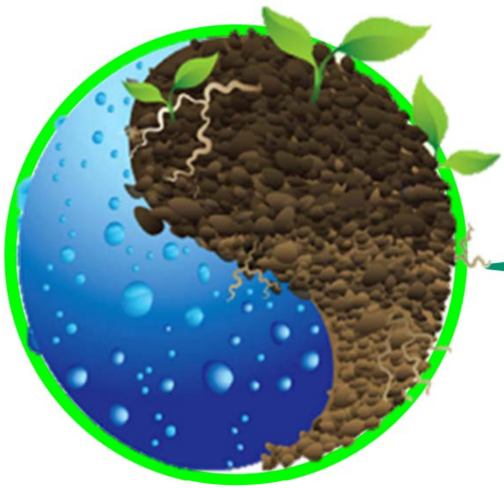
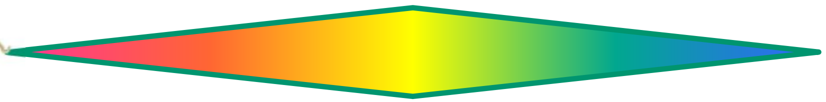
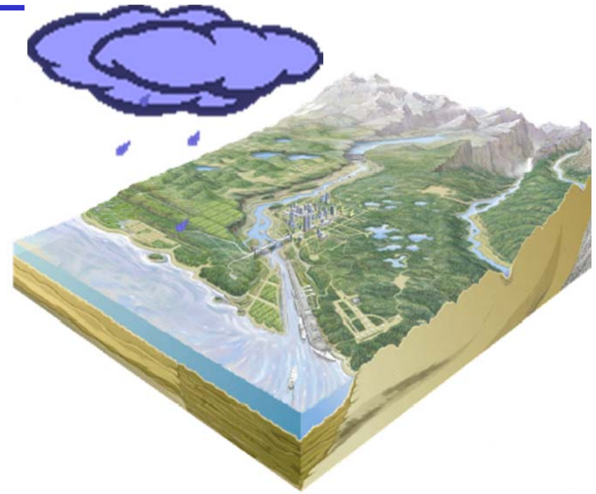




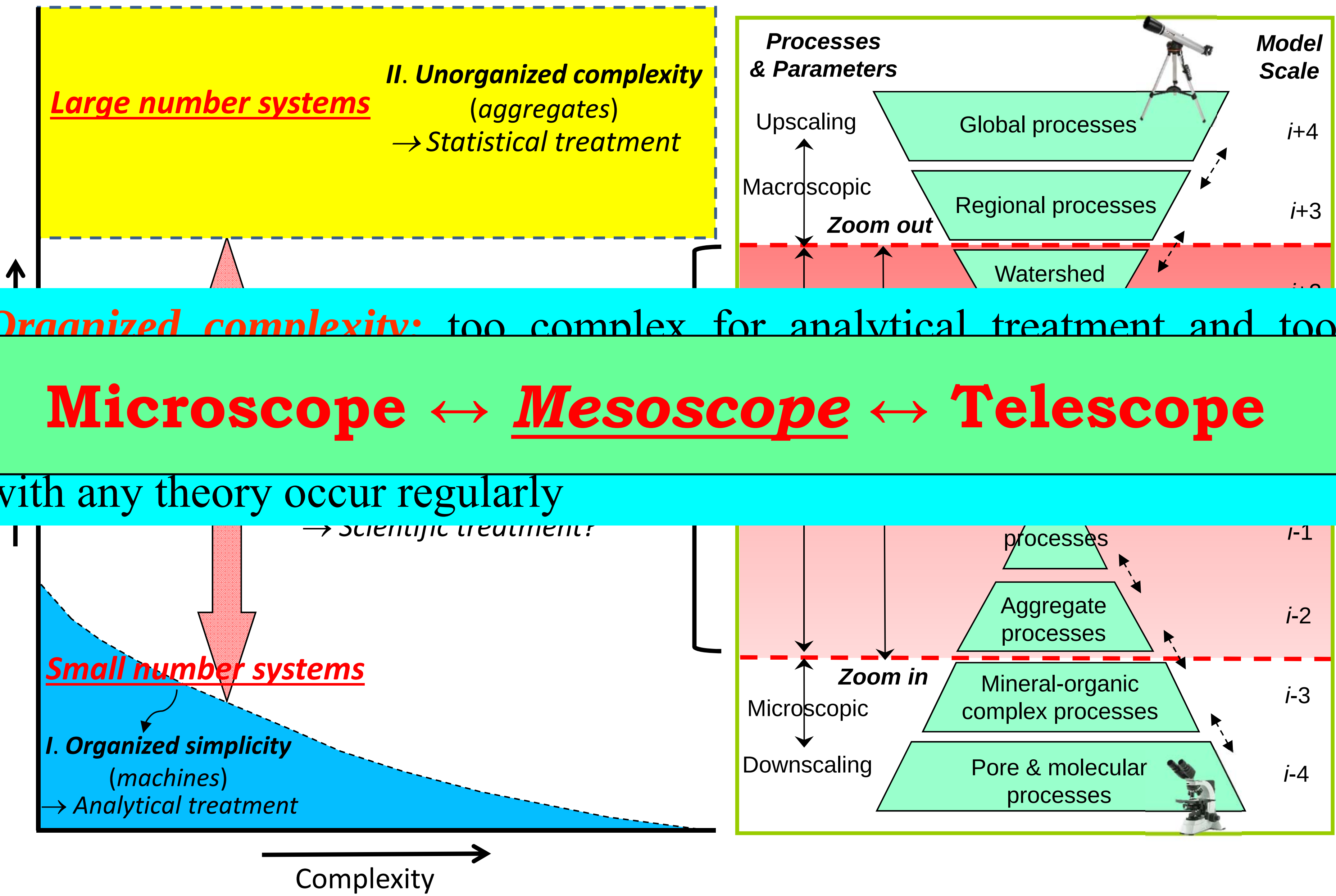


Soils: "The Heart of the Critical Zone"

Understanding Soils – Their Architecture & Functional Manifestations

- *Heterogeneity differs from randomness*: the former is associated with order while the latter is linked to disorder.
- *Organized heterogeneity* reflects underlying structure that governs the direction and efficiency of energy and matter transfer.
- *Evolutionary processes* have been made possible because of heterogeneity of all kinds leading to the flow of energy and mass that are driven by various gradients at different scales.

Photo Courtesy: John A. Kelley

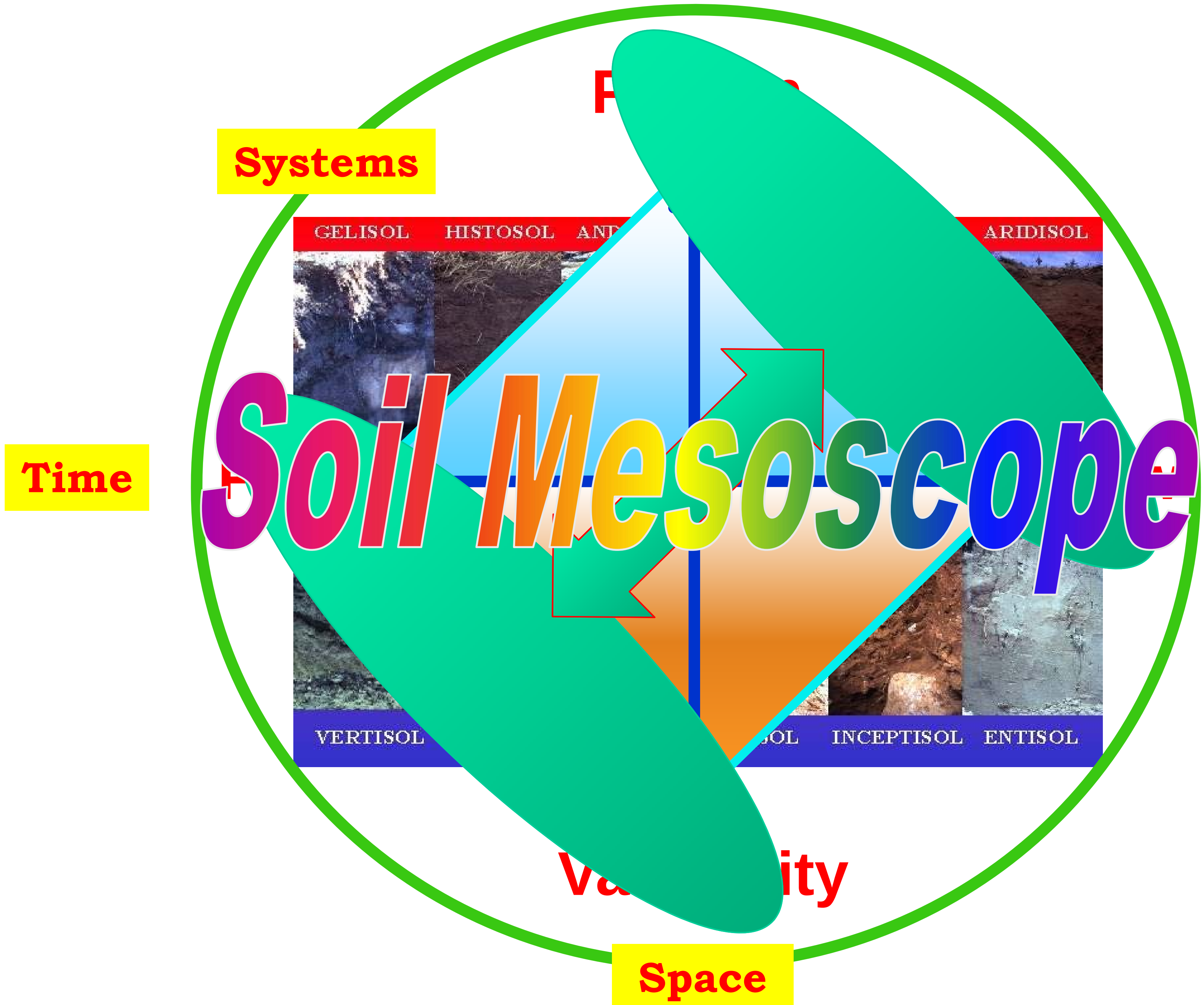


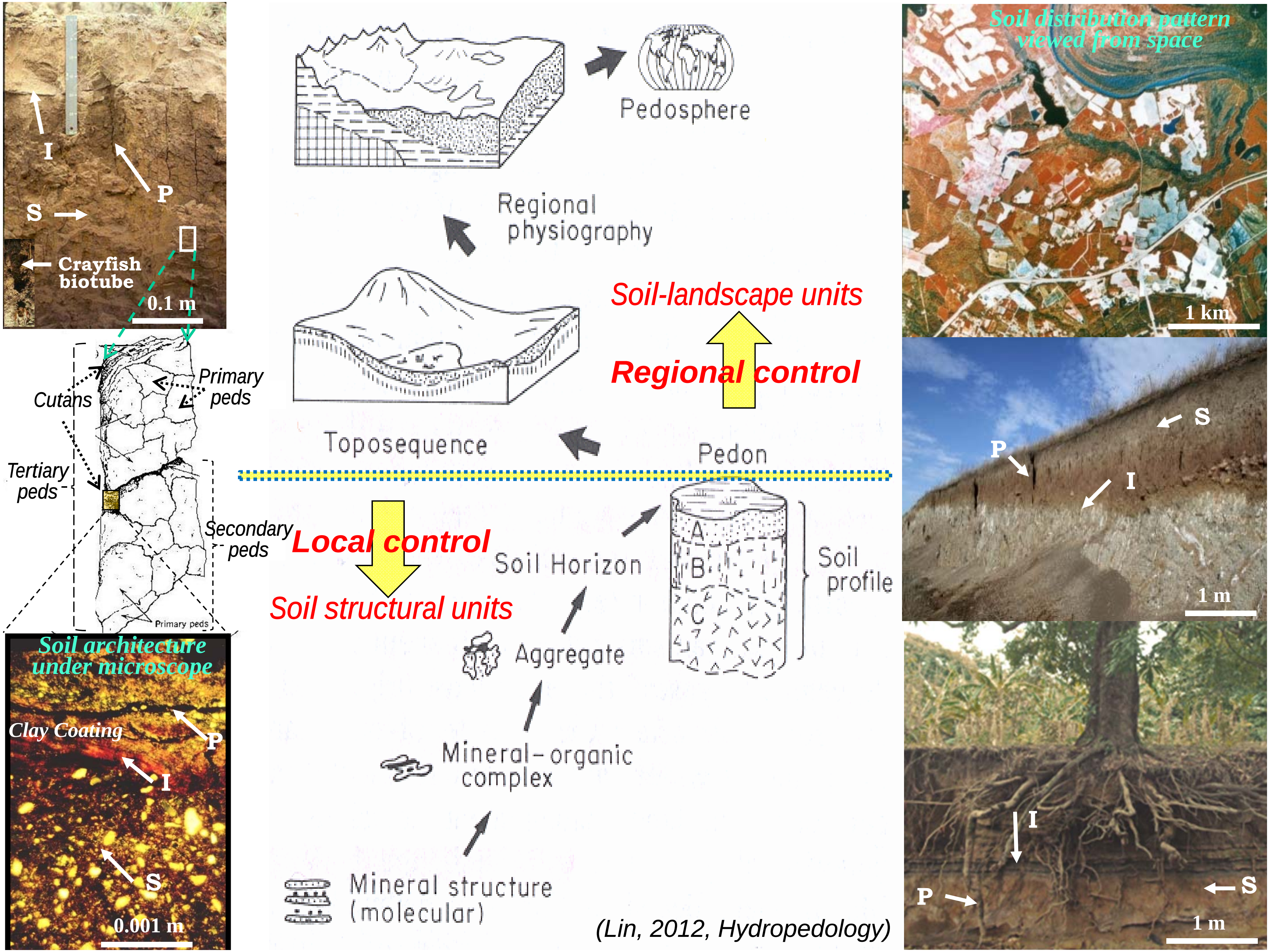
Organized complexity: too complex for analytical treatment and too

Microscope ↔ *Mesoscope* ↔ Telescope

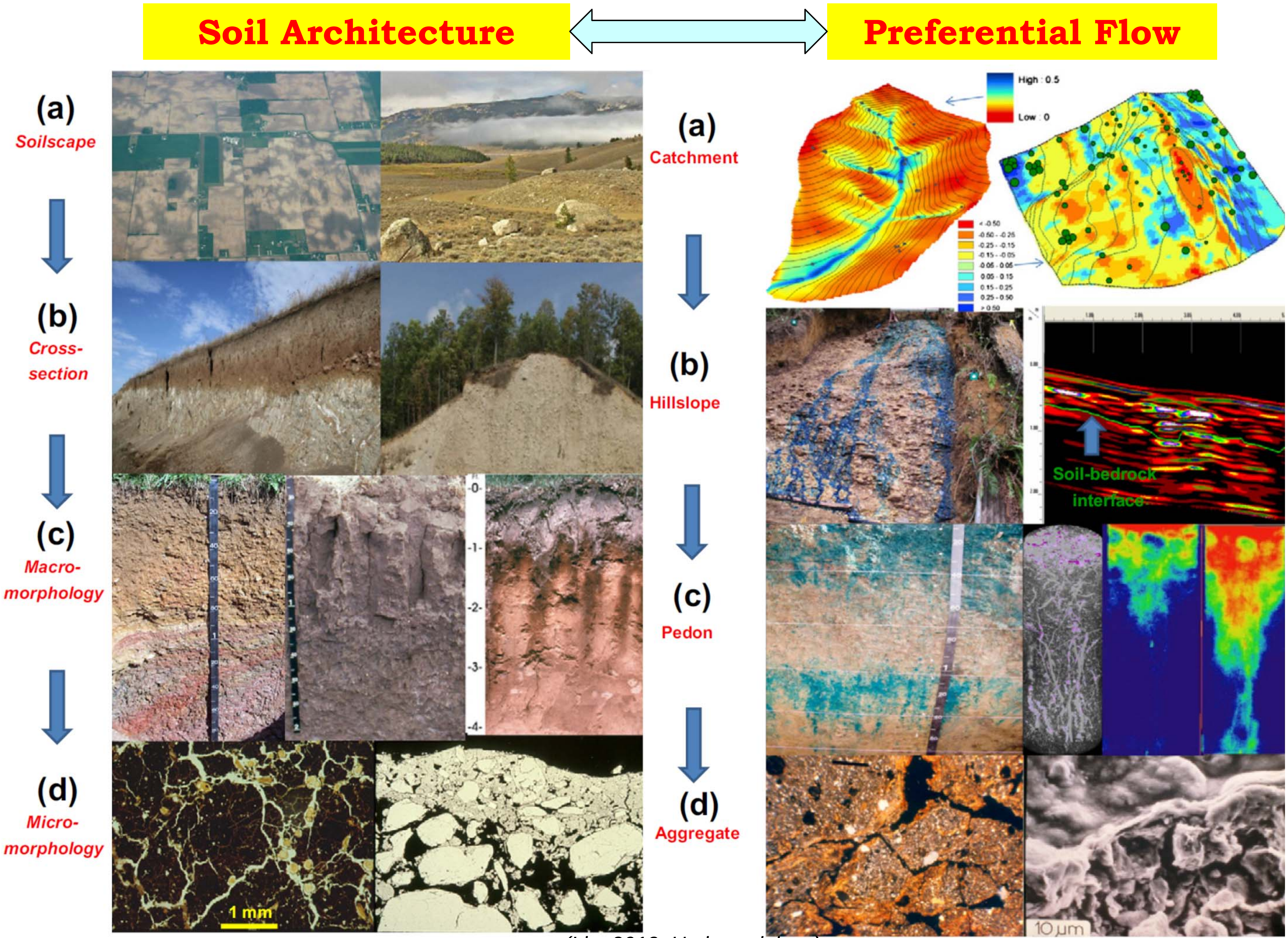
with any theory occur regularly

(Modified from: Weinberg, 1975)

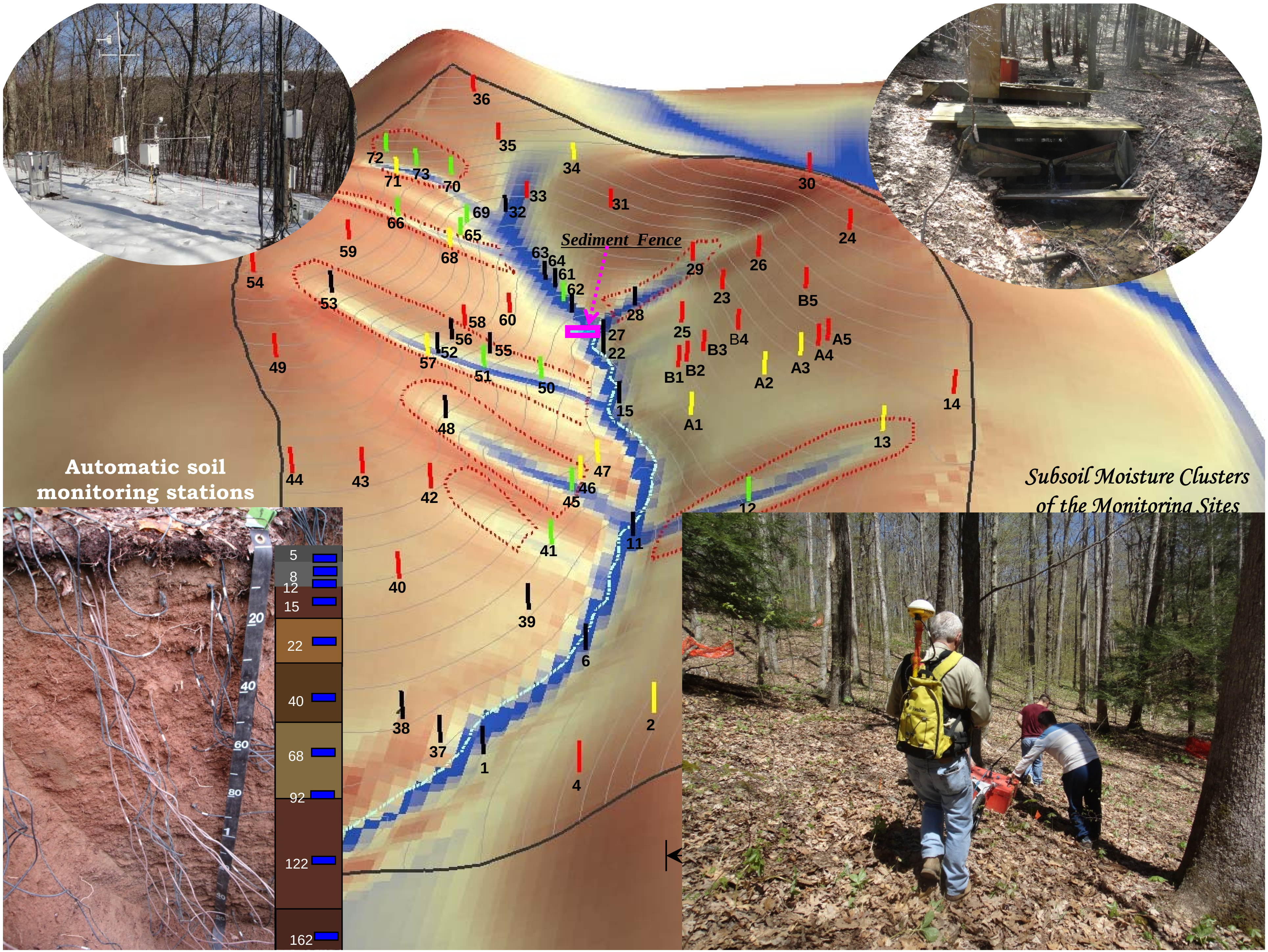

Systems
GELISOL
HISTOSOL
ARIDISOL
Time
Soil Mesoscope
VERTISOL
INCEPTISOL
ENTISOL
Space



I
P
S
Crayfish biotube
0.1 m
Cutans
Primary peds
Tertiary peds
Secondary peds
Primary peds
Soil architecture under microscope
Clay Coating
P
I
S
0.001 m
Pedosphere
Regional physiography
Soil-landscape units
Regional control
Toposequence
Pedon
Local control
Soil Horizon
A
B
C
Soil profile
Soil structural units
Aggregate
Mineral-organic complex
Mineral structure (molecular)
(Lin, 2012, Hydropedology)
Soil distribution pattern viewed from space
1 km
S
P
I
1 m
I
P
S
1 m

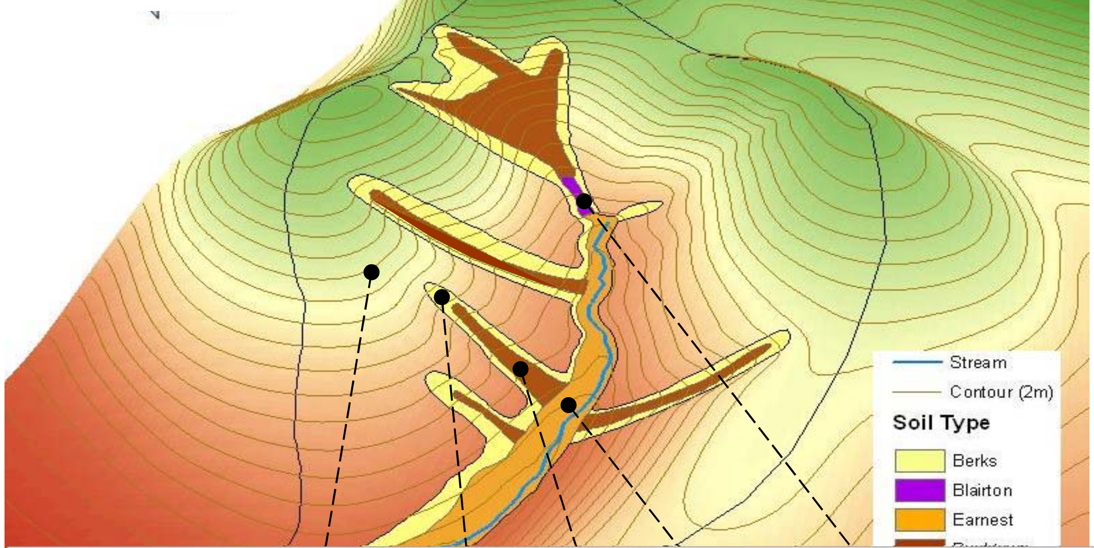


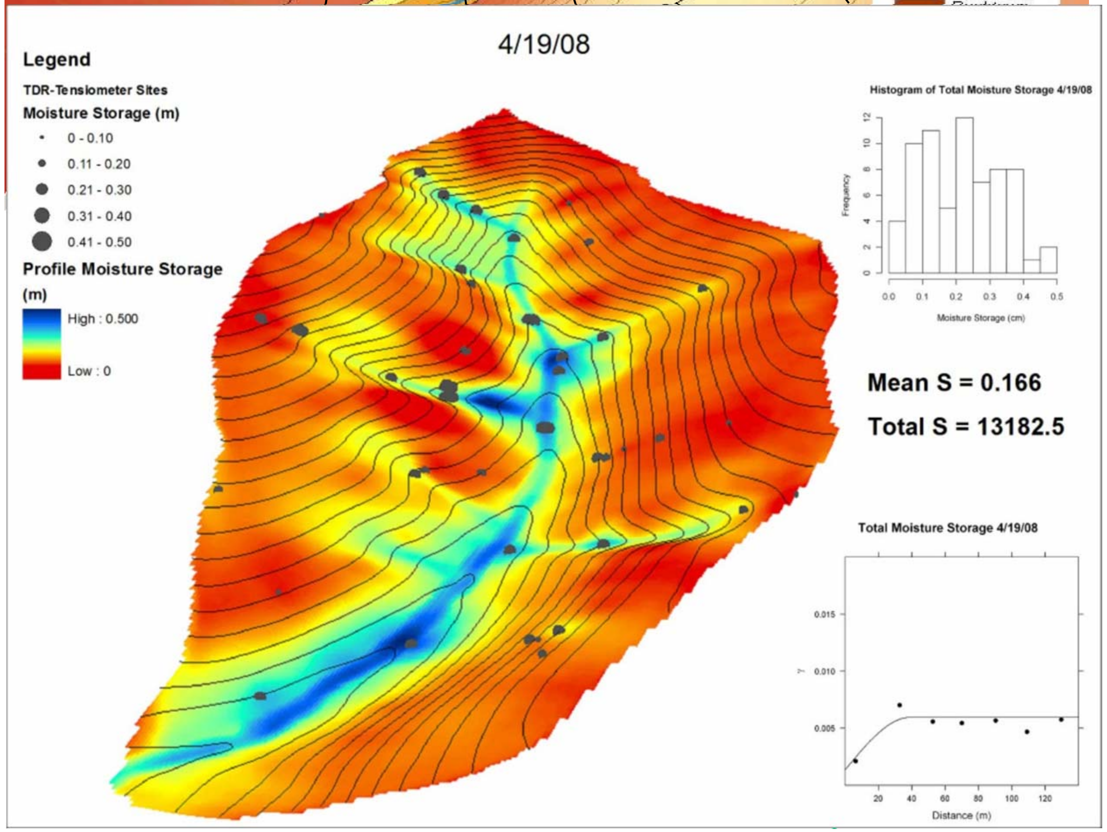
(Lin, 2012, Hydropedology)

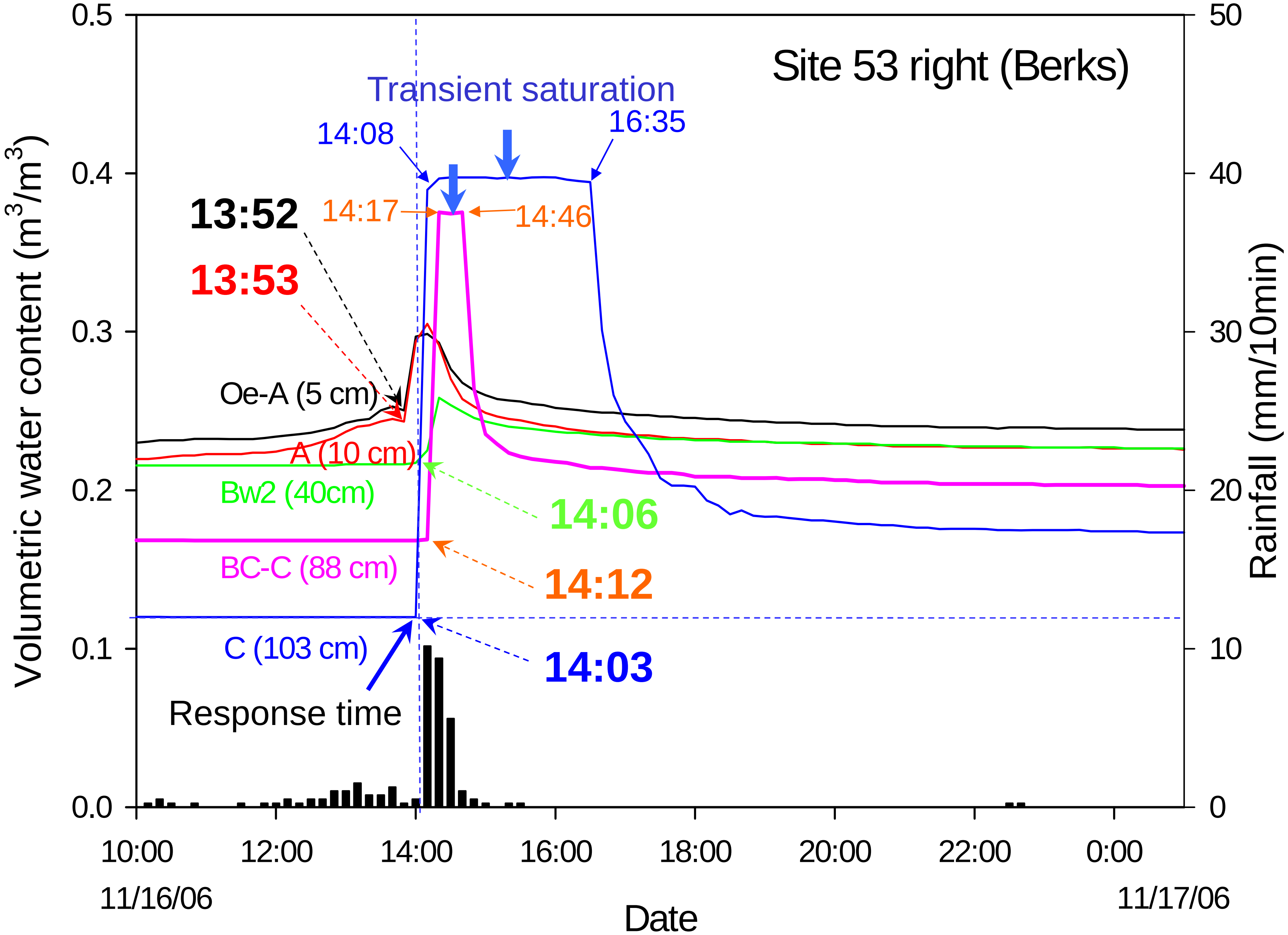


Automatic soil monitoring stations
Subsoil Moisture Clusters of the Monitoring Sites
Sediment Fence
5
8
12
15
22
40
68
92
122
162
36
35
34
33
32
31
30
72
73
71
70
66
69
65
68
59
54
53
63
64
61
62
29
26
24
23
28
B5
58
60
56
52
55
27
22
25
B4
B3
B2
B1
A5
A4
A3
A2
49
57
51
50
15
A1
14
48
13
44
43
42
47
46
45
12
41
11
40
39
6
2
38
37
1
4

Soil Map


Stream
Contour (2m)
Soil Type
Berks
Blairton
Earnest

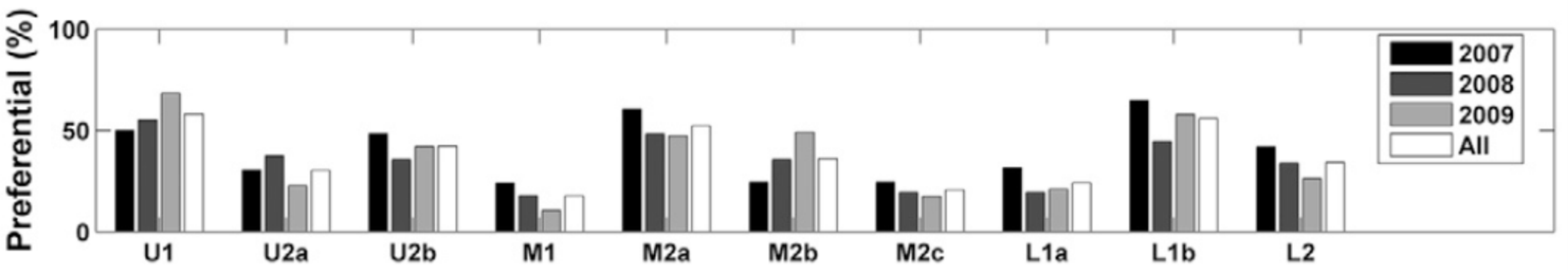

4/19/08
Legend
TDR-Tensiometer Sites
Moisture Storage (m)
0 - 0.10
0.11 - 0.20
0.21 - 0.30
0.31 - 0.40
0.41 - 0.50
Profile Moisture Storage (m)
High : 0.500
Low : 0
Histogram of Total Moisture Storage 4/19/08
Frequency
Moisture Storage (cm)
Mean S = 0.166
Total S = 13182.5
Total Moisture Storage 4/19/08
Distance (m)



(Lin and Zhou, 2008, EJSS)

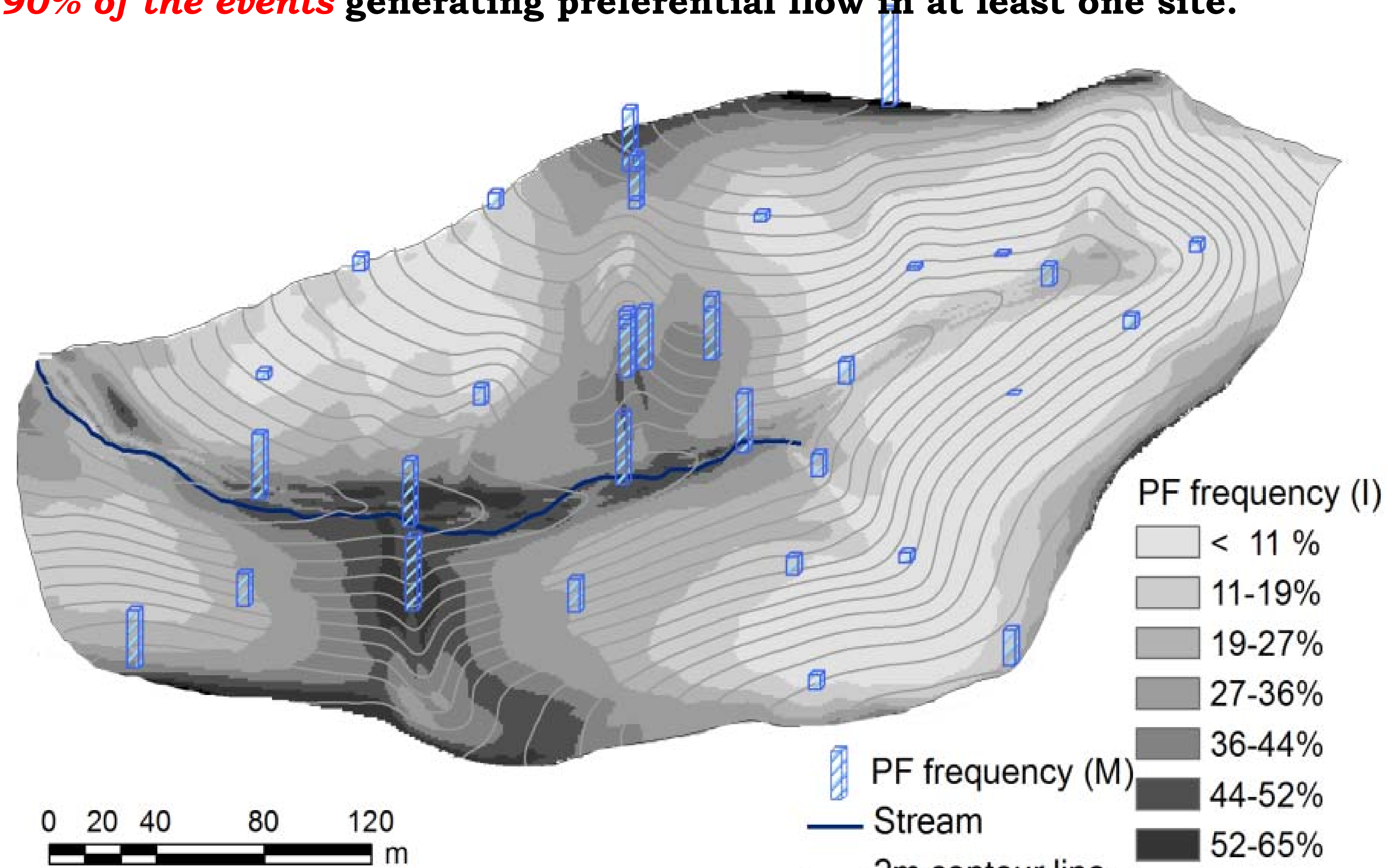
Controls and Frequency of Preferential Flow Occurrence: A 175-Event Analysis

- **Preferential flow was common throughout the catchment, occurring during *17 to 54% of the 175 events* at each of the 10 monitored sites along a hillslope. Preferential flow occurred in at least one site during *90% of the 175 events*. While the frequency of preferential flow appeared insensitive to topographic position, the controls on preferential flow initiation varied with landscape position. While the frequency of preferential flow can be determined from 1 yr of real-time monitoring, the controls on preferential flow require much longer (≥ 3 yr) monitoring to be reliably identified.**



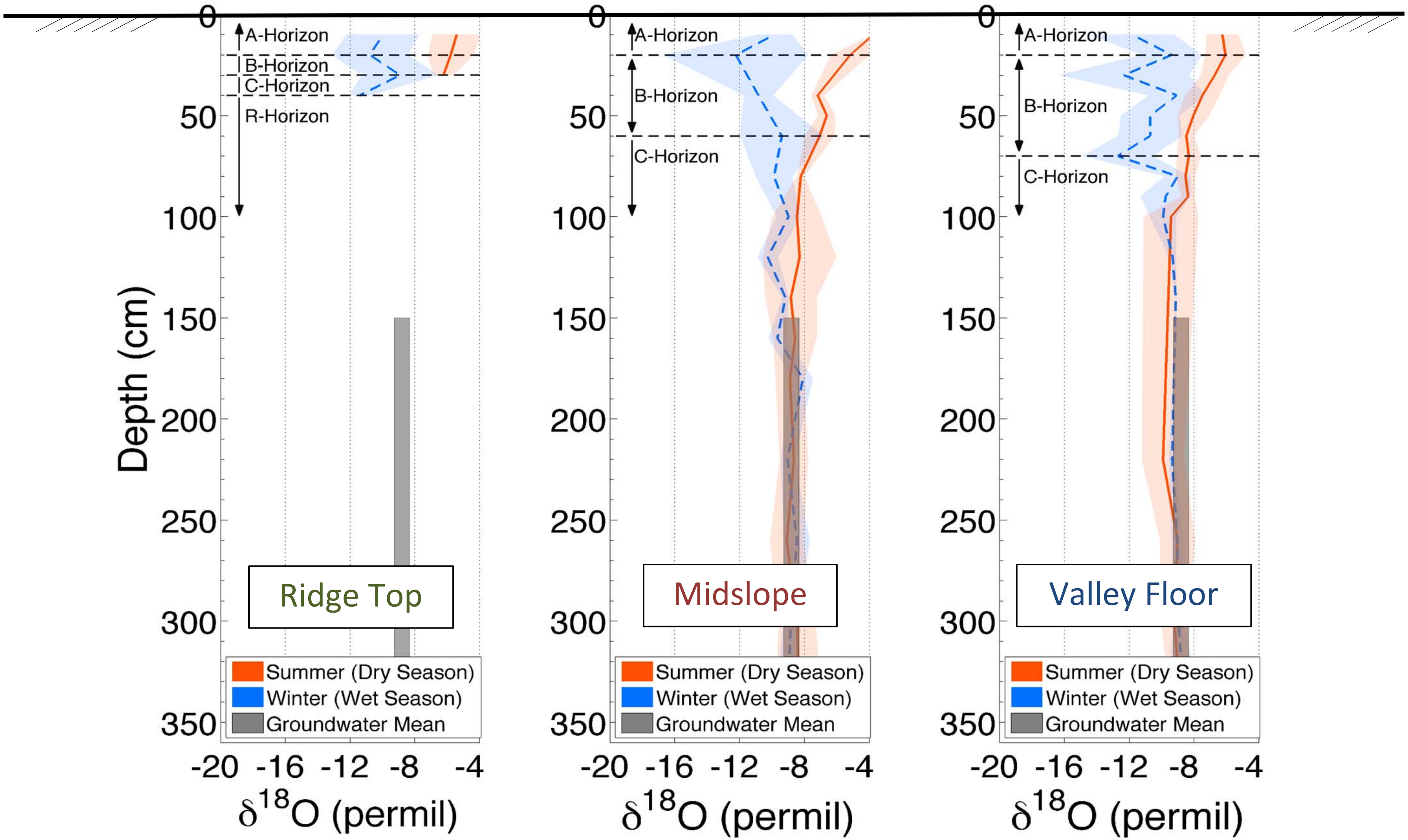
(Graham and Lin, VZJ, 2011)

Preferential flow occurred during *<1% to 70% (overall average 26%) of 323 events over 5.5 years (2006-2012)* at each of 35 monitored sites, with *90% of the events* generating preferential flow in at least one site.

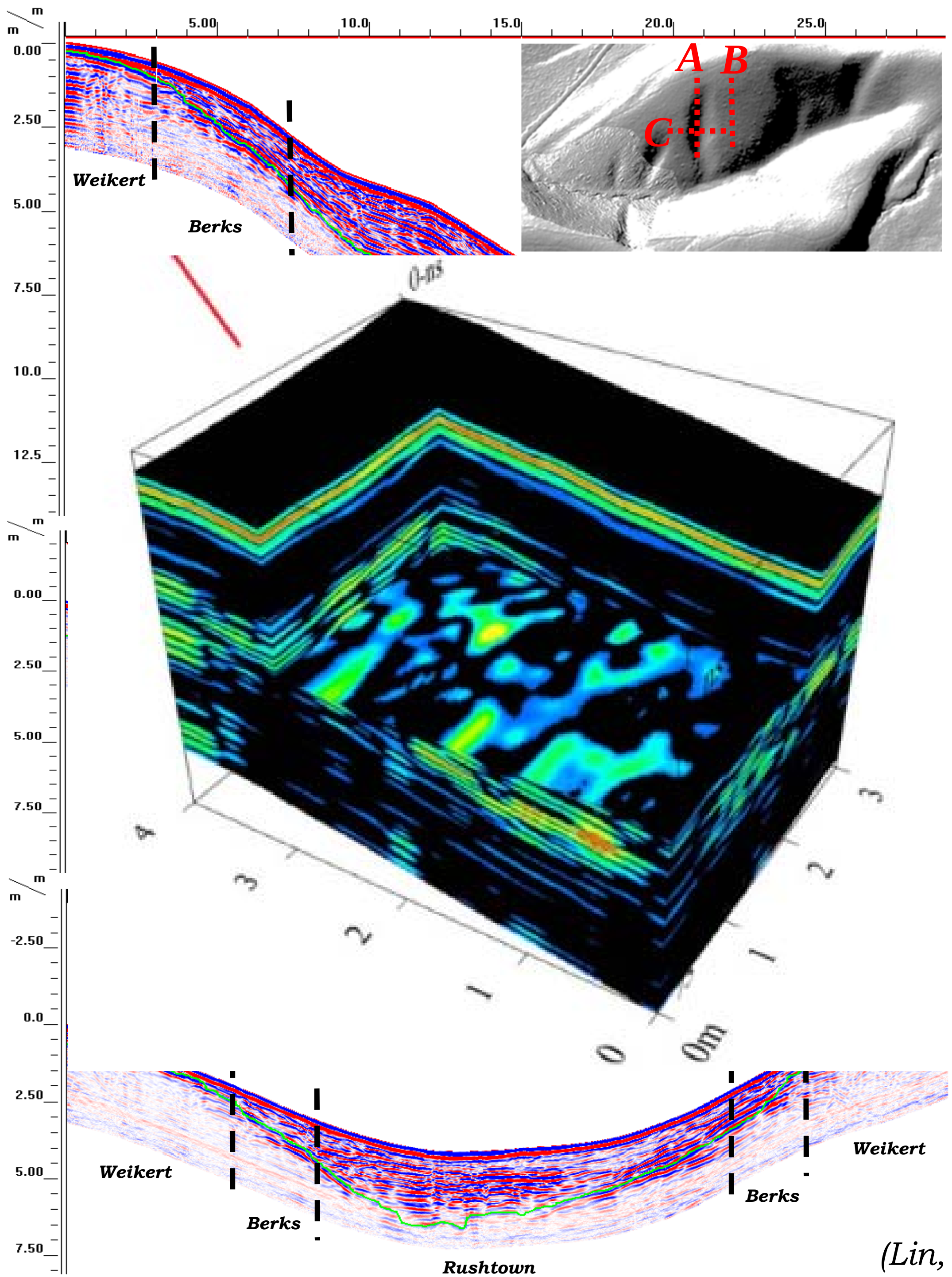


(Liu and Lin, SSSAJ, 2014)

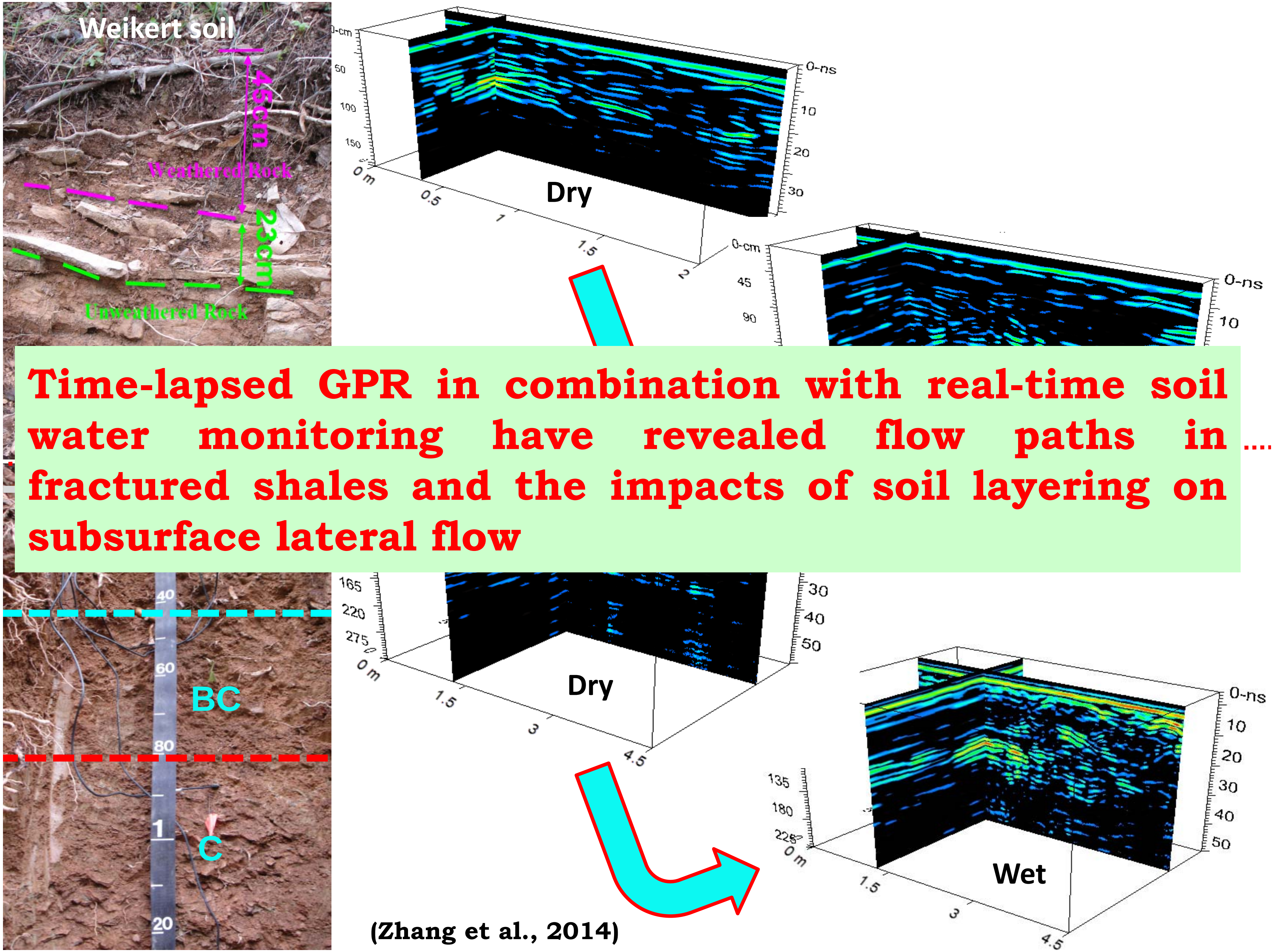
Seasonal profiles show strong isotopic attenuation with depth.
In winter, preferential flow occurs along soil-horizon and soil-bedrock interfaces.
In summer, preferential flow occurs vertically through macropores.



(Thomas et al., VZJ, 2013)

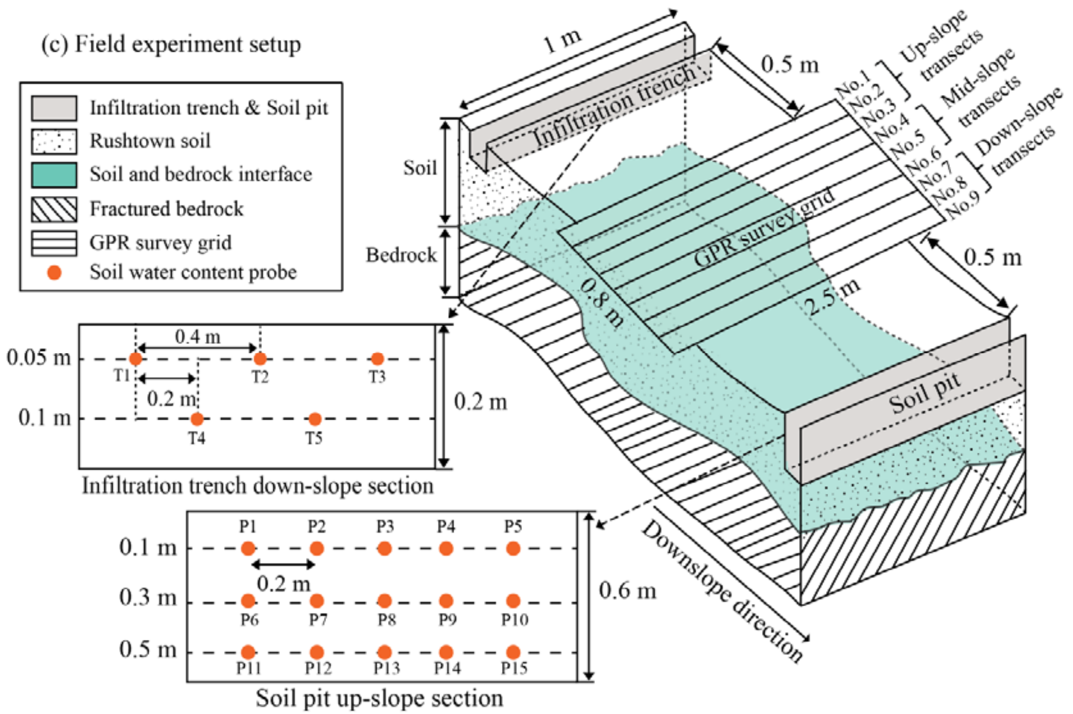


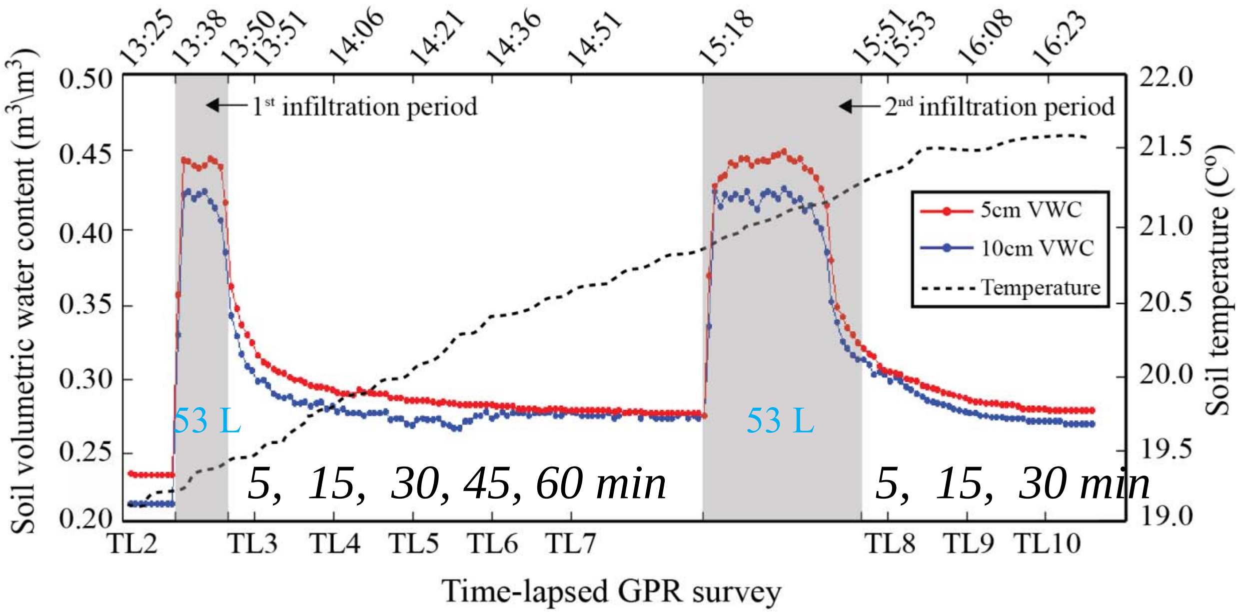
(Lin, Hydropedology, 2012)

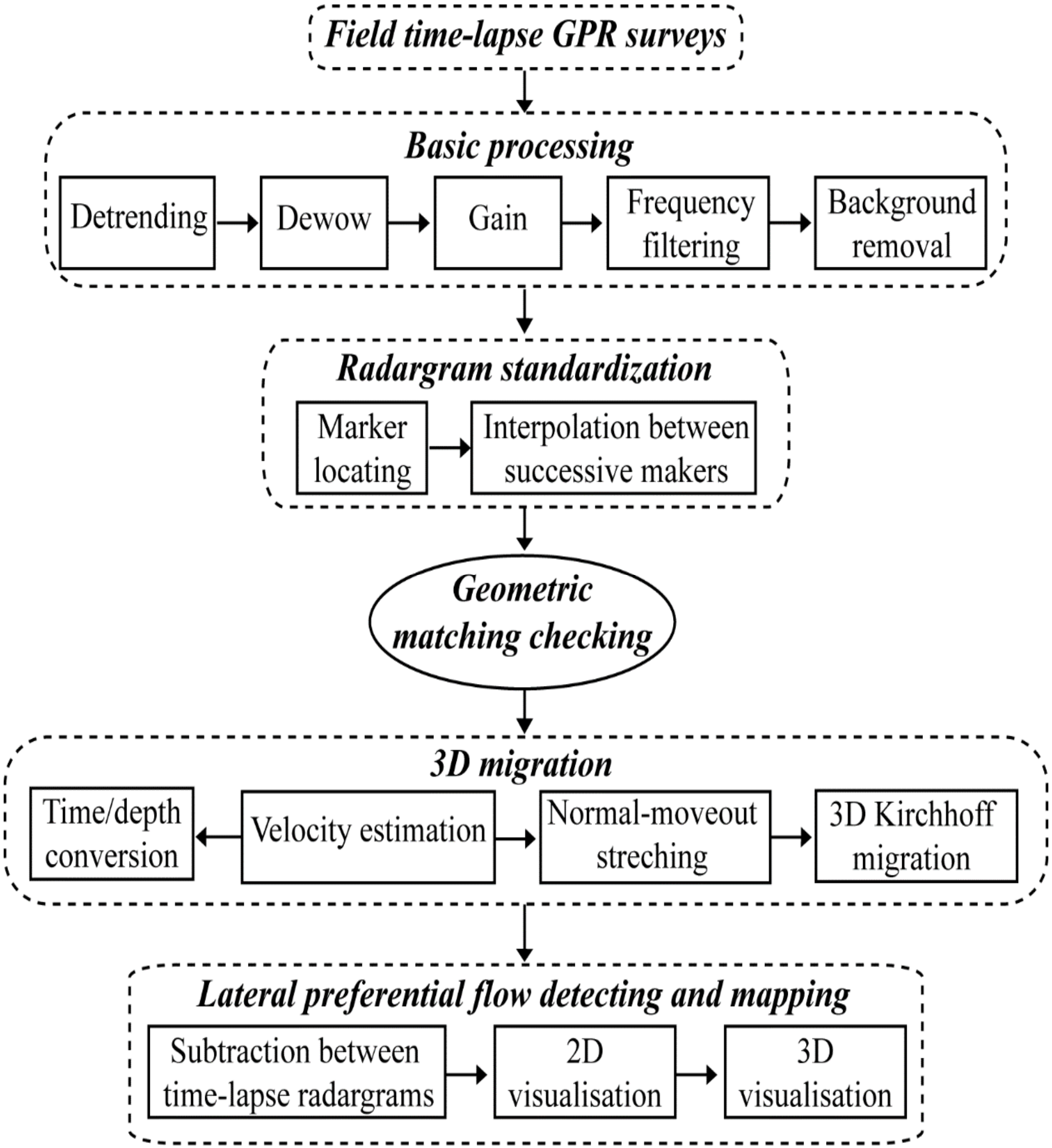


Time-lapsed GPR in combination with real-time soil water monitoring have revealed flow paths in fractured shales and the impacts of soil layering on subsurface lateral flow ....

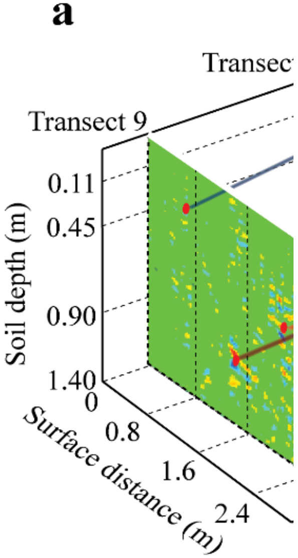
(Zhang et al., 2014)

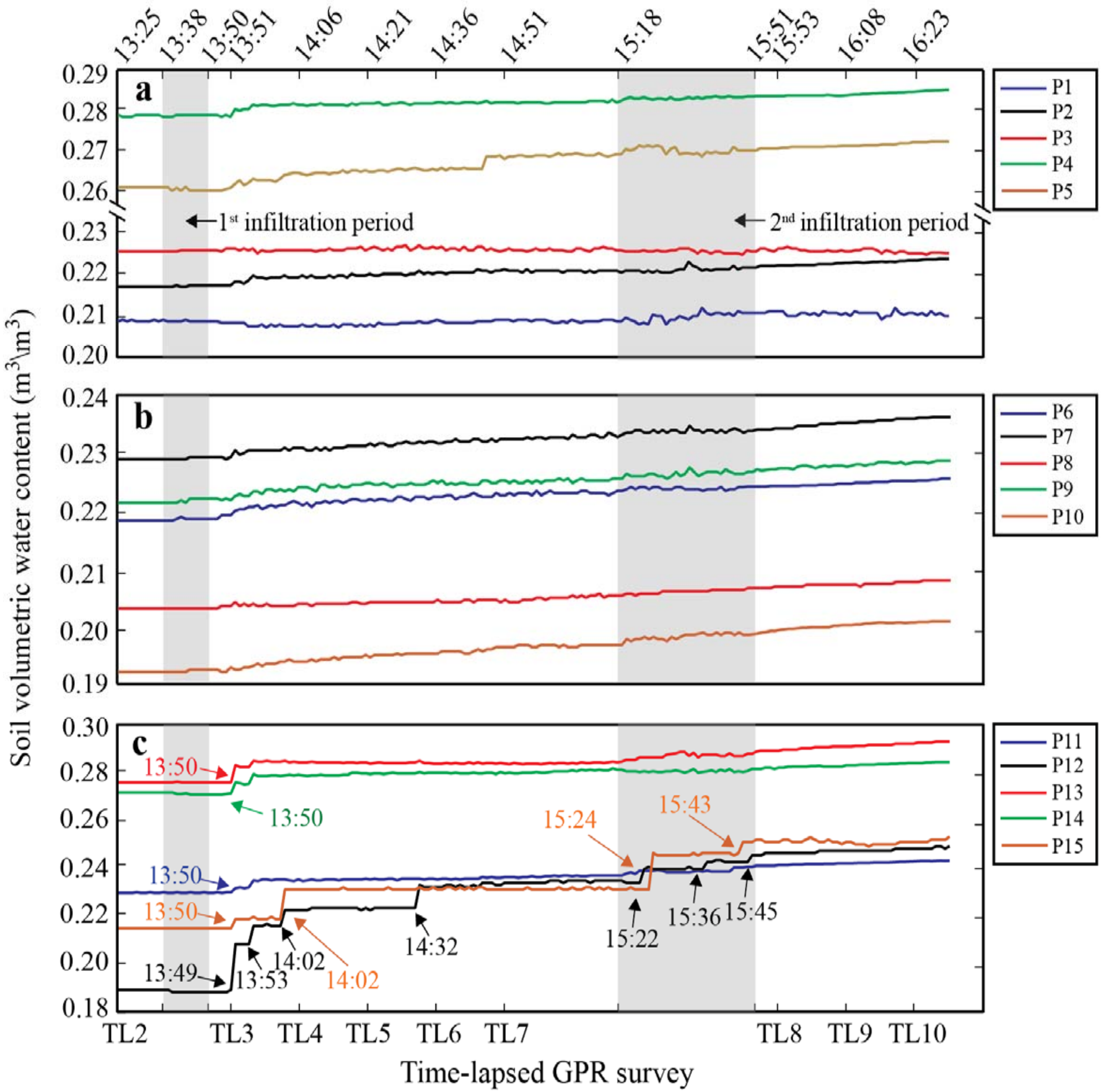

(c) Field experiment setup
Infiltration trench & Soil pit
Rushtown soil
Soil and bedrock interface
Fractured bedrock
GPR survey grid
Soil water content probe
1 m
0.5 m
Infiltration trench
Soil
Bedrock
GPR survey grid
0.8 m
2.5 m
0.5 m
Soil pit
No.1
No.2
No.3
No.4
No.5
No.6
No.7
No.8
No.9
Up-slope transects
Mid-slope transects
Down-slope transects
Downslope direction
0.4 m
0.05 m
T1
T2
T3
0.2 m
0.1 m
T4
T5
0.2 m
Infiltration trench down-slope section
P1
P2
P3
P4
P5
0.1 m
0.2 m
0.3 m
P6
P7
P8
P9
P10
0.5 m
P11
P12
P13
P14
P15
0.6 m
Soil pit up-slope section

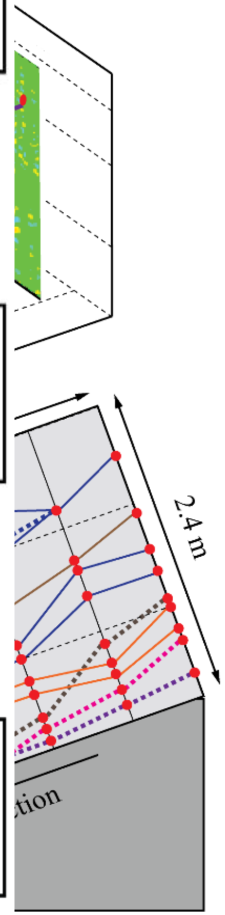

13:25
13:38
13:50
13:51
14:06
14:21
14:36
14:51
15:18
15:51
15:53
16:08
16:23
1st infiltration period
2nd infiltration period
5cm VWC
10cm VWC
Temperature
53 L
53 L
5, 15, 30, 45, 60 min
5, 15, 30 min
Soil volumetric water content (m3\m3)
0.50
0.45
0.40
0.35
0.30
0.25
0.20
Soil temperature (Co)
22.0
21.5
21.0
20.5
20.0
19.5
19.0
TL2
TL3
TL4
TL5
TL6
TL7
TL8
TL9
TL10
Time-lapsed GPR survey



Field time-lapse GPR surveys
Basic processing
Detrending
Dewow
Gain
Frequency filtering
Background removal
Radargram standardization
Marker locating
Interpolation between successive makers
Geometric matching checking
3D migration
Time/depth conversion
Velocity estimation
Normal-moveout streching
3D Kirchhoff migration
Lateral preferential flow detecting and mapping
Subtraction between time-lapse radargrams
2D visualisation
3D visualisation

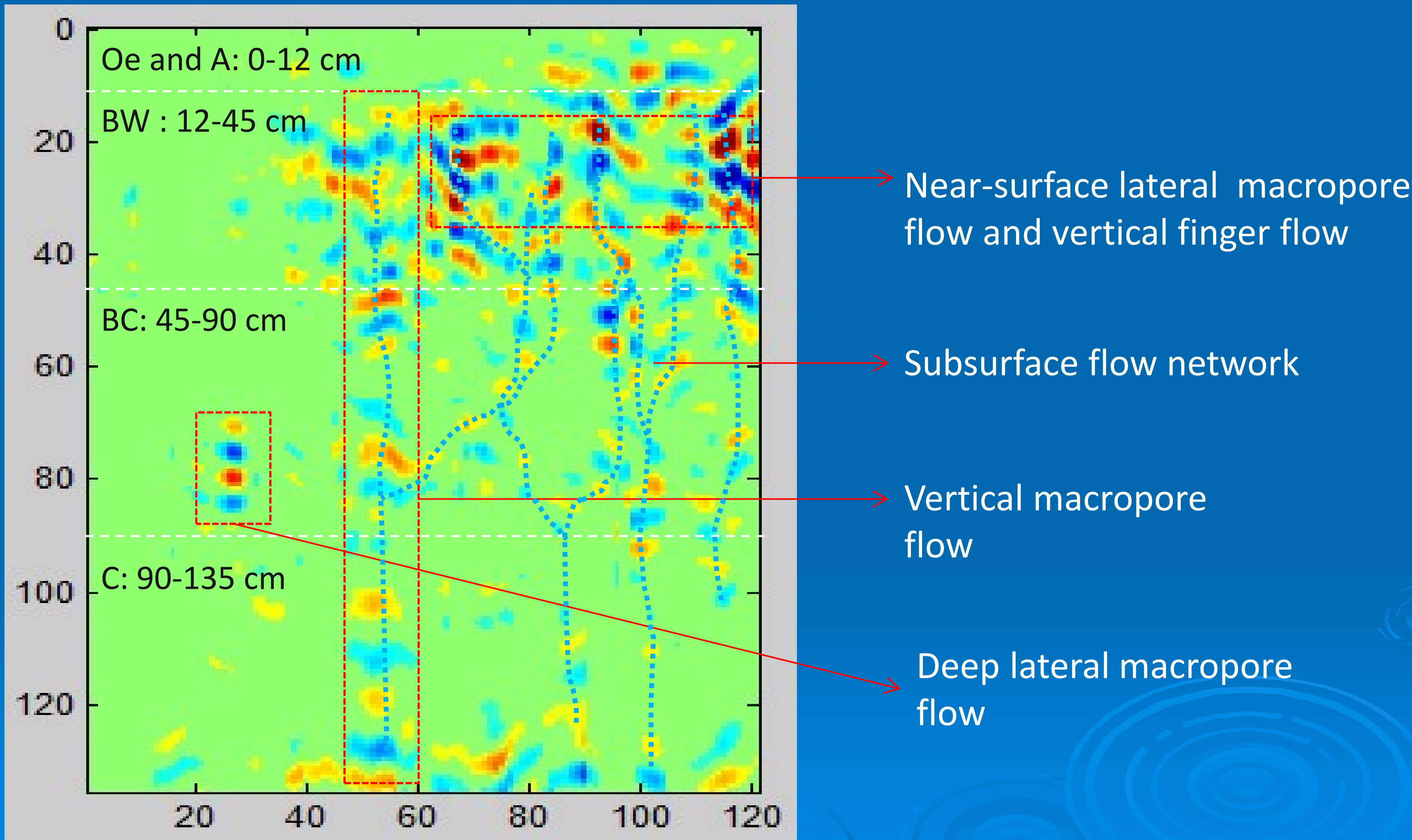

a
Transect 9
Transec
Soil depth (m)
0.11
0.45
0.90
1.40
0
0.8
1.6
2.4
Surface distance (m)


13:25
13:38
13:50
13:51
14:06
14:21
14:36
14:51
15:18
15:51
15:53
16:08
16:23
a
1st infiltration period
2nd infiltration period
P1
P2
P3
P4
P5
b
P6
P7
P8
P9
P10
c
P11
P12
P13
P14
P15
13:50
13:49
13:53
14:02
14:32
15:22
15:24
15:36
15:43
15:45
Soil volumetric water content (m3\m3)
TL2
TL3
TL4
TL5
TL6
TL7
TL8
TL9
TL10
Time-lapsed GPR survey

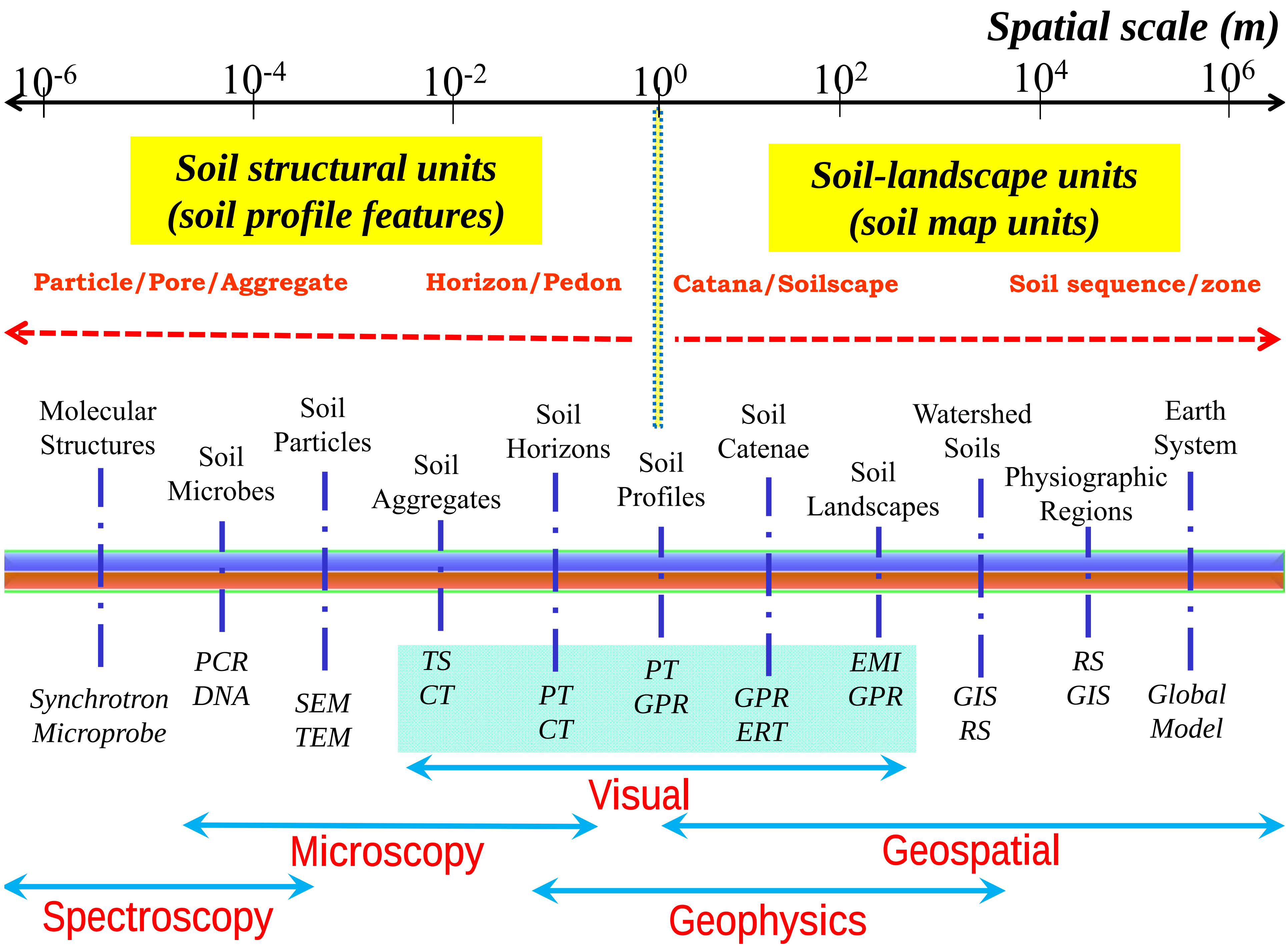

2.4 m
tion

revision)

Time-Lapsed GPR Radargram Interpretation After Water Infiltration into Soils

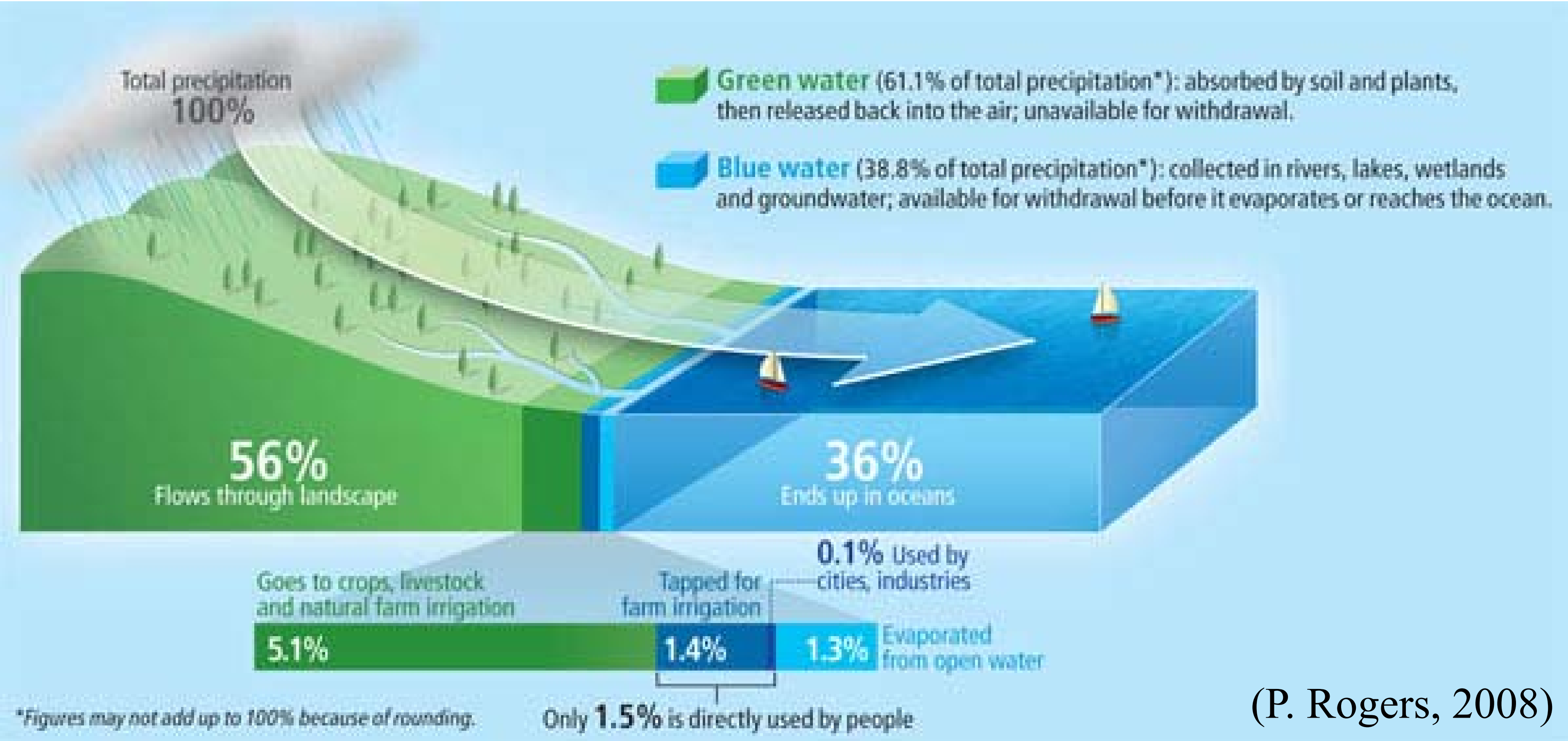


(Guo et al., WRR, in revision)



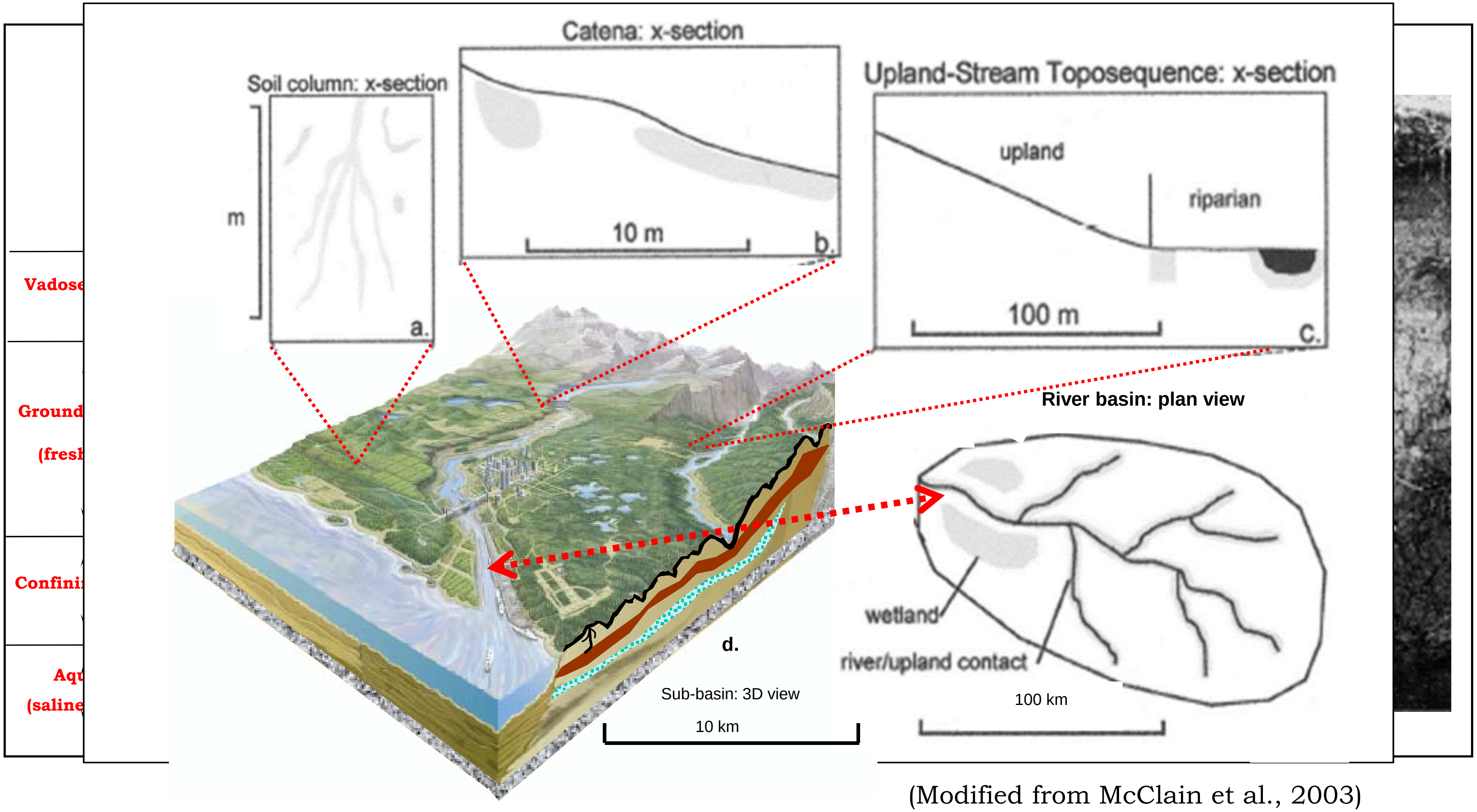
Spatial scale (m)
10^{-6}
10^{-4}
10^{-2}
10^{0}
10^{2}
10^{4}
10^{6}
Soil structural units
(soil profile features)
Soil-landscape units
(soil map units)
Particle/Pore/Aggregate
Horizon/Pedon
Catana/Soilscape
Soil sequence/zone
Molecular Structures
Soil Microbes
Soil Particles
Soil Aggregates
Soil Horizons
Soil Profiles
Soil Catenae
Soil Landscapes
Watershed Soils
Physiographic Regions
Earth System
Synchrotron Microprobe
PCR DNA
SEM TEM
TS CT
PT CT
PT GPR
GPR ERT
EMI GPR
GIS RS
RS GIS
Global Model
Visual
Microscopy
Geospatial
Spectroscopy
Geophysics

Green water: Essential in combating looming global freshwater crisis



(P. Rogers, 2008)

Biogeochemical hot spots and hot moments in the landscape



(Modified from McClain et al., 2003)

While landform and vegetation can now be mapped with high resolution, we lack adequate tools and techniques for in situ, precision, continuous, and noninvasive mapping and sensing of the complex subsurface. Improved mesoscopes (i.e., devices or techniques that are between microscopes and telescopes) are needed to shed better light on the complex subsurface in the Critical Zone.