Measuring Soil Carbon in Papua New Guinea's Forests

P. Nimiago (PNGFRI Lae), H. Abe (PNGFA) and P. McIntosh (FPA, Hobart)



Four issues:

1. What do we know about soil carbon in PNG?
2. How can present knowledge guide the sampling strategy for measuring soil carbon?
3. What replication is required to cover expected soil carbon variation?
   - between sites
   - within sites.
4. Costs and logistics

Previous studies

Groundbreaking study by Edwards and Grubb (1977):

Primary forest remnant,
River Fatima catchment
Mt Wilhelm
Edwards and
Grubb site
Sek Island
Madang
Jiwaka
Mt Kerigomna
Goroka
Kainantu
Chimbu
© 2014 Google
Image Landsat
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Google earth
Imagery Date: 4/10/2013
5° 49.000' S 145° 41.811' E elev 1162 m
eye alt 214.45 km

Soil: **Alluvium from gabbro**

(The soil may also contain Quaternary volcanic ash).

"Humic brown clay" – probably a **Mollisol** (Vermudoll) in USDA Soil Taxonomy

Above-ground biomass carbon (t/ha)	Below-ground biomass carbon (t/ha)	Soil carbon (t/ha; to 1 m)	% total carbon held in the soil
Edwards and Grubb 1977			
155	20	**600**	77
Malaysia (Kira 1977)			
475	not determined	68	< 14

Compare to soil carbon in temperate forests

Soil	Site Characteristics	Depth (cm)	Soil carbon (t/ha)	Reference
Stronach **Tasmania**	Wet eucalypt forest on granite (Paleudalf?}; 16° slope	0-100	**207**	Grant et al. 1995
Edendale **New Zealand**	Wet broadleaf-podocarp forest on loess (Dystrudept); flat	0-100	**248**	McIntosh 1995

(Both soils are non-stony and on stable sites – stoniness and erosion lower soil carbon values on a t/ha basis)

The biomass carbon total of Edwards and Grubb (**155 t/ha**) is close to typical

Fox et al. (2011), plot method (35 sites):

- **137 t/ha** in primary forests

Bryan et al. (2010), Western Province, transect method (12 sites):

- **87–127 t/ha** in primary forests

But soil carbon is high – is it typical?

SOIL CARBON – OTHER PNG SITES

Site	Characteristics	Soil carbon (t/ha to 1 m)	Reference
Oomsis-1	Lowland, schist, upper slope	**86**	Matsuura 1997
Oomsis-2	Lowland, schist, lower slope	**132**	Matsuura 1997
Buang	1400 m, schist upper slope,	**97**	Matsuura 1997
Madang-Kumil	Lowland, sedimentary, upper slope	**123**	Matsuura 1997
Madang-Kumil	Lowland, sedimentary, lower slope	**95**	Matsuura 1997
Mongi-Busiga 9720	Lowland primary forest, limestone, 34^{o} slope, slight erosion	**157**	Abe 2007
Mongi-Busiga 9721	Lowland primary forest, limestone, 17^{o} slope, no erosion	**101**	Abe 2007
Mongi-Busiga 9722	Lowland primary forest, limestone, 17^{o} slope, slight erosion	**112**	Abe 2007
Mongi-Busiga 9720	Lowland primary forest, limestone, 13^{o} slope, slight erosion	**134**	Abe 2007

Summary

Above-ground carbon

- Range: 60-140 t/ha

Soil carbon

- Range: 85-160 (-600) t/ha

Proportion of ecosystem carbon in the soil

So in PNG soil carbon levels appear to be about **50%** of total ecosystem carbon. So soil carbon should be taken into account when measuring total ecosystem carbon.

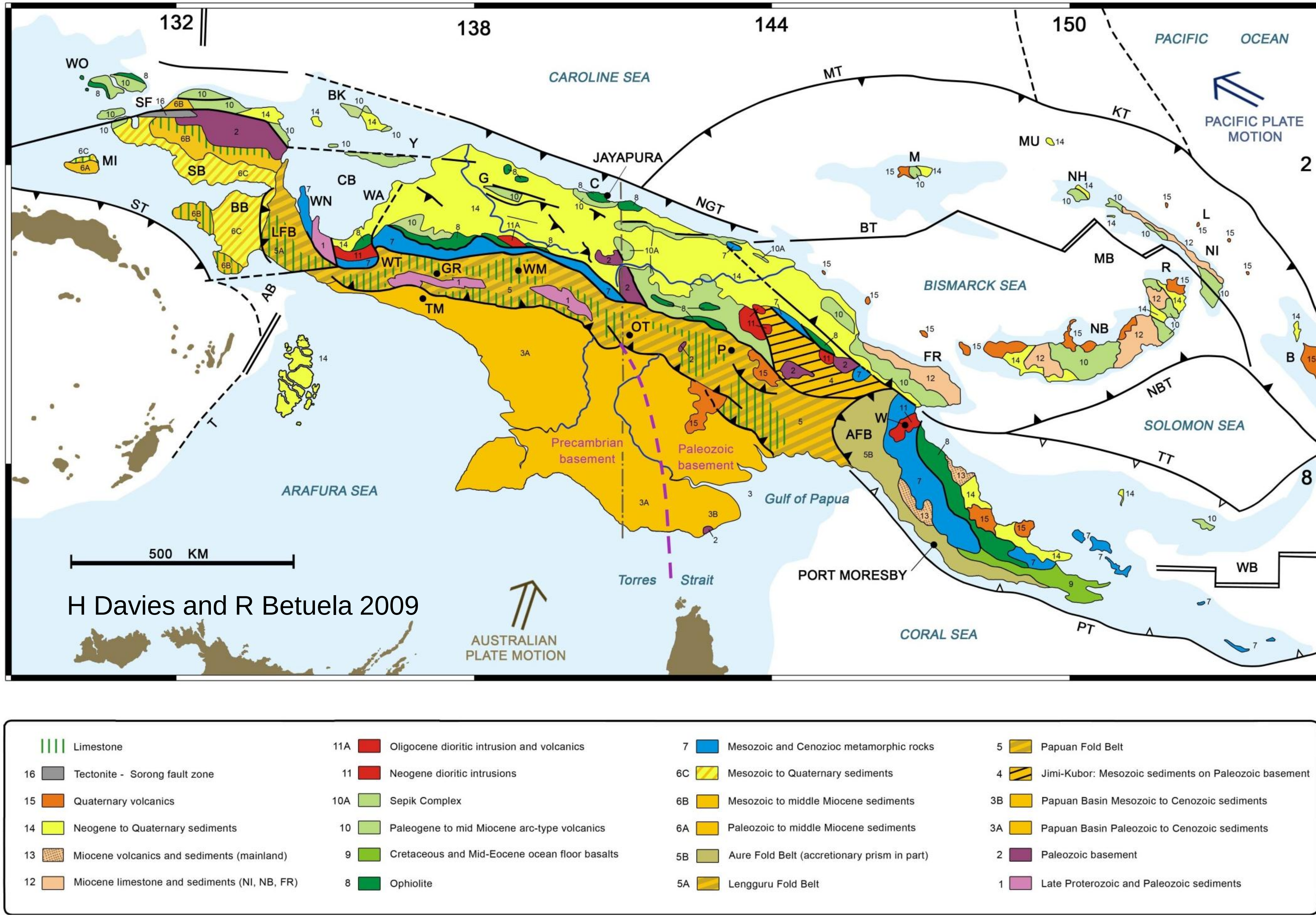
Why does the Mt Kerigomna site have such high soil carbon?

Edwards and Grubb 1977:

- Soil carbon has formed a complex with amorphous clays (gels of allophane and poorly ordered iron oxides)*
- High amounts of amorphous clay are found in soils formed from volcanic ash, or by the weathering (in humid montane conditions) of intermediate and basic igneous rocks rich in Al and Fe minerals

Similar soils probably occur in the geological map units Tp, Tm, Tmm (Tertiary volcanics and igneous rocks) in the highlands and higher-altitude Owen Stanley Ranges.

*Sowden et al. 1976; Gu et al. 1994; Woignier et al. 2007; see also *www.springerreference.com/docs/html/chapterdbid/76649.html*



Map drawn by Randall Betuela UPNG

Factors to take into account:

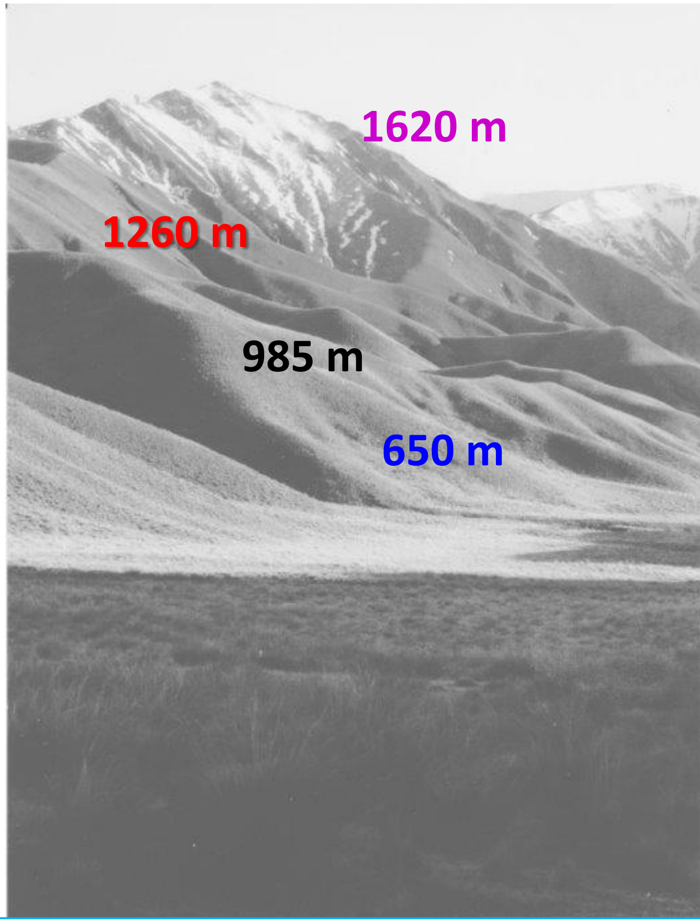
1. Geology – especially volcanics and basic igneous rocks.

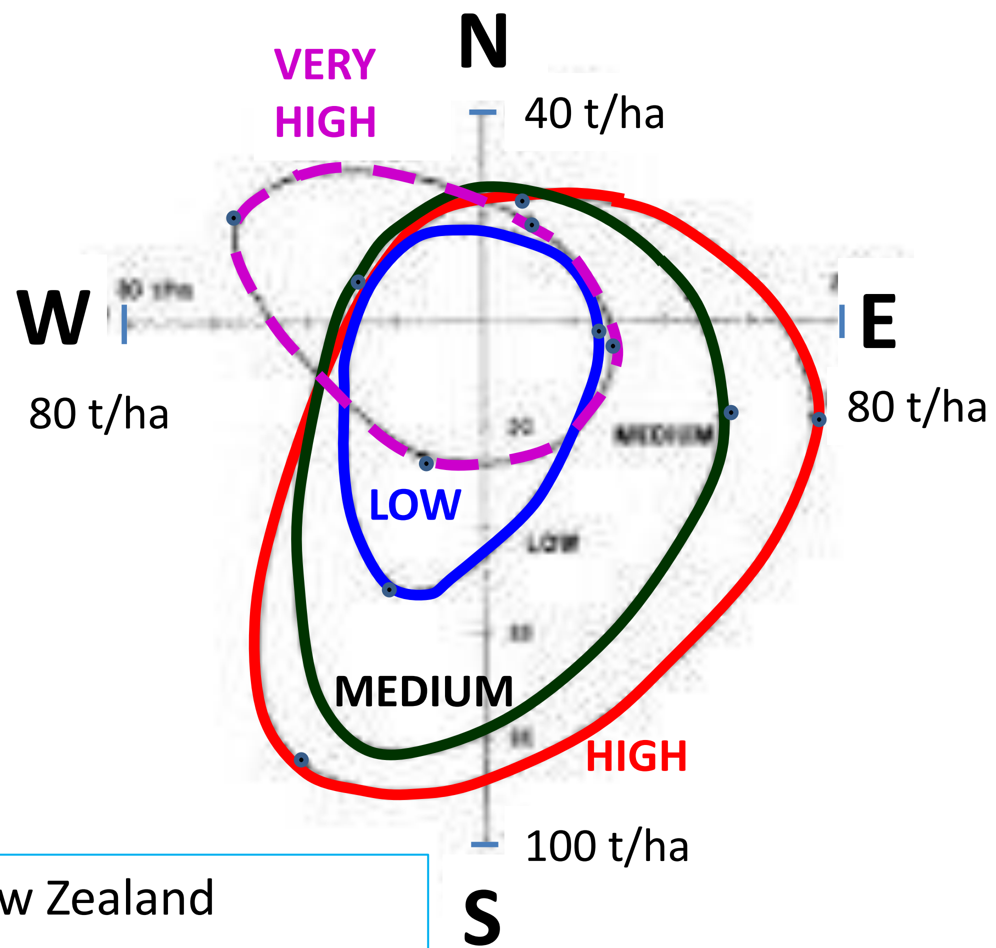
Altitude also appears to have an effect

(but disturbance and stoniness are likely to affect values)

Site	Characteristics	Soil carbon (t/ha to 30 cm)	Reference
Kui	Logged pre-1990, lowland, stony	**45**	Nimiago 2011
Danar 1	Cultivated plot, lowland, degraded	**56**	Nimiago 2011
Danar 3	Logged 2006, lowland, degraded	**31**	Nimiago 2011
Watut 3	Logged 1995, montane	**113**	Nimiago 2011
Watut 7	Primary forest, montane	**103**	Nimiago 2011

Altitude certainly has an effect in temperate environments – and aspect too





A horizon carbon, Benmore Range, New Zealand
(McIntosh et al. 2000)

Factors to take into account

at the broad landscape scale:

1. **Geology** – especially volcanics and basic igneous rocks.
2. **Altitude** – at least lowland versus montane

   (is altitude closely correlated with vegetation type?)

3. **Aspect** – probably not important in the tropics
4. **Past erosion** – very hard to model

At the catchment scale

5. **Soils of swamps and poorly drained floodplains** – soil carbon independent of geology or altitude (?)

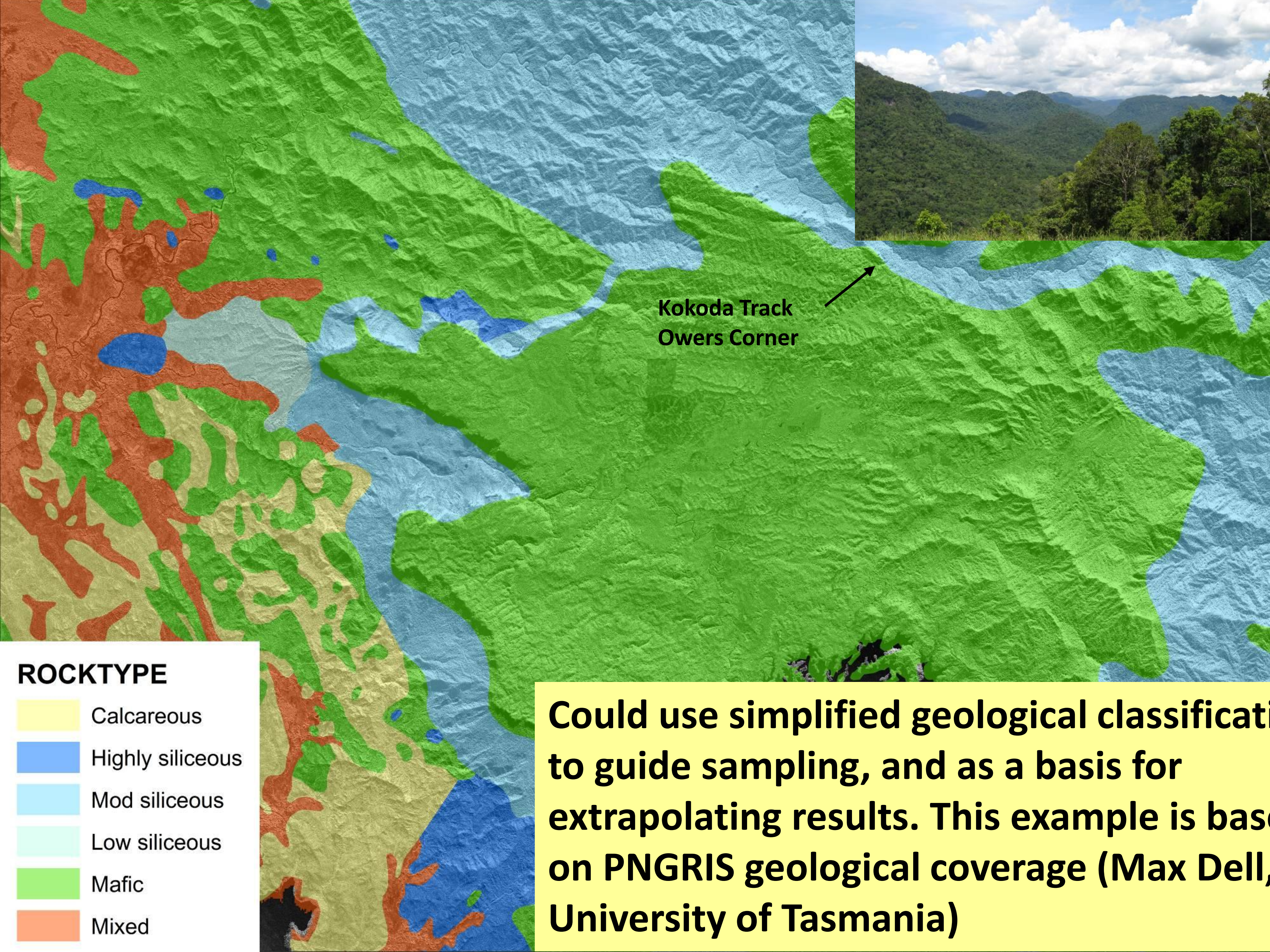
Possible sampling strategy

Ideal strategy: c. 1000 sites in random stratified sampling

- 10 rock types x 3 altitudes (lowland *and* mid-altitude *and* montane) x c. 30 replicates, + 30 independent sites = **930** sites in total

Simple alternative factorial strategy

- 5 rock types (sedimentary, metamorphic, acid igneous, basic igneous, siliceous alluvium) x 3 altitudes (lowland *and* montane) x 6 replicates, + 6 incidental sites = **96** sites in total



Could use simplified geological classificati to guide sampling, and as a basis for extrapolating results. This example is base on PNGRIS geological coverage (Max Dell, University of Tasmania)

Sampling within sites

Question: How many samples are needed to characterise a site (i.e. to cover site variation)?

McIntosh et al. 1997, Table 2:

For A horizons (0-10 cm and 10-20 cm) ten replicates per site were sufficient to show significant ($P<0.05$) C% and BD differences between farmland (n=12) and reserves (n=12) and between soil types (n=3).

So ten sub-sites for each site is probably the minimum to cover within-site variation.

Sampling at sites

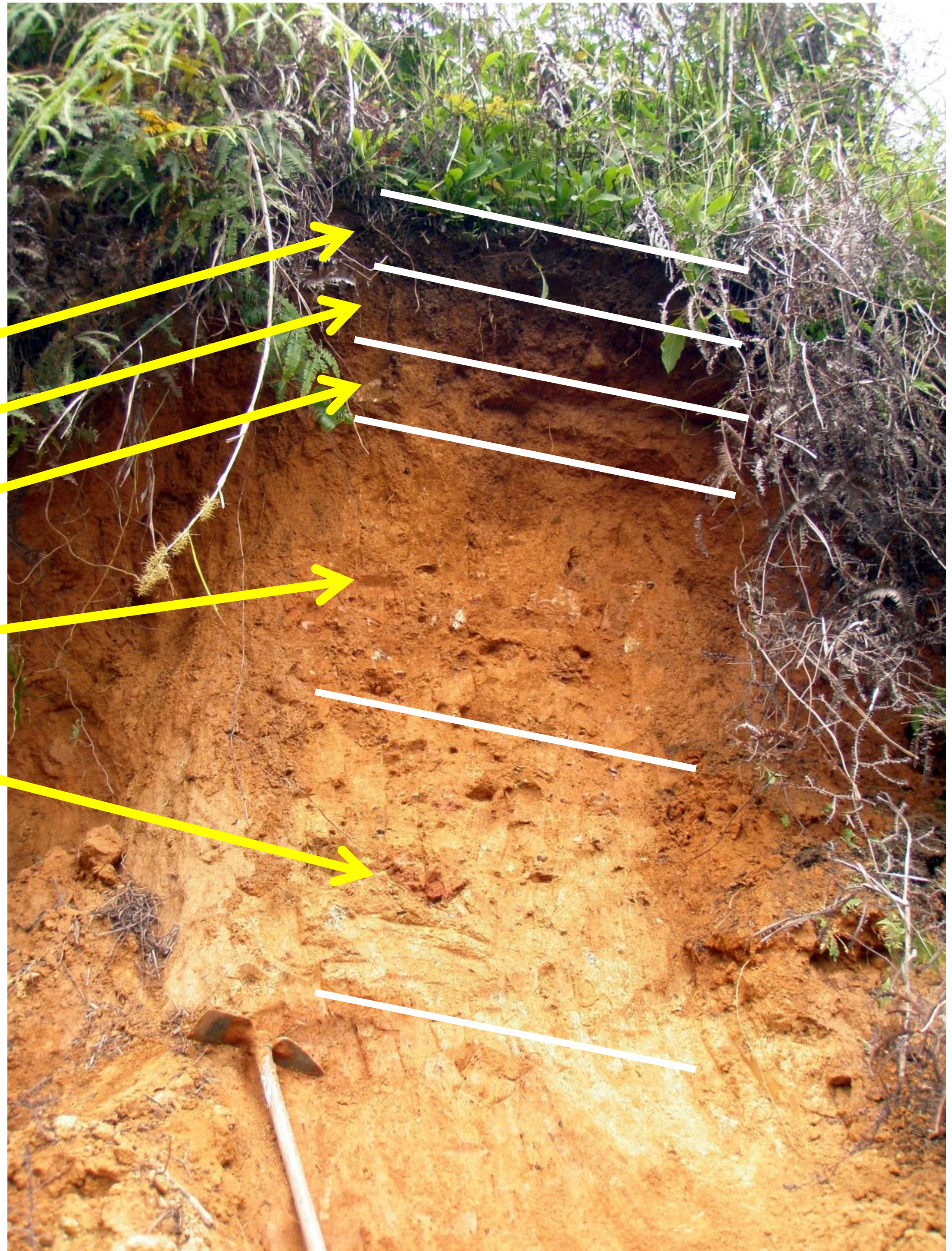
10 samples for C and BD: 0-10 cm

10 samples for C and BD: 10-20 cm

10 samples for C and BD: 20-30 cm

1 sample for C and BD: 30-60 cm

1 sample for C and BD: 60-100 cm



5 samples for analysis per site (if topsoils combined);
32 per site (if topsoils kept separate)

Number of samples for analysis

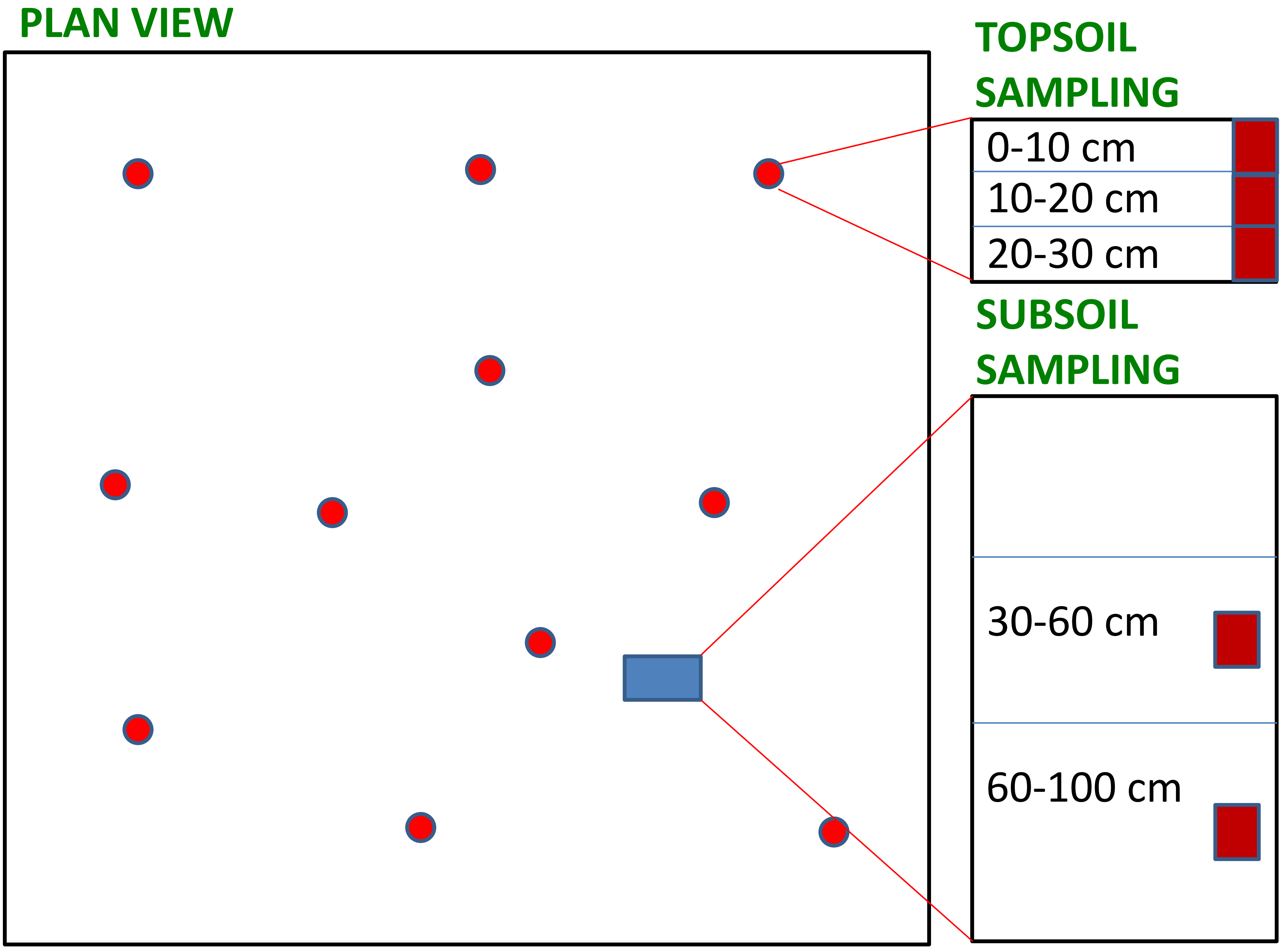
	Ideal strategy (930 sites)	Factorial strategy (96 sites)
Within-site bulk sampling (5 samples per site)	**4650** ~$140 000	**480** ~$14 500
Within-site replication (32 samples per site)	**29960** ~$900 000	**1920** ~$52 500

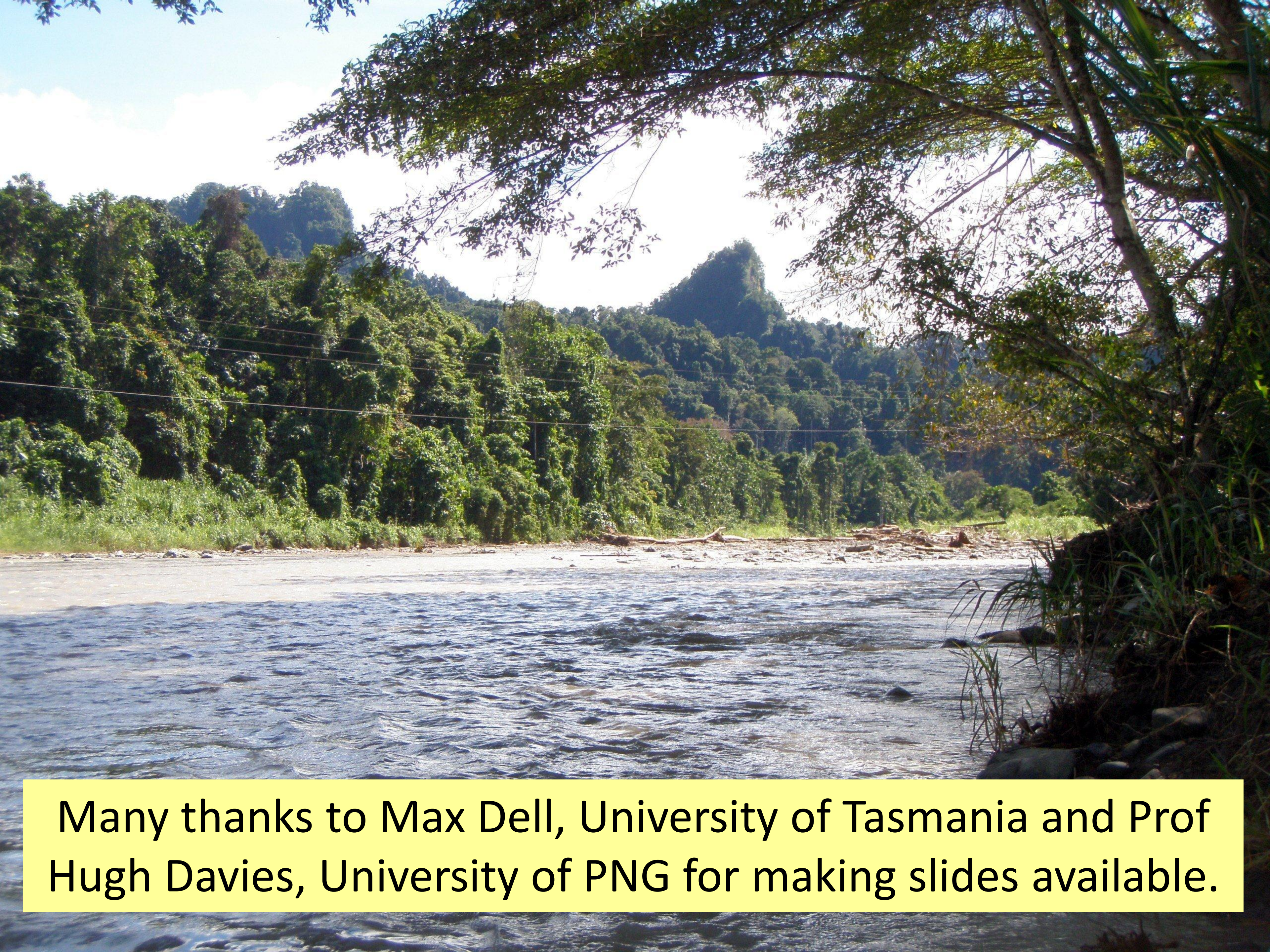
The choice is essentially between maximum landscape coverage integrated with above-ground surveys, and a readily analysed factorial design

Sampling team and sample numbers

At each site

- Two people dig ten 0-30 cm soil pits and sample 0-10 cm, 10-20 cm and 20-30 cm soils for soil carbon and bulk density.
- Samples for the same depth are combined to give a total of 3 samples for soil carbon and BD.
- Two people dig 0-100 cm soil pit and sample 30-60 cm and 60-100 cm soils for soil carbon and bulk density (2 samples for soil carbon and BD).


PLAN VIEW
TOPSOIL SAMPLING
0-10 cm
10-20 cm
20-30 cm
SUBSOIL SAMPLING
30-60 cm
60-100 cm


Many thanks to Max Dell, University of Tasmania and Prof
Hugh Davies, University of PNG for making slides available.