Spatial and Temporal Variation of Residence Time and Storage Volume of Subsurface Water Evaluated by Multi-tracers Approach in Mountainous Headwater Catchments

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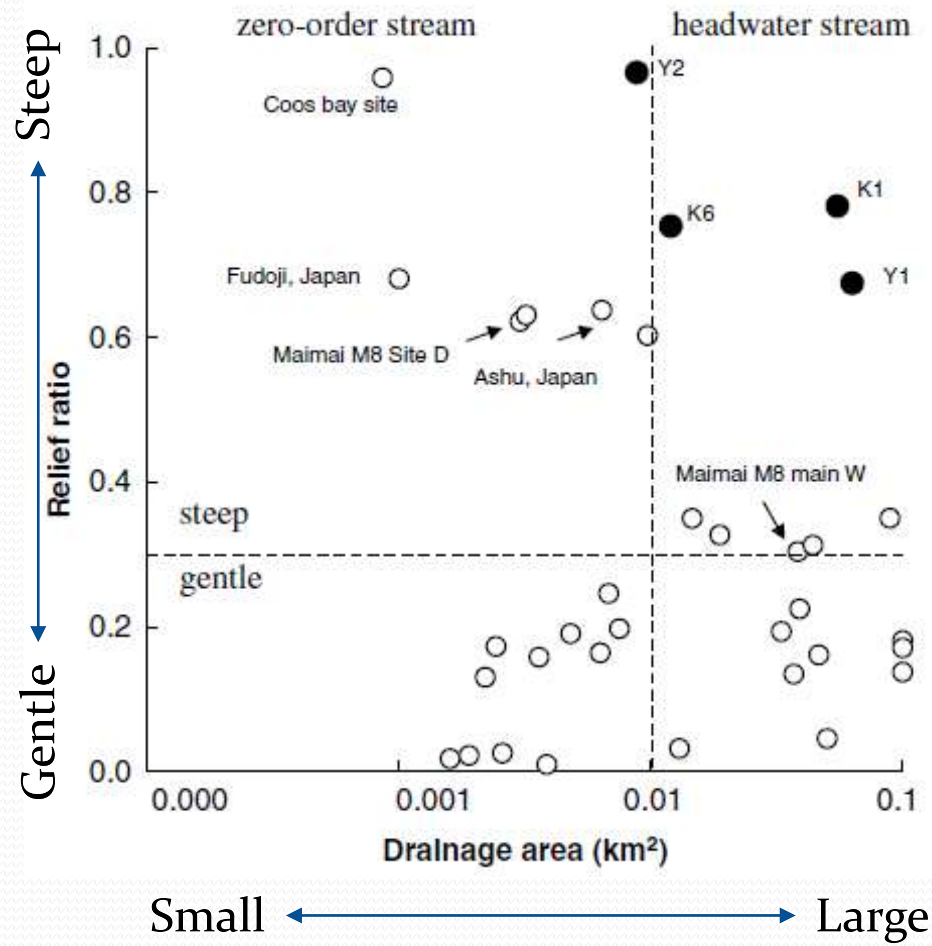
Mountainous Headwaters

- Recharge area for every water resource
- Steep topography
  - > 60% of land covered by mountainous area in Japan
- Reactive to hydrological processes in time and space
  - Rainfall-runoff processes …
  - → Variation in time/ space of water residence time and storage in watershed
- Few researches on variation of water residence time in time and space in mountainous watersheds

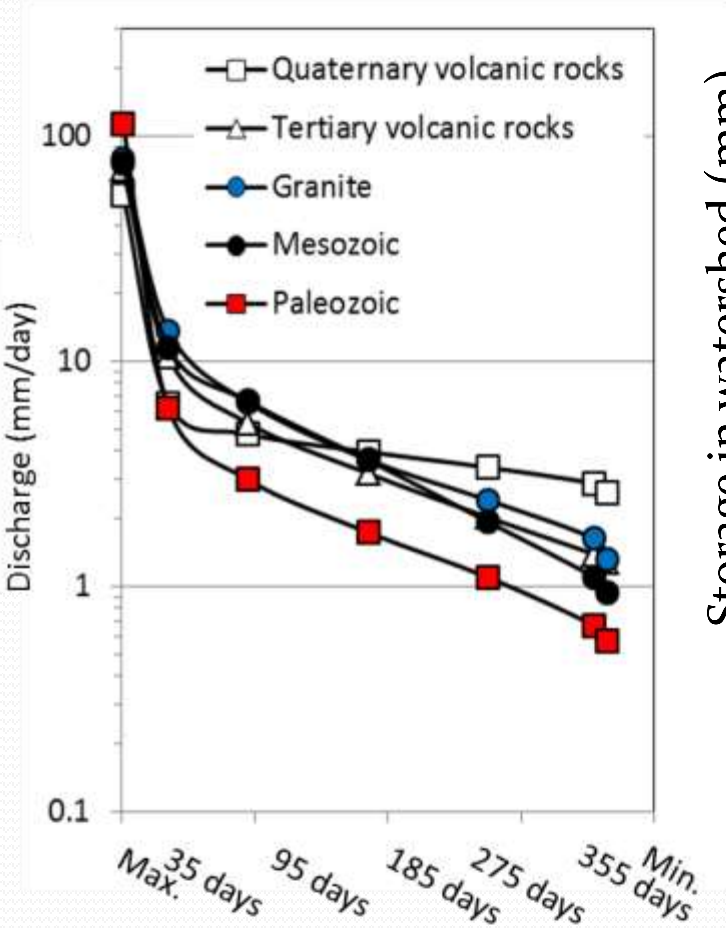


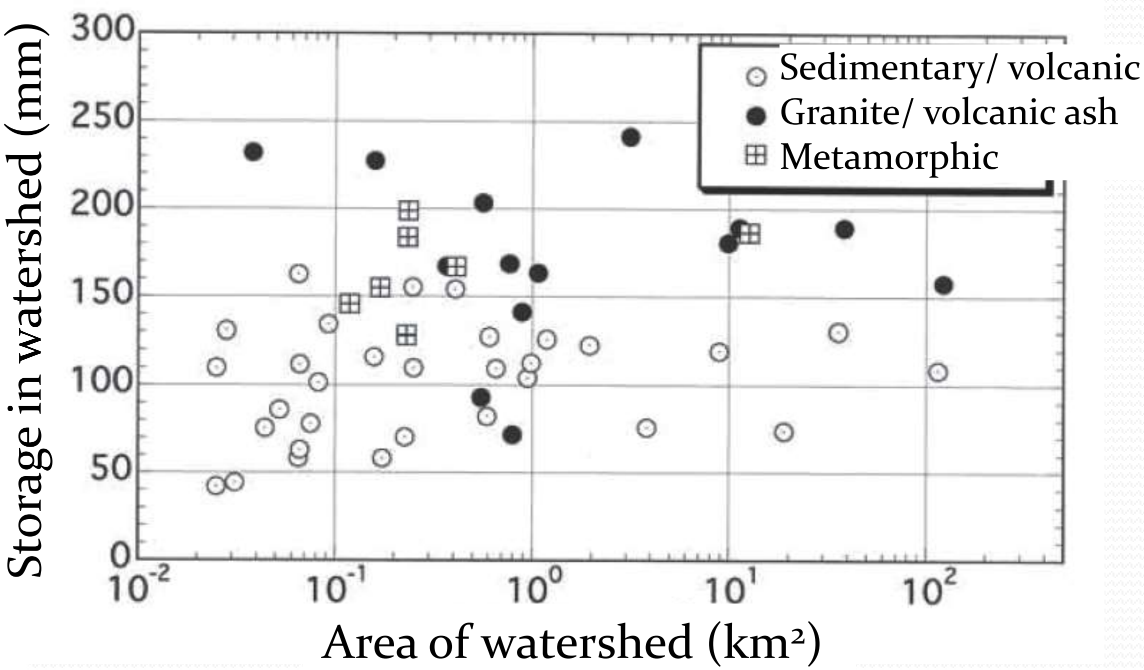
Onda et al. (2006)
Topographical characteristics of previous studies on rainfall-runoff processes in headwaters

Previous studies on residence time of groundwater in mountainous regions

Study area	Geology	Tracer	Residence time (year)	References
Mt. Rokko	Granite	^3H	15 – 40	Kitaoka, Yoshioka (1984)
Mt. Tsukuba	Granite, Gabbro	CFCs	10 – 44	Matsumoto (2011)
Mt. Iwate	Andesite, Basalt (Quaternary)	^3H	17 – 38	Shimada (2011)
Mt. Yatsugatake	Andesite (Quaternary)	^3H	1 – 60	Kakiuchi, Marui (1994)
Mt. Yatsugatake Mt. Ontake	Andesite (Quaternary)	CFCs	20 – 30 Less than 10	Asai, Tsujimura (2010)
Mt. Ontake Mt. Dainichigatake	Andesite (Quaternary)	SF_6	4 – 10 9 – 32	Asai et al. (2011)
Mt. Aso Caldera	Andesite (Quaternary)	^3H, CFCs	20 – 35	Kagabu et al. (2011)

Storage volume in mountainous headwaters





Storage vs watershed area estimated by short term water budget (Fujieda, 2007)

Discharge duration curves evaluating storage capacity of watersheds (Musiake, et al., 1981)

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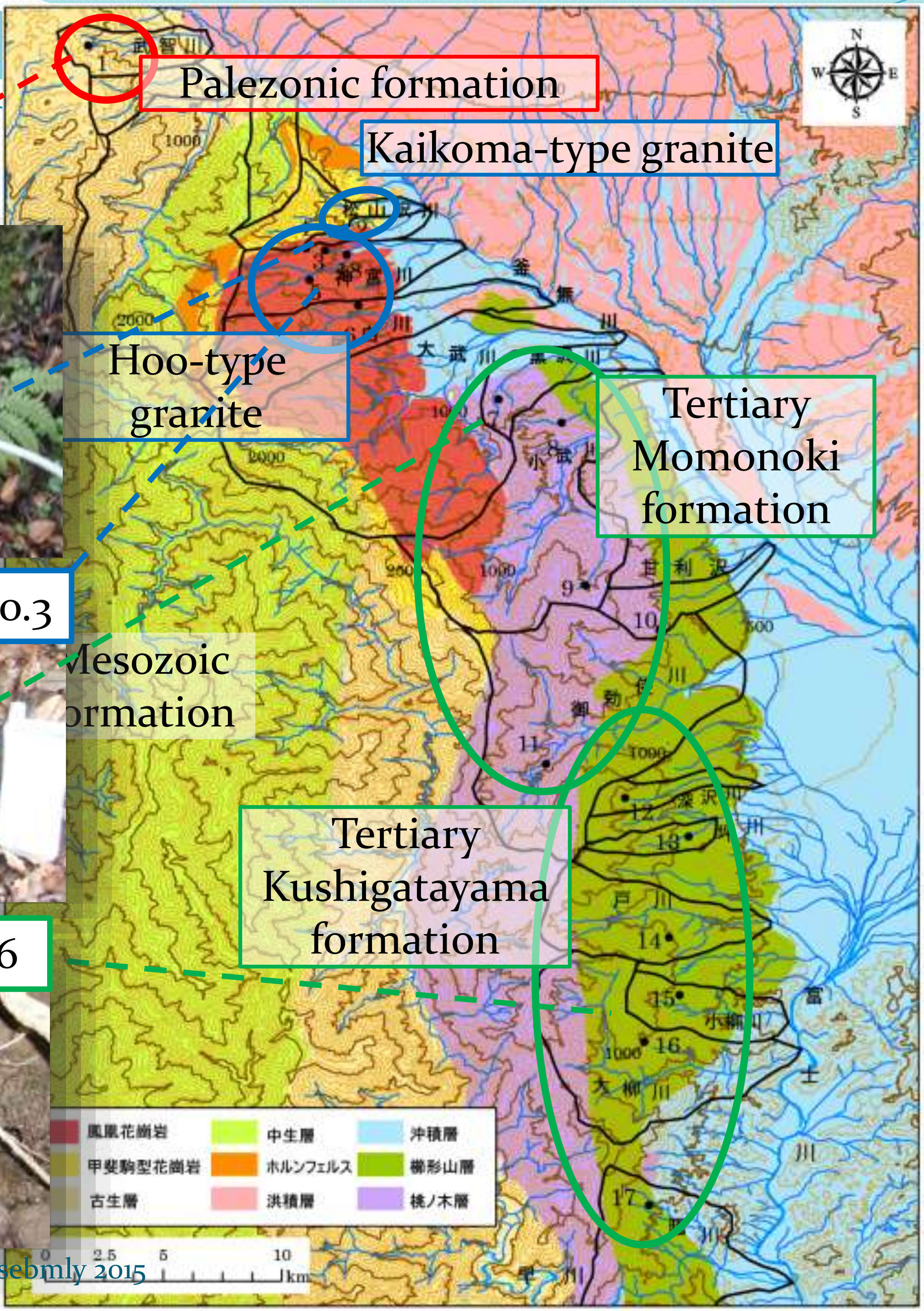
Objective

To investigate temporal and spatial variation of residence time and storage in subsurface water to understand hydrological processes / dynamics causing them in mountainous headwaters underlain by different lithology

Study Area



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Methods

- Periods and locations
  - Temporal change
    - Small scale: Jingu River Watershed (Granite); 15 Springs/ Streams
    - Aug, Nov 2007, June, Aug, Sep, Nov 2008 (6 times)
  - Spatial distribution
    - Large scale: 18 Springs
    - Mar, Apr, Aug, Nov 2011, Aug 2012, May, Sep 2013 (7 times)
- Measurement in situ

  Water temperature, pH, EC, ORP
  Discharge (incl. monitoring)
- Analysis
  - CFCs concentration for age dating
  - Inorganic ion (Na^+, K^+, Mg^{2+}, Ca^{2+}, Cl^-, NO_3^-, SO_4^{2-}, HCO_3^-, SiO_2)
  - Hydrogen and Oxygen stable isotopes(δD, $\delta^{18}O$)

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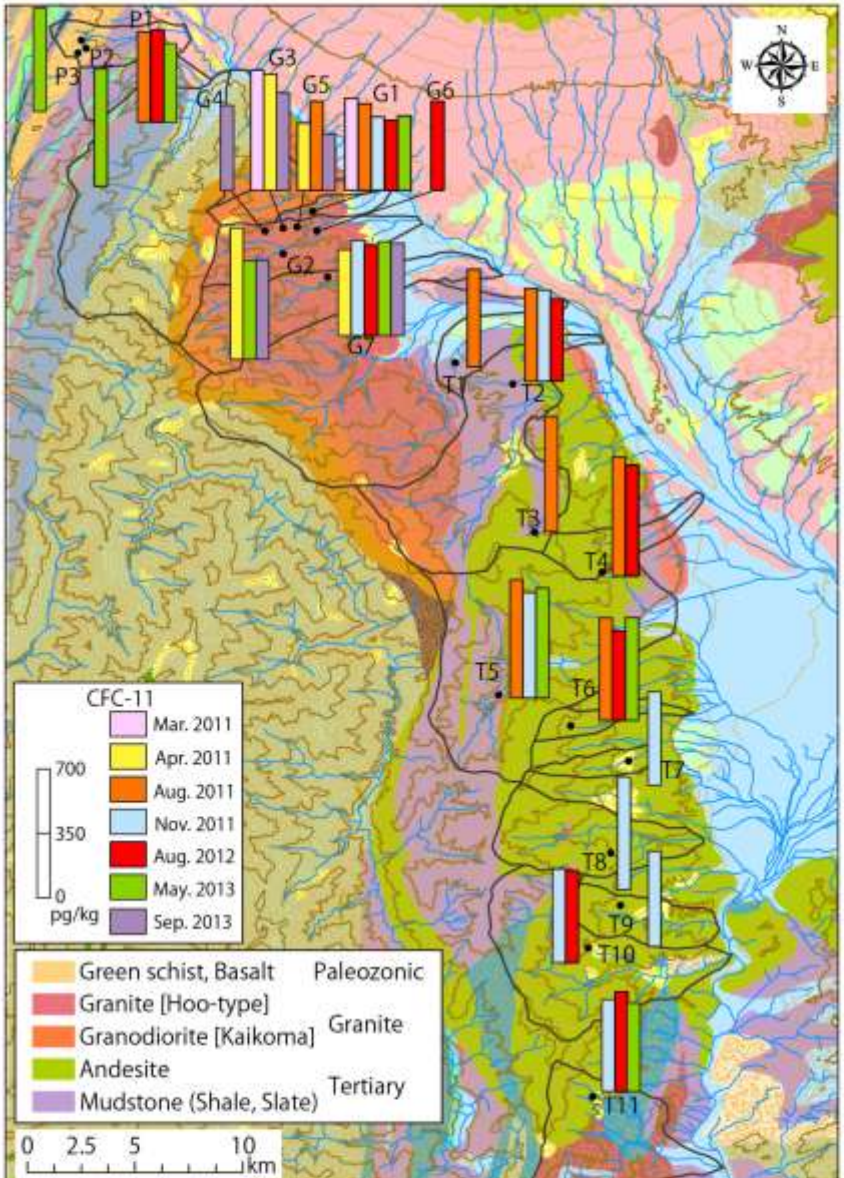
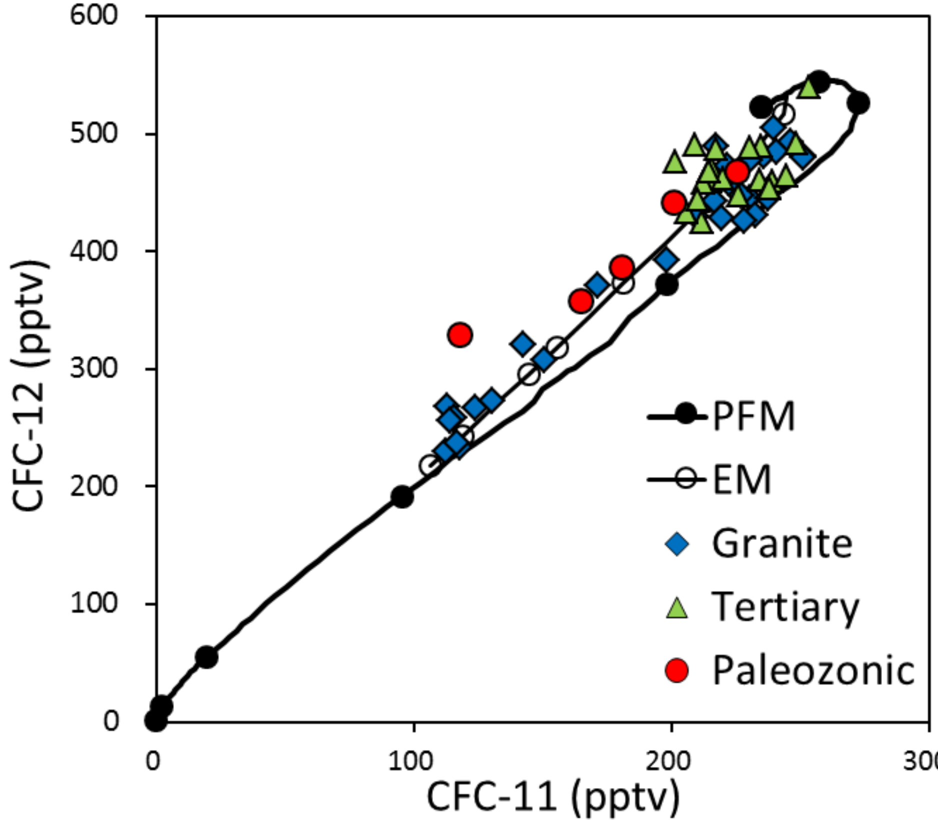
CFC-11 variation in time & space





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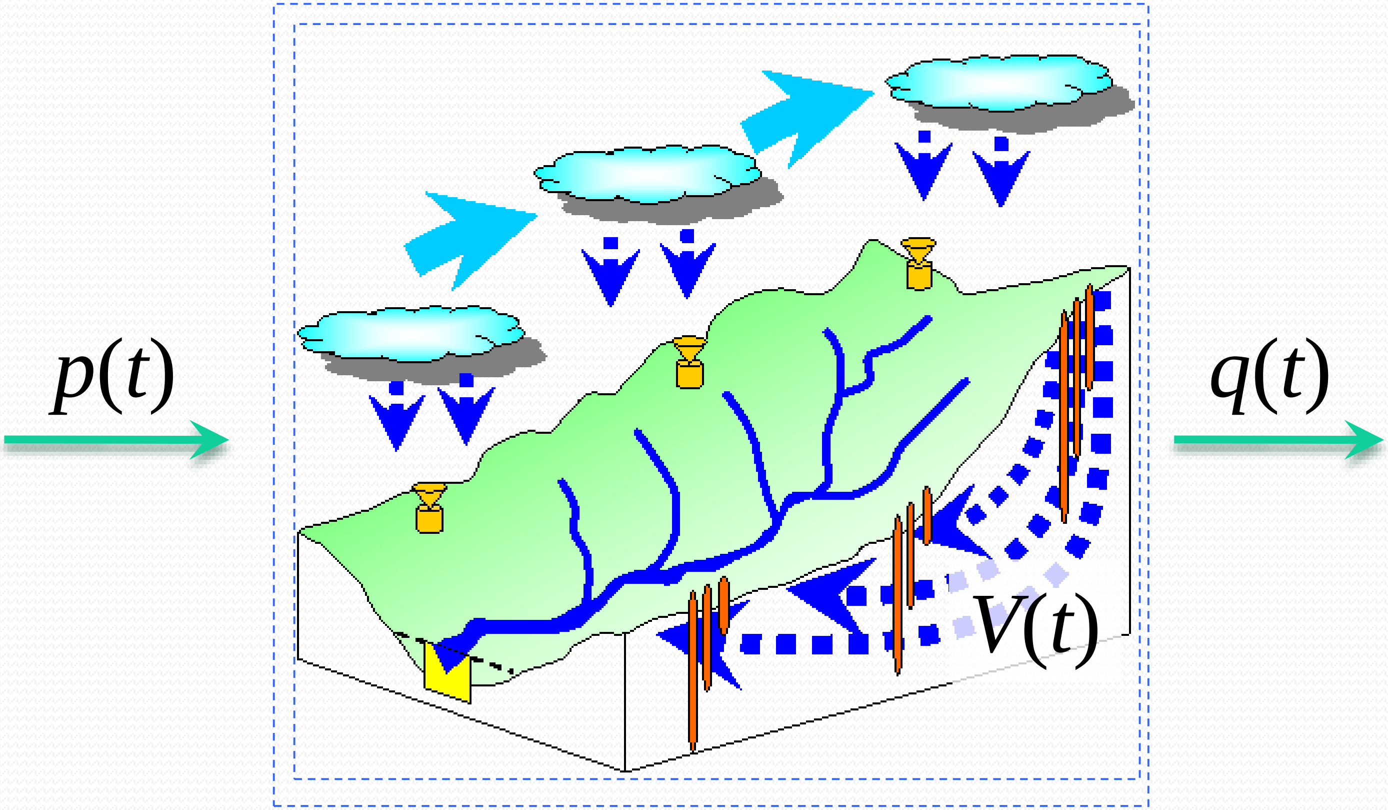
Age (*Tr*) vs. Storage (*V*)

$$Tr = \frac{V}{q} \Rightarrow V = Tr \times q$$



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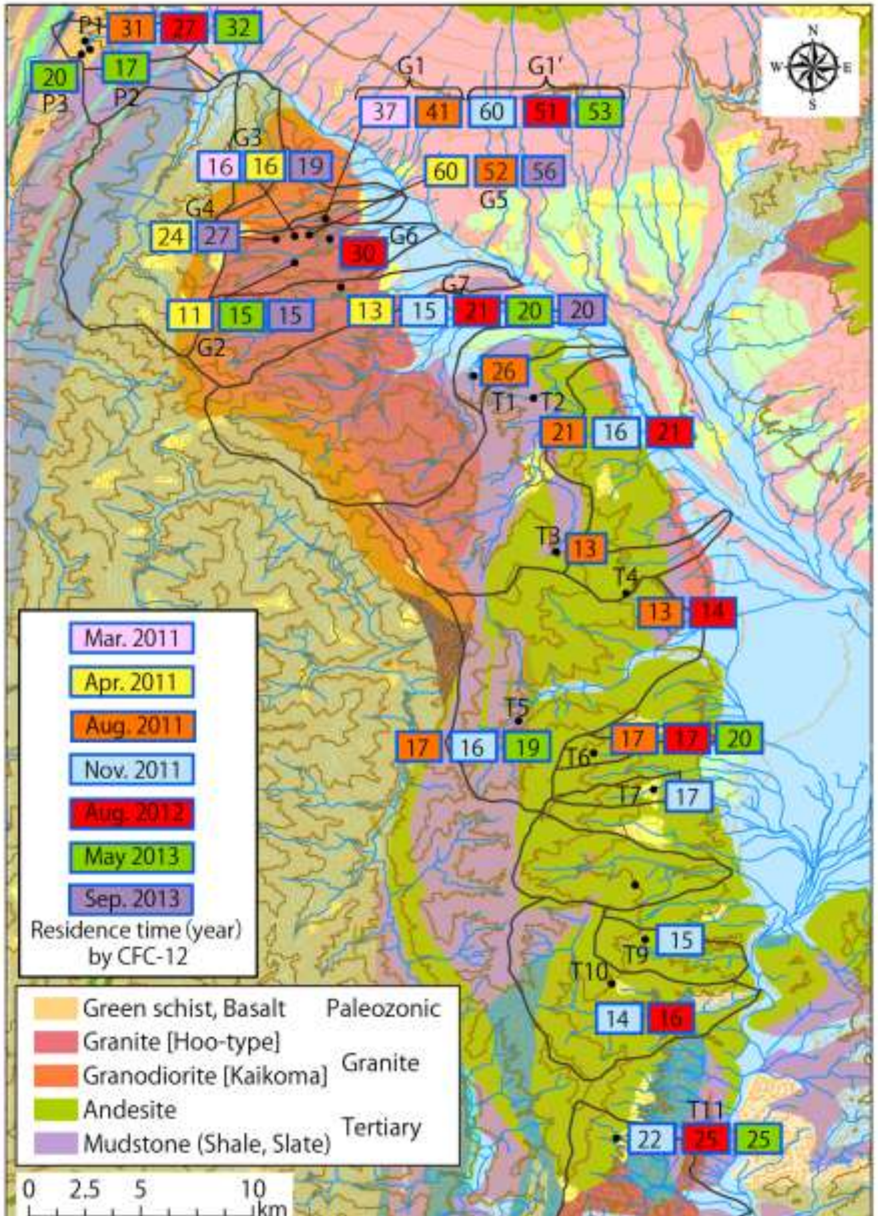
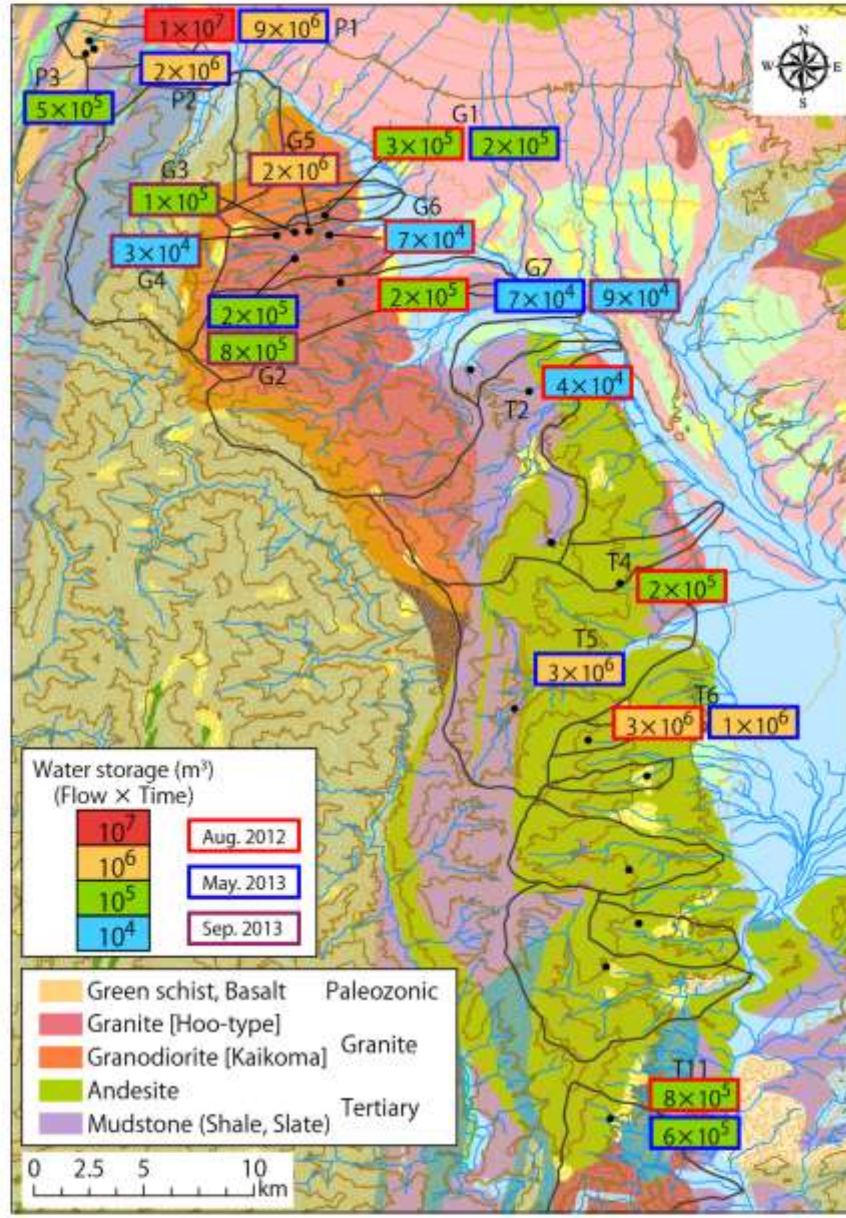
Age



Storage



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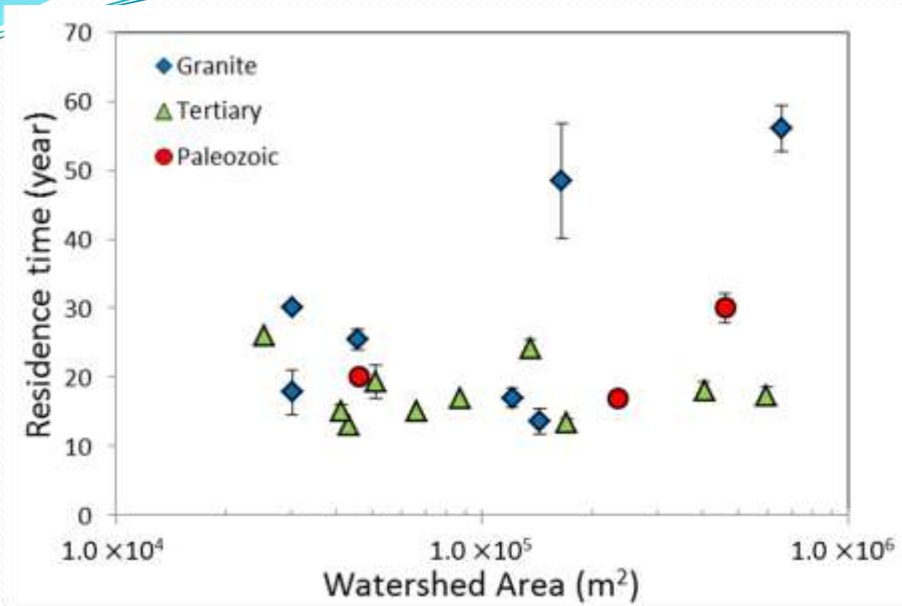
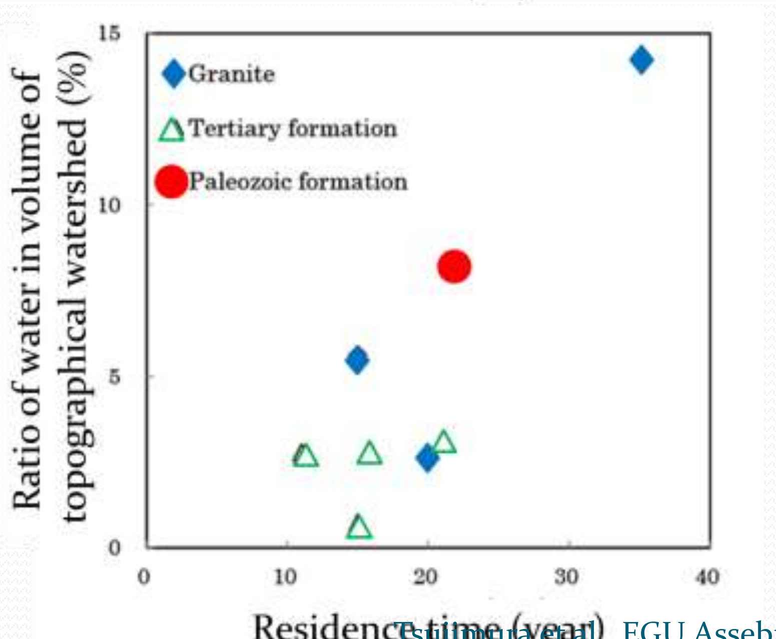
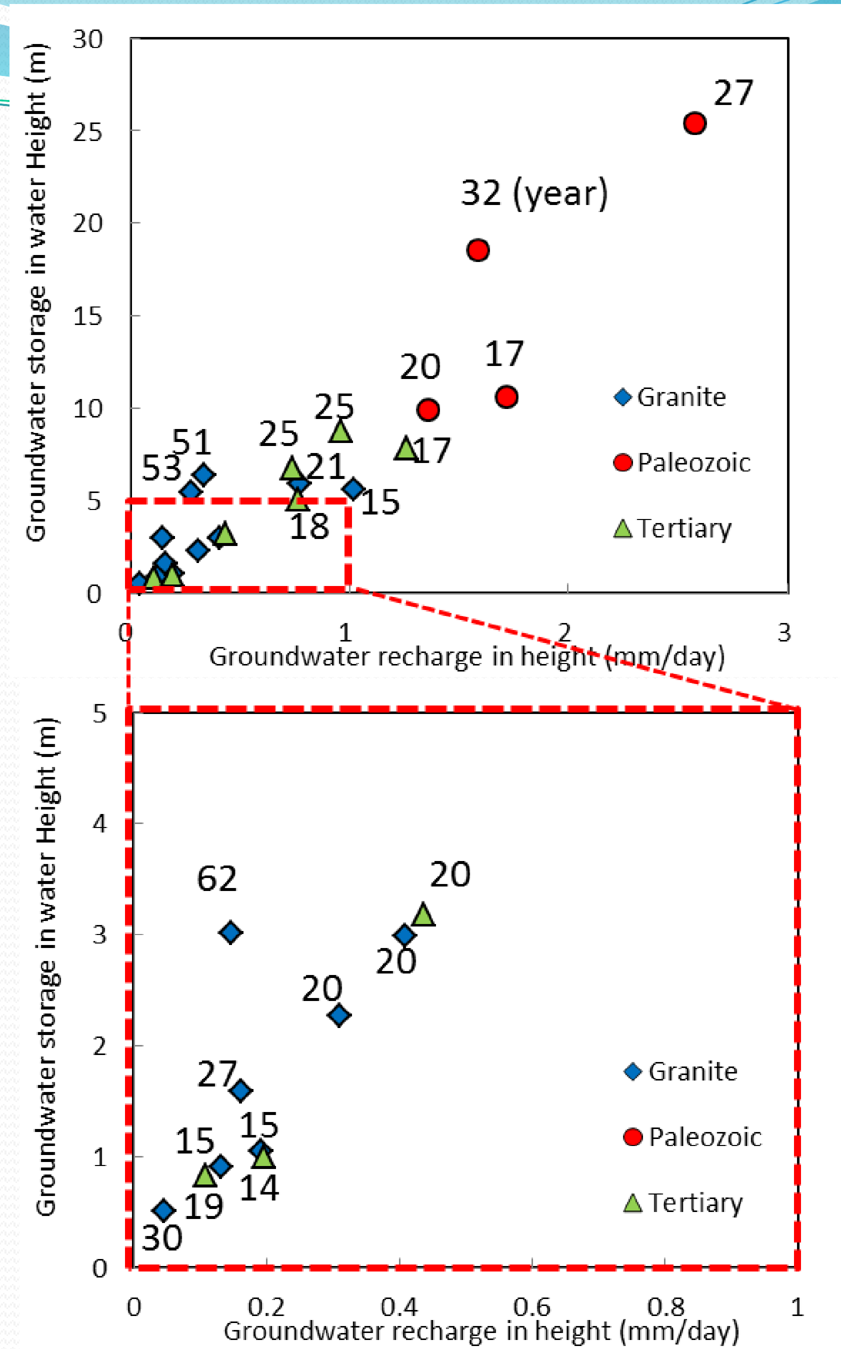
Age vs. Storage







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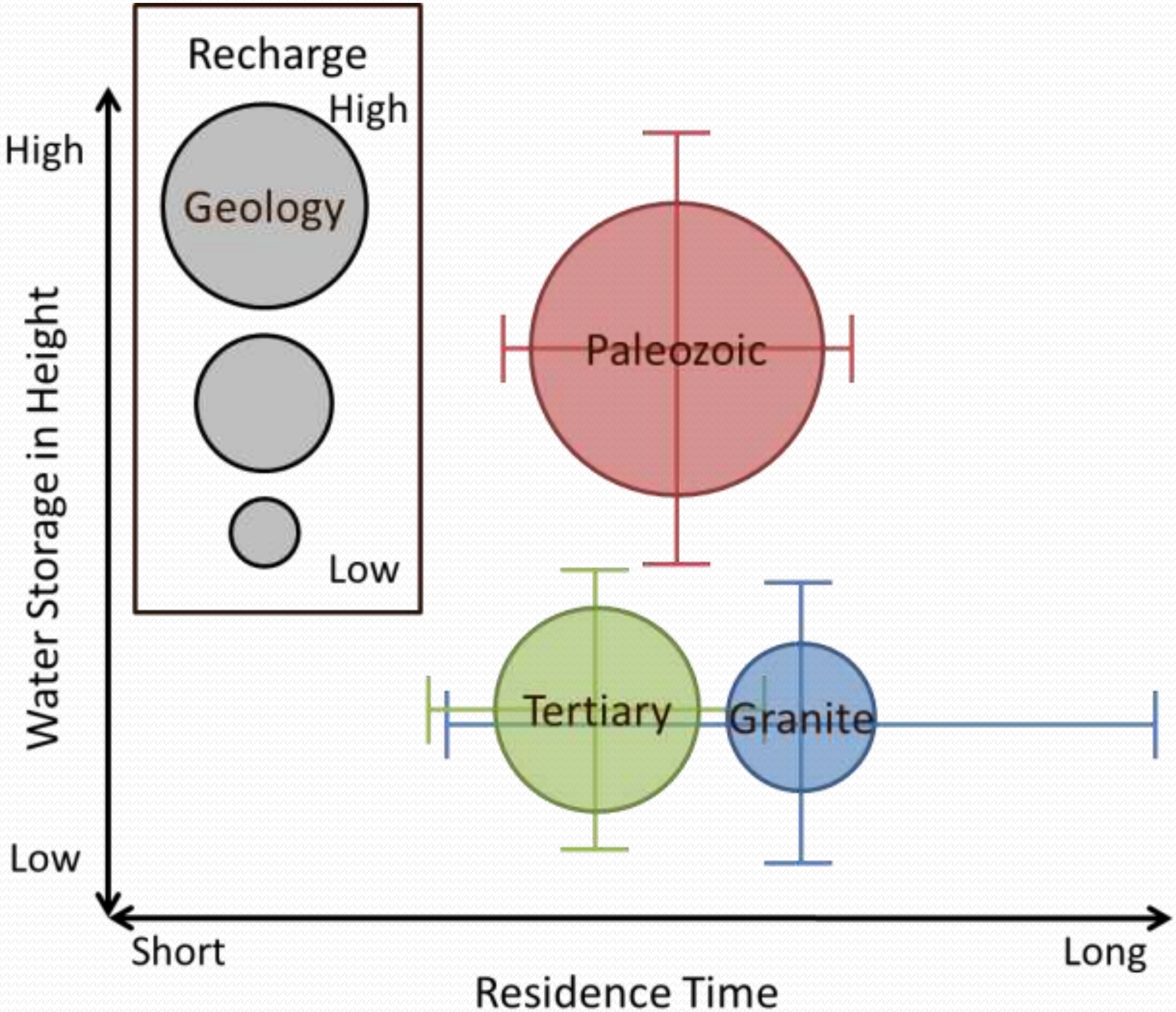
Geology, Age and Storage



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Concluding remarks

- Residence time of subsurface water varies with hydrological situation with a range of 3 yrs to 10 yrs.
  - High flow situation causes a dominant contribution of young water, whereas old water contributes much in low flow situation.
- Residence time of subsurface watert in granite watersheds ranges from 11 to 36 yrs, 22 to 28 yrs in Paleozoic, 6 to 22 yrs in Tertiary.
- Water storage ranges from 10^4 to 10^6 m^3.
  - Paleo: 10^5 - 10^7; Granite: 10^4 - 10^6; Tertiary: 10^5 - 10^6
  - Storage in high flow season is 30% to 100% higher than low flow season

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