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Abstract:
Most Hard Rocks (HR) are or were exposed to deep weathering processes. It turns out that the hydraulic conductivity of HR is mostly inherited from these weathering processes (Lachassagne *et al.*, 2011):

(i) within their permeable Stratiform Fissured Layer (SFL) located below the low hydraulic conductivity unconsolidated weathered layer (saprolite). The thickness of both layers often reaches more than 100 m (Dewandel *et al.*, 2006),

(ii) and within the permeable vertical fissured layer developed at the periphery of or within preexisting geological discontinuities (joints, dykes, veins, lithological discontinuities, etc.) (Dewandel et al., 2011, Roques *et al.*, 2012).

From this conceptual model, the drainage discharge and the surface hydrogeological (piezometry in wells) and hydrological (discharge of streams) impacts of shallow highway tunnels drilled in a metamorphic series (metasedimentary and metavolcanic rocks) intruded by granitic bodies have been forecasted. These tunnels belong to the A89 highway recently opened (2012) in France between Balbigny and La Tour de Salvagny (Monts du Lyonnais, 50 km West of Lyon city). They are up to 4 km long, and their depth below ground level ranges between 0 and 300 m. The method is based on:

1. the location of the tunnel within or below the various layers constituting the weathering profile. Four different weathering profiles with ages from Triassic to post Miocene were identified , and mapped (extension, thickness). Their relative effects (fissuration) in the various lithologies of the area have been identified (Fig. 1);
2. steady state groundwater discharge measurements in existing tunnels (railway) of the area where weathering profiles were similarly mapped;
3. application of the Goodman *et al.* (1965) analytical solution that allowed (i) to inverse steady state railway tunnels groundwater discharge into the hydraulic conductivity of the various layers of the weathering profiles, and (ii) to compute the discharge of the future highway tunnels, on the basis of the hydraulic conductivity of the weathering profiles that these highway tunnels crosscut.

The actual discharge of the now completed highway tunnels (Fig. 2) validates the accuracy of the methodology. For instance, the forecasted discharge of the main 4 km long Violay tunnel was between 4 and 7 l/s and was finally about 6 l/s in the tunnel. The hydrological impact on surface water (low stage stream discharge) was also forecasted for each surface watershed intersected by the tunnels (Fig. 2, Gantet watershed, in red). This method proves to be very efficient for shallows tunnels in hard rock areas.

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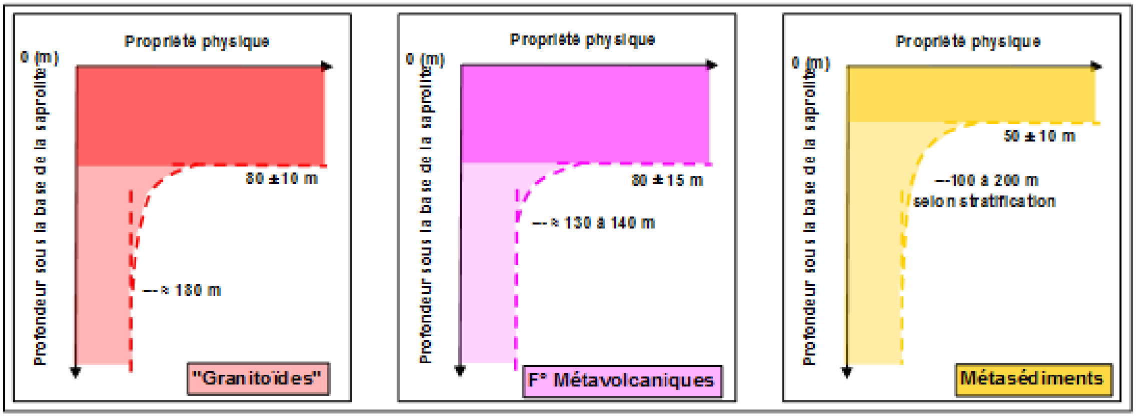

Figure 1: geometric characteristics of the phase 2 weathering profile SFL for various lithologies (Y: depth below the saprolite base, Z: modelled physical property, hydraulic conductivity for instance)

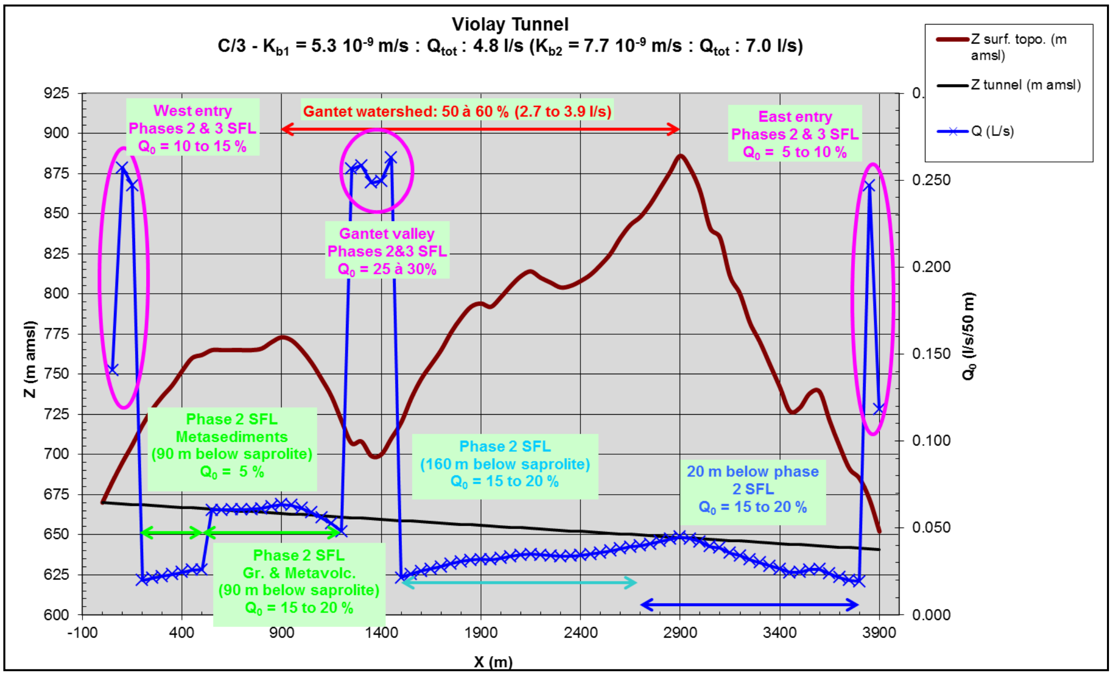

Figure 2: Violay tunnel computed discharge Q_0 (blue crosses - L/s/50 m of tunnel) according to the lithology, the weathering grade and the depth of the tunnel (black line) below the topographic surface (brown profile). Red: estimated low stage discharge loss in the Gantet watershed