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Impact of active faulting on the post LGM infill of Le Bourget Lake (western Alps, France)

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ABSTRACT

We have used high resolution seismic imaging to detect and characterize the recent deformation recorded by the Quaternary sediments of Le Bourget Lake. The last glacial episodes (MIS 6a and 2, i.e., Riss and Würm) scoured out an elongated over-deepened basin to more than 300 m below the present lake level and the basin accumulated 150 m of post-LGM to Holocene sediments. The well-stratified character of the infill is locally disturbed by tectonic deformations and gravity reworking. A northern fault zone, in continuation with the left-lateral strike–slip Culoz Fault, is imaged within the Holocene and Late Glacial accumulations. A southern fault zone is also detected, which can be related to the sub-lacustrine continuation of a much smaller fault affecting the Jura alpine foreland: the Col du Chat left lateral strike–slip fault. Different generations of fractures have been identified in the lake, allowing correlation and mapping. In pre-Quaternary substratum, the Culoz Fault has a N 160° orientation. Within the post-LGM sediments, fractures related to the Culoz Fault have an orientation between N135° and 95°. A Cloos model (1932) is thus proposed to explain the observed pattern of lacustrine deformations. The calculated horizontal slip rate for Culoz Fault during Holocene is about 1.3 mm·yr^{-1}, and for the Col du Chat Fault is around 0.6 mm·yr^{-1}.

1. Introduction

High-resolution seismic reflection profiling has been used by different authors to image neotectonic faults. Doughty et al. (2013) employed this method to image faults in Lake Timiskaming (Canada). Adams et al. (1999) used it in the Lake Lahontan Basin (Nevada, California) to see isostatic rebound, active faulting and potential geomorphic effects. Van Daele et al (2011) saw Riedel faults in Gulf of Cariaco, along El Pilar Fault. In particular, we can consider the pattern of faults associated with the major strike–slip El Pilar Fault as possible analogue of the Cloos (1932) model. This model shows Riedel fractures forming in the clay on 2 metal plates acting in shear.

The north-western Alps foreland and the Jura Mountains (Fig. 1) are currently subjected to moderate deformation induced by the anticlockwise rotation of the Adria microplate relative to stable Eurasia (Biju-Duval et al., 1977; Delacou et al., 2008; Nocquet, 2012; Vigny et al, 2002). In addition to this kinematics, the fast disappearance of the Last Glacial Maximum (LGM) glacial cover and the mass transfer following the LGM is considered to have significantly enhanced seismicity and gravity instabilities through the unloading effect (Beck et al., 1996; Vernant et al., 2013).

Based on seismological, geological and geodetic surveys, detailed patterns of active faulting (including subsurface décollements, blind ramps and deeper crustal thrusts) have been proposed (e.g., Jouanne et al., 1995, 1998; Thouvenot et al., 1998), underlining the importance of NW–SE left-lateral strike–slip offsets as along the Vuache Fault (cf. the 1996 Epagny event; Thouvenot et al., 1998). In parallel with this tectonic evolution, the last glaciation/deglaciation cycles (isotopic stages 1 and 2) contributed to develop large and over-deepened lacustrine basins represented either by thick lacustrine, marshy and fluvial deposits, or by still sub-aqueous sediments accumulations. A cross section of Lake Le Bourget (Fig. 2) illustrates this mixed heritage of alpine tectonics (Miocene growth strata in front of ramps), glacial erosion, and interglacial lacustrine accumulation (remnants of the last major cycles, MIS 6a and 2). In this paper, we propose to use the post-LGM infill of Lake Le Bourget as a recorder of the moderate deformation caused by the strike–slip faults that structured the southern Jura Mountains. To do this, we used high-resolution seismic profiles to highlight and map Quaternary fault activity in Lake Le Bourget.

2. Geological setting

2.1. The pre-Quaternary substratum

The Jura fold and thrust belt represents the most external part of the Alpine Chain in its northwestern portion (Burkhard and Sommaruga,

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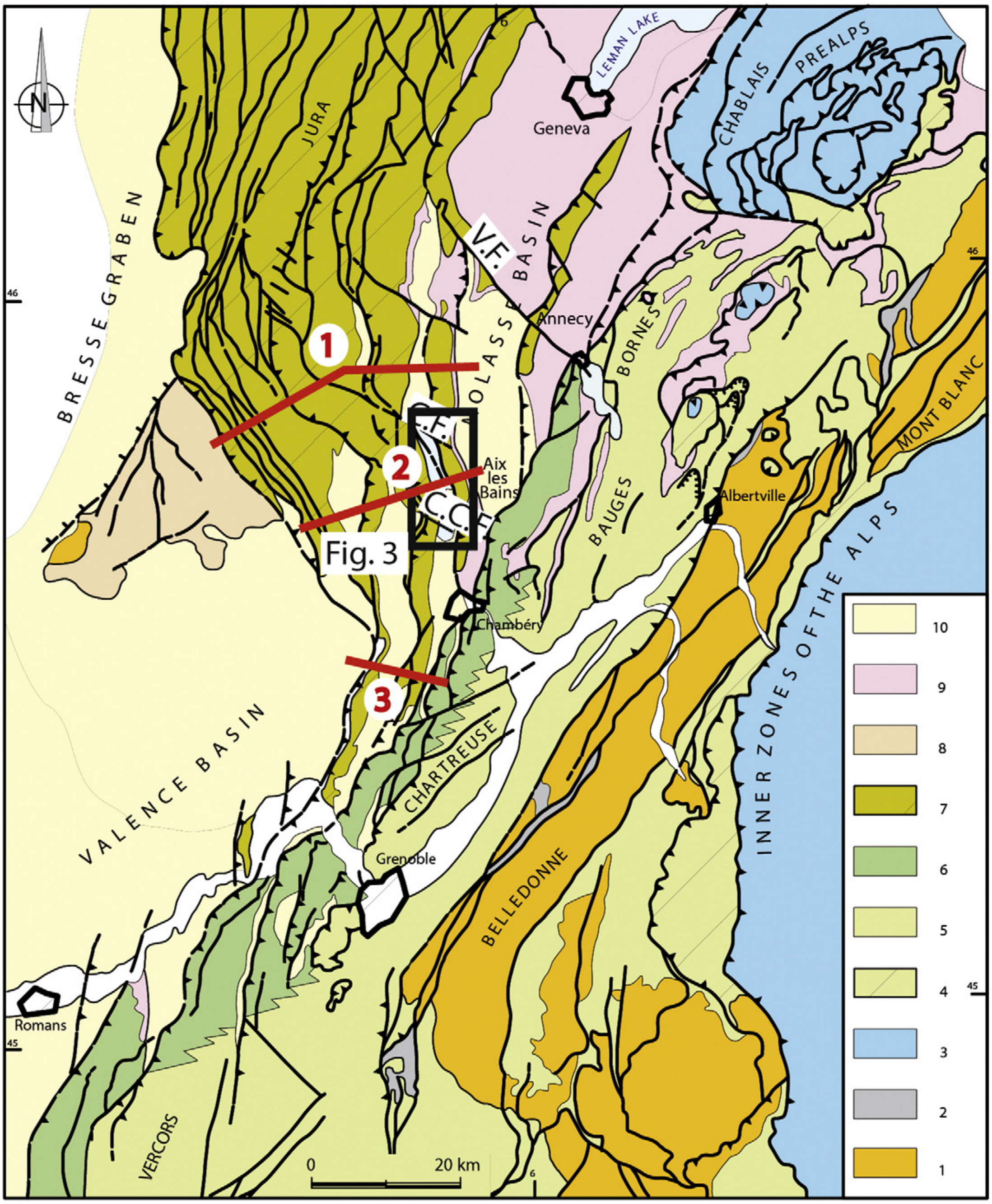

Fig. 1. Geological and structural sketch map of northwestern Outer Alps and Jura foreland. 1. Crystalline basement; 2. Permo-Carboniferous basins; 3. Inner Alps; 4 to 7: Outer Alps Mesozoic series (4, Ultra-dauphinois s.; 5, Dauphinois s.; 6, Pre-subalpine s.; 7, Jurassian s.); 8. Autochthon Mesozoic series; 9. Oligocene–Lower Miocene siliclastics; 10. Middle–Upper Miocene and Pliocene silicilastics. V.F.: Vuache Fault; C.F.: Culoz Fault; C.C.F.: Col du Chat Fault. Location of Fig. 2's cross sections is shown in red.

1998; Guellec et al., 1989; Philippe, 1995; Willett and Schlunegger, 2010). Horizontal shortening in the Jura took place above a basal décollement horizon within Triassic evaporites during the Miocene and Pliocene.

In its southern part, the Jura Mountains present a virgation (an arch form) related to the tapering of Triassic evaporite levels towards the Chambéry area (Fig. 2). North of Lake Le Bourget, the Jura mountains are well developed, with a remarkable structural morphology. The thinning (?) of the low friction detachment level between the southern and central Jura mountains is also accommodated by a set of strike–slip transfer faults (Vuache, Culoz, and Col du Chat faults; Fig. 1), which promotes differential deformation in both sides of the faults.

2.2. The southern termination of the Molassic Basin

Le Bourget Valley is located at the northwestern front of the French Alps between the Gros Foug and Le Chat Mounts, two N–S trending reliefs which bound the south-westernmost occurrence of Rupelian to Serravalian molassic deposits. The Gros Foug and Le Chat Mount ramp anticlines (Figs. 2 and 3) mainly formed during an Early–Middle Miocene thrust sequence (Deville et al., 1994).