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“Late Quaternary lacustrine paleo-seismic archives in north-western Alps: Examples of earthquake-origin assessment of sedimentary disturbances”

Christian Beck

Laboratoire de Géodynamique de Chaînes Alpines, U.M.R. C.N.R.S. 5025, Université de Savoie, 73 376 le Bourget du Lac Cedex, France

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A B S T R A C T

The late Quaternary sedimentary fills of several lakes of the north-western Alps are revealed to be possible paleo-seismological “archives” in a moderately active seismo-tectonic region. The strongest historically reported events can be correlated with specific layers, whose textures result from different processes: i) mass failures of sub-aqueous slope deposits (especially delta foresets) evolving into hyperpycnal currents influenced by seiche effects and/or multiple reflections on lake basin slopes; ii) *in situ* liquefaction and flowage; and iii) micro-fracturing. Based on identification of the sedimentary signature of a well-documented historical earthquake, the paleoseismic interpretation can be extrapolated back to 16,000 yrs BP with a reconstruction of a time series and textural identification of slope failure-related turbidites (the most frequent earthquake signature). The obtained time series are compatible with historical seismicity in terms of recurrence interval.

Contents

1. Introduction . . . 327
2. Signature of a historical earthquake in Lake Le Bourget . . . 332
   2.1. Characterization of the 1822 earthquake in Lake Le Bourget sediments . . . 332
      2.1.1. Chronological constraints . . . 334
      2.1.2. Specific texture of the 1822-homogenite . . . 335
      2.1.3. Lateral correlations, 3D distribution, and origin of the reworked material . . . 335
   2.2. Summary and explanatory model . . . 336
3. Time distribution of earthquake-related events along a 16,000 yr-record in Lake Annecy . . . 337
   3.1. The post-LGM lacustrine sedimentary fill . . . 337
   3.2. Types of sedimentary events tentatively related to earthquakes . . . 337
   3.3. Time distribution of events tentatively related to moderate earthquakes. . . . 337
4. Discriminating flood-related turbidites from slump-induced turbidites: destabilization of lacustrine deltas and huge runoff, in a small high altitude lake (Anterne Lake) . . . 339
   4.1. Grain-size evolution in Lake Anterne's turbidites . . . 340
   4.2. Comparison of time distribution of “slump turbidites” with local historical seismicity . . . 340
5. Conclusions and perspectives . . . 342
Acknowledgements . . . 342
References . . . 342

1. Introduction

As combined seismology and seismo-tectonics progressively led to the development of concepts and models dealing with the “seismic cycle” or the “stick-slip behaviour”, it has become essential to estimate “recurrence time intervals” (e.g. Burridge and Knopoff, 1967; Shimazaki and Nakata, 1980). For this purpose, long-lasting paleoseismic records along major active fault zones, representing time series longer than historical datasets, became essential data. Detailed studies, such as along the North-Anatolian Fault, discuss time and space distributions of major events and their driving mechanisms

E-mail address: beck@univ-savoie.fr.

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(e.g. Ambraseys and Finkel, 1991; King et al., 1994; Armijo et al., 1999). In parallel, the effects of sudden earthquake-induced increase of pore-water pressure in unconsolidated sediments have been investigated both for geotechnical needs (Mulder and Cochonat, 1996) and as potential means of recording ancient earthquakes. These investigations concern both sub-aqueous marine or lacustrine settings, or continental area involving groundwater. The connection between co-seismic ruptures and/or liquefaction is investigated through natural outcrops or trenches studies, and combined with modelling (e.g. Kuenen, 1958; Seilacher, 1984, Sieh, 1978; Obermeier, 1989; Obermeier et al., 1991; Tuttle and Seeber, 1991; McCalpin, 1996; Sieh, 1996; Moretti et al., 1999). Empirical relationships between three groups of parameters – magnitude/intensity, distance between affected sediments and epicentral area, and sediment texture – have been established and are progressively refined with new data (e.g. Allen, 1986; Pederneiras, 1991; Vittori et al., 1991; Audemard and De Santis, 1991; Hibsch et al., 1994).

Concerning marine or lacustrine sub-aqueous processes, contributions from different geodynamic settings and periods (from Proterozoic to Recent) progressively converge to better assess the interpretation of several sedimentary features and layering types as earthquake signatures (e.g. Macar and Antun, 1950; Plaziat et al., 1988; Van Loon et al., 1995; Ringrose, 1989; Ben-Menahem, 1976; Beck et al., 1992; Piper et al., 1992; Roep and Everts, 1992; Syvitski and Schafer, 1996; Calvo et al., 1998; Pratt, 1998; Nakajima and Kanai, 2000). Biochemical effects of earthquake-induced fluid release also have been mentioned (e.g. Twiddle and Crossley, 1991). Estimations of paleo-intensities of recorded earthquakes have been proposed, based on properties and volumes of remobilized sediments (e.g. Séguret et al., 1984; Hibsch et al., 1994; Rodriguez-Pascua et al., 2003). Besides, time-distributions of paleo-earthquakes have been proposed for extended periods (in Holocene and older accumulations), both in marine and in lacustrine settings (e.g. Adams, 1990; Sims, 1973; Marco and Agnon, 1995; Beck et al., 1996; Weidlich and Bernecker, 2004).

In several cases, different kinds of evidences – surface faulting, rock slides, lacustrine sediments disturbances – can be used together to characterize the same major event (Becker et al. 2005) and thus better assess the seismic origin. When widespread and visible in different outcrops of the same unit, disturbed layers (interpreted as seismites and thus representing an isochronous surface), may offer reliable criteria for lateral correlation (Beck et al., 1998). Repeated earthquake-induced liquefactions have also been invoked by Francis (1971) to explain the geometry of terrigenous accumulations in a deep subduction trough. As the seismic profiles he analyzed show horizontal non-deformed layering in a structural position where horizontal shortening could be expected, Francis (1971) related this apparent anomaly to liquefaction and reworking of sediments during major earthquakes; he considered these processes as responsible for erasing previous structures within the sedimentary pile.

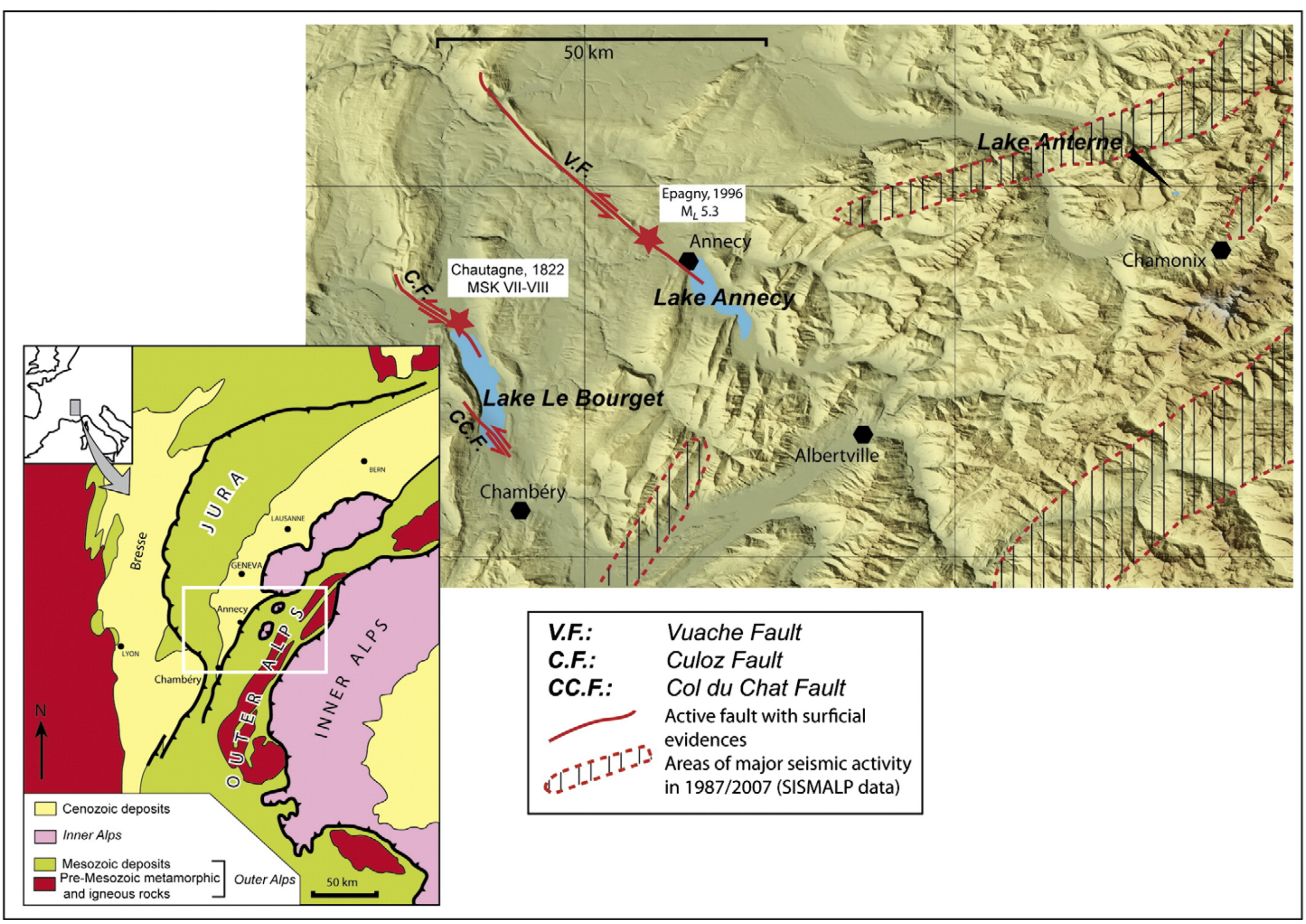

Fig. 1. Simplified structural geological map of the western Alps, and location of the studied lakes. (N.A.S.A. S.R.T.M. D.E.M.; active fault and earthquake data from Rothé (1941), Thouvenot et al. (1998), and Jouanne et al. (1994)).