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Corresponding author:
Sabyasachi Mandal;
Emails: sabyajugeo@gmail.com/ sabyasachi.mandal@bsip.res.in

Linking the impact of seismicity on palaeogeographic evolution and sedimentary architecture: A case study from Middle Jurassic succession of Spiti Himalaya

Sabyasachi Mandal[1], Abha Singh[1], Santanu Banerjee[2], Premraj Uddandam[1] and Ranveer Singh Negi[1]

[1]Birbal Sahni Institute of Palaeosciences, Lucknow, India and [2]Department of Earth Sciences, Indian Institute of Technology Bombay, Powai, Mumbai, India

Abstract

The traces left by earthquakes in the unlithified sediments, recorded as soft-sediment deformation structures (SSDS), are well reconstructed as palaeo-seismic signals, while the origin of SSDS, seismic vs. Aseismic, is challenging. The present study discusses the origin of SSDS and its implications on palaeoceanography and sediment architecture. In the Middle Jurassic succession of Spiti Himalayan region in India, the topmost part of the Ferruginous Oolitic Formation (FOF) consists of four layers of SSDS and is underlain by the lower member of the Spiti Formation (SF). The sedimentary facies analysis documents the palaeogeographic shift from the middle shelf (carbonate-shale repository: FOF) to the outer shelf (black shale: lower member of SF). The SSDS layers, exhibiting load casts, ball and pillow structures, indicate gravitational instability, while syn-sedimentary faults and insitu breccia are the results of brittle deformation. The dominance of storms in depositional sites often argues for a possible triggering agent for SSDS. Therefore, it was necessary to distinguish between seismic vs. aseismic triggering agents. The lateral continuity, vertical repetition, confinement of SSDS at the top part of FOF and sharp change of facies assemblage indicate seismicity-induced syn-sediment deformation, i.e. seismite. The transition from middle shelf to outer shelf at the onset of seismite indicates that seismic impact possibly caused the rapid subsidence, resulting in the palaeogeographic shift. The rapid transgression is recorded as carbonate-shale repository to anoxic black shale. This study highlights the importance of sedimentological analysis to distinguish the seismite and its implications on palaeogeographic evolution and sedimentary architecture.

1. Introduction

Soft-sediment deformation structures (SSDS), typically form during or shortly after sedimentation, but prior to lithification, are observed in various sedimentary environments from mountain to deep sea (Sims, 1973, 1975; Quia *et al.* 1994; Sarkar *et al.* 1995; Owen, 1996; Owen *et al.* 2011; Owen and Moretti, 2011; He *et al.* 2014; Sarkar *et al.* 2014; Laborde-Casadaban *et al.* 2021). The primary processes for SSDS formation, liquefaction and fluidization, governs by various factors, including deformation mechanisms, driving forces, and triggering agents (Owen *et al.* 2011). Liquefaction and fluidization processes are primarily induced by reverse density or gravitational instability (Owen, 1987; Quia *et al.* 1994; Moretti *et al.* (2016). Several significant research in deep-time sediment sequence relates the SSDS with ancient earthquake (*seismite*; Seilacher, 1969). The correlation of SSDS with earthquake magnitude and its relation with maximum distance of liquefaction from earthquake epicentre provide a better understanding of tectonics activity (Silva *et al.* 1997; Vanneste *et al.* 1999; Rodríguez-Pascua *et al.* 2000; Greb and Archer, 2007; Salomon *et al.* 2018; Morsilli *et al.* 2020). Recent investigations have revealed that the formation of SSDS can also be triggered by aseismic forces such as storm waves, tidal shearing, rapid sedimentation and overloading (Quai *et al.* 1994; Moretti and Sabato, 2007; Owen *et al.* 2011; Van Loon and Dechan, 2013; Van Loon and Pisarska-Jamroży, 2014; Jamil *et al.* 2021). Studies exploring the relationship between seismic and aseismic triggers of SSDS suggest that neither the deformation structures nor their characteristics can uniquely identify the triggering agents (Owen *et al.* 2011). The researchers engaged in palaeo-seismicity study propose that seismic deformed beds may exhibit lateral persistence, vertical repetition and change of SSDS morphology in lateral continuity (Seth *et al.* 1990; Montenat *et al.* 2007; VanLoon, 2009; VanLoon and Pisarska-Jamroży, 2014; Owen *et al.* 2011; Quai *et al.* 2013; Zhong *et al.* 2022). However, a number of researchers records these characteristics of SSDS beds in storm- and tide-dominated environments (Alfaro *et al.* 2002; Owen *et al.* 2011; Shanmugam,