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Unusual soft-sediment deformation structures in the Maritimes Basin, Canada: Possible seismic origin

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ABSTRACT

Soft-sediment deformation structures provide information on the early deformation history of sedimentary rocks. In the Mississippian Horton Group of the Windsor–Kennetcook subbasin of the Maritimes Basin in Nova Scotia, soft-sediment deformation structures include well-known features like load structures, neptunian dykes, and an intraformational breccia. More unusual features include sedimentary boudins, upward-convex bulb structures, and unique structures here termed microbasins. Microbasins are geometrically similar to minibasins associated with salt tectonics, but about three orders of magnitude smaller. These deformation structures formed when primary stratification was in a weakened state due to liquidization of sediment. Two types of structures exist: those that formed at the sediment surface and those that formed later, during burial. The triggering mechanism for soft-sediment deformation structures in the Horton Group was likely seismicity and overpressured conditions. A strong preferred orientation of soft-sediment structures oriented NW–SE is attributed to dextral strike-slip on the E–W Minas Fault Zone. Seismicity associated with movement along faults associated with the Minas Fault Zone could have induced liquidization of sediment.

1. Introduction

Soft-sediment deformation structures provide information on early deformation of sedimentary rocks mainly in tectonically active environments such as strike-slip systems, pull-apart basins, and sedimentary basins cut by faults (Hempton and Dewey, 1983; Plint, 1985; Rossetti, 1999; Alsop and Marco, 2011; Berra and Felletti, 2011; Waldron and Gagnon, 2011). Common soft-sediment deformation structures include convolute laminae, load structures, and slump deposits (Allen, 1986; Obermeier, 1996; Collinson, 2005; Gibert et al., 2005; Kang et al., 2010; Owen and Moretti, 2011), interpreted to result from liquidization of sediment. Striking soft-sediment deformation structures are present in the Mississippian Horton Group within the Windsor–Kennetcook subbasin of the Maritimes Basin in Nova Scotia (Fig. 1), which is known to have been tectonically active during deposition. The structures here described include common examples like load structures, neptunian dykes, and an intraformational breccia, but also structures that have been more rarely described, here termed sedimentary boudins, bulb structures, and microbasins. Dykes within Horton Group strata were described by Hesse and Reading (1978) and Martel and Gibling (1993); sedimentary boudins were described by Waldron et al. (2007). However, these authors made contrasting interpretations. No previous interpretation accounts for all soft-sediment deformation structures in the Windsor–Kennetcook subbasin. The purpose of this study is to describe and interpret the many soft-sediment deformation structures present in the well-exposed coastal outcrops on the shores of the macrotidal Bay of Fundy, and to integrate interpretations in order to attribute them to a deformation mechanism and trigger for deformation.

2. Regional geology

The Upper Paleozoic Maritimes Basin is a large (400 km maximum diameter) and deep (>12 km) basin covering a large portion of onshore and offshore Atlantic Canada (Fig. 1) (Roliff, 1962; Keppie, 1982; Gibling et al., 2008; Hibbard and Waldron, 2009). This basin formed in the Appalachian orogen, following Devonian (Acadian) orogenic events, during a period of transtension (Calder, 1998; Hibbard and Waldron, 2009; Waldron et al., 2014; Waldron et al., 2015). The Maritimes Basin is structurally complex, consisting of multiple subbasins trending generally northeast and east, and separated by uplifted basement rocks (Boehner and Giles, 1993; van de Poll et al., 1995; Murphy et al., 2011; Waldron et al., 2013). Deformation of strata within the Maritimes Basin was a multi-stage process including periods of folding, faulting, uplift, salt tectonism, erosion, and subsidence (Knight, 1983; Hamblin and Rust, 1989; Calder, 1998; Waldron, 2004; Wilson et al., 2006; Waldron et al., 2013; Craggs et al., 2015; Dafoe et al., in press). The subbasins have undergone multiple phases of subsidence and inversion, leading to the deposition of stratigraphic sequences separated by unconformities (St. Peter, 1993). Because of these basement block

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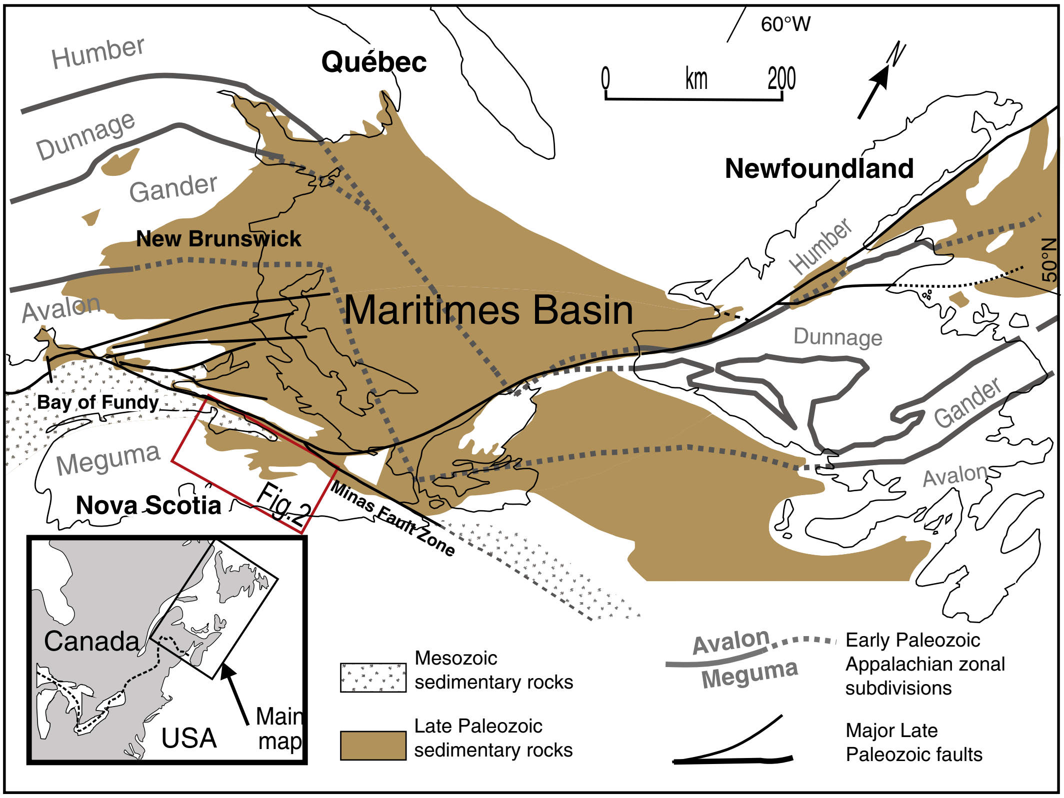

Fig. 1. Distribution of the Maritimes Basin in Atlantic Canada. Location of the Windsor–Kennetcook subbasin highlighted. Modified from Waldron et al. (2007).

movements, there is much lateral and vertical facies variation within and between subbasins.

The Windsor–Kennetcook subbasin is located within the Maritimes Basin (Fig. 2). The lowest stratigraphic unit within the subbasin, and the unit of interest in this study, is the Late Devonian to Tournaisian Horton Group (Fig. 2) (Bell, 1929). Across the Maritimes Basin, Horton Group and equivalent strata are typically interpreted as fluvial and lacustrine clastic deposits with possible local marine influence (Bell, 1944; Knight, 1983; Martel and Gibling, 1996; Lynch et al., 1998; Park et al., 2010); Wightman et al. (1993).

Within the Windsor–Kennetcook subbasin the Horton Group is separated into two formations: the lower Horton Bluff Formation, and the upper Cheverie Formation (Bell, 1929).

2.1. Horton Bluff Formation

Several stratigraphic schemes have been used to subdivide the Horton Bluff Formation in the Windsor–Kennetcook subbasin. Bell (1929) initially divided the formation into a basal, middle and upper member, whereas Martel and Gibling (1996) recognized four members: Harding Brook, Curry Brook, Blue Beach and Hurd Creek. Moore et al. (2000) grouped Martel and Gibling's Harding Brook Member and Curry Brook Member into a redefined lower member, and recognized middle and upper members that are approximately equivalent to the Blue Beach Member and Hurd Creek Member respectively of Martel and Gibling (1996). Fig. 2 details the relationship between different schemes; the Martel and Gibling (1996) classification is used in this paper.

The lowermost Harding Brook Member of the Horton Bluff Formation is defined by dominant sandstone with variable conglomerate, siltstone, and mudstone interpreted as the deposits of active channels (Martel and Gibling, 1996). This unit is the most coarse-grained unit within the Horton Bluff Formation. The Curry Brook Member is defined by coarsening-up mudstone to sandstone cycles (Martel and Gibling, 1996). The mudstone is bioturbated; organic-rich layers and siderite nodules are present. Cycles consist, from base to top, of: mudstone, alternating mudstone and planar-bedded siltstone to sandstone, and are capped by tabular coarsening-up ripple cross-laminated fine- to very coarse-grained sandstone (Martel and Gibling, 1996). The Curry Brook Member is interpreted as lacustrine deposits (Martel and Gibling, 1996).

The Blue Beach Member contains most of the soft-sediment deformation structures described here. It is defined by dark grey shale and mudstone, fine sandstone, dolostone, and common paleosol horizons (Moore et al., 2000). Six repeating facies are described by Martel and Gibling (1993) as: (1) grey mudstone and shale; (2) hummocky cross-stratified siltstone; (3) wave-rippled sandstone; (4) planar siltstone; (5) green mudstone; and (6) dolomite. The Blue Beach Member is interpreted by Martel and Gibling (1991) as deposited in a large, wave-dominated lake, although Wightman et al. (1993) inferred a marine influence based on the presence of agglutinated foraminifera.

The facies are organized in coarsening- and shallowing-up cycles that are interpreted to represent repeated cycles of tectonic subsidence followed by shoreline progradation (Martel and Gibling, 1993). The soft-sediment deformation structures described below occur in facies (1), (2) and (4) and include dykes, microbasins and boudins.

The Hurd Creek Member is composed of coarse grey medium- to coarse-grained sandstone (Moore et al., 2000). Cycles consist from base to top: (1) basal shale, (2) planar and lenticular siltstone and shale, (3) flaser-bedded sandstone and/or (4) interbedded rippled sandstone (Martel and Gibling, 1996). Martel and Gibling (1996) interpret the Hurd Creek Member as deposited within a large wave-influenced standing body of water.

2.2. Cheverie Formation

The Cheverie Formation consists of three sections, which have not been distinguished as formal members. The bottom part of the