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Characterization of hirnantian paleo-ice streams in central Sahara : implications on the Late Ordovician ice sheet dynamics.

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Ice streams are corridors of fast ice flow between stagnant ice within an ice sheet. They are of major interest since they discharge most of ice and sediments of an ice sheet. Authors assumes that ice streams affect thermohaline circulation, so global climate. Thus their recognition in former glacial series is capital to grasp former ice sheets history, dynamic and associated sedimentary record. An aboundant litterature treats of recent and present day ice streams, in particular concerning the Laurentide, North Europeean, Antarctic and Greenlandic ice sheets. Topographic ice streams and pure ice streams have been discrimined, in the basis of the occurence of a basal deformable sediment layer for the latter. Although, criteria for the recognition of Pleistocene ice streams were recapitulated and discussed by Stokes et Clark (1999).

However, phanerozoic paleo-ice streams characterization is still poorly documented, but has been evidenced in the Djado-Murzuk basin (Denis et al., 2004 ; Moreau et al., 2004) in Late Ordovician series. The Late Ordovician glaciation was characterized by the setting of an extensive grounded ice sheet centered near the southern pole, on the Gondwana continental shield. Numerous evidences of this glaciation have been reported from central Sahara. A study has been carried out on the Late Ordovician outcrops, which included the following approaches : (i) the compilation of paleo-ice flow direction indicators (glacial striaes, drumlins and other glacier-bed structures, incised paleo-valleys) from the Saharan glacial litterature as well as the present study demonstrates a general ice flow convergence towards basin axes, in relation with the existence of paleotopographies. (ii) The detailed analysis of remote sensing images

and aerial photographies for a large part of Late Ordovician outcrops shows evidences of fields of highly lenghtened subglacial bedforms such as drumlins, megaflutes and megascale glacial lineations (elongation ratio generally $>$10, up to 48). These specific structures are spatially restricted to three domains from Algeria : Tin Seririne syncline-shaped intracratonic basin, in the Tassili des Ajjers and have been described in southern Tassilis. Highly lenghtened subglacial bedforms are indicative of fast ice flows. Large dimensions of these fields suggest a great extent of the fast ice flow zone. Moreover, these fields have abrupt lateral margins, which are assumed to be shear margins. (iii) Glacial pavements are characterized by soft-bed deformation, such as sheath folds. These observations are indicative of high shear rates and high fluid pressures which characterize ice-bed interface and temperate ice occurence.

These data compiled at a basin scale correspond to most of criteria for the recognition of paleo-ice streams defined by Stokes and Clark (1999) and shows a spatially restricted distribution. They gather a sufficient set of evidences to conclude on the existence of paleo-ice streams in central Sahara. Paleo-ice streams are found to occur in large syncline-shaped intracratonic extensional basins including Djado-Murzuk, Mouydir, Ahnet, Illizi, Tin Seririne and Lullimeden basins, dated as Cambro-ordovician age. These basins are bordered by horst structures made of Precambrian rocks. The spatial restriction of soft sediments in saharan basins as well as the extensional horst and graben structuration are likely to control the distribution of both pure and topographic type hirnantian paleo-ice streams.

Evidences of paleo-ice streams in central Sahara suggest that the Late Ordovician ice sheet had a comparable ice-discharging dynamics with Late Neogene and present day ice sheets.

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