ELSEVIER

Journal of Structural Geology 28 (2006) 776–792

JOURNAL OF STRUCTURAL GEOLOGY

www.elsevier.com/locate/jsg

Development of a dilatant damage zone along a thrust relay in a low-porosity quartz arenite

Jennie E. Cook [a], William M. Dunne [a,*], Charles M. Onasch [b]

[a] *Department of Earth and Planetary Sciences, University of Tennessee, Knoxville, TN 37996-1410, USA*
[b] *Department of Geology, Bowling Green State University, Bowling Green, OH 43403, USA*

Received 12 August 2005; received in revised form 26 January 2006; accepted 15 February 2006
Available online 18 April 2006

Abstract

A damage zone along a backthrust fault system in well-cemented quartz arenite in the Alleghanian foreland thrust system consists of a network of NW-dipping thrusts that are linked by multiple higher-order faults and bound a zone of intense extensional fractures and breccias. The damage zone developed at an extensional step-over between two independent, laterally propagating backthrusts. The zone is unusual because it preserves porous brittle fabrics despite formation at >5 km depth. The presence of pervasive, late-stage fault-normal joints in a fault-bounded horse in the northwestern damage zone indicates formation between two near-frictionless faults. This decrease in frictional resistance was likely a result of increased fluid pressure. In addition to physical effects, chemical effects of fluid also influenced damage zone development. Quartz cements, fluid inclusion data, and Fourier Transform Infrared analysis indicate that both aqueous and methane-rich fluids were present within the damage zone at different times. The backthrust network likely acted as a fluid conduit system, bringing methane-rich fluids up from the underlying unit and displacing resident aqueous fluids. The presence of methane not only enhanced the effects of fluid pressure, which facilitated brittle fracturing, but inhibited formation of later-stage quartz cements, thereby preserving open fractures and porous breccias.

Keywords: Damage zone; Quartz arenite; Methane; Breccia; Extensional relay; Backthrust

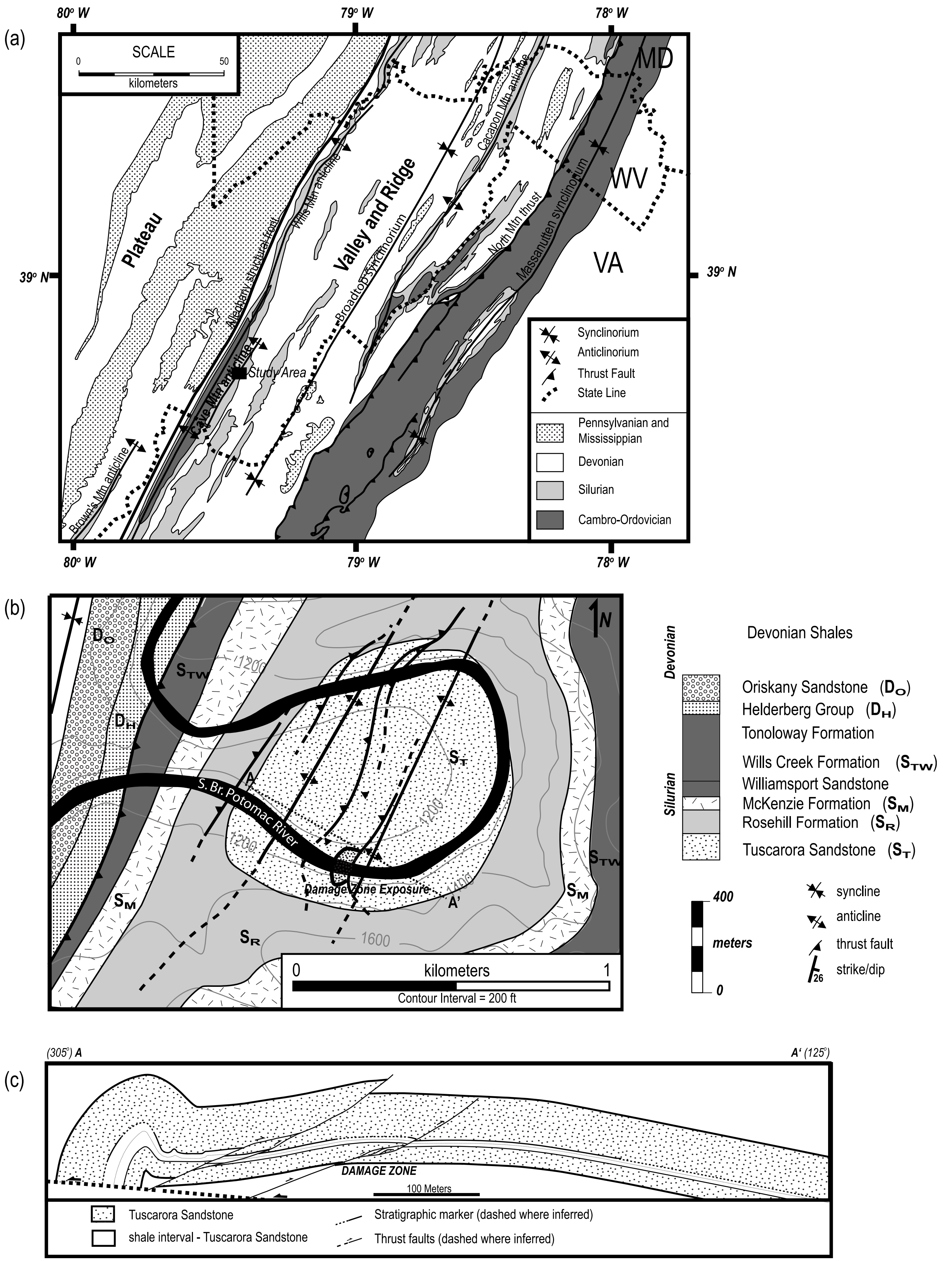
1. Introduction

Damage zones are deformed wall rock spatially associated with faults that form during the initiation and propagation of a fault, during the interaction of slip in fault linkages or jogs, or during the flexure of beds around a fault (Jamison and Stearns, 1982; Chester and Logan, 1986; Shipton and Cowie, 2001, 2003; Flodin and Aydin, 2004; Kim et al., 2004). An understanding of damage zones provides insight into faulting and displacement transfer processes, and the influence of fault structure on fault permeability (Antonellini et al., 1994; Caine et al., 1996). Fault damage zones are broadly grouped into three categories based on their location relative to the host fault: tip damage zones that develop from stress perturbations at the fault tip; wall damage zones that develop because of slip accumulation, asperities, or tip damage zone abandonment; and linking damage zones that form by the interaction of slip between two linked faults (Kim et al., 2004; Tarasewicz et al., 2005). Damage zones have typically been described for near-surface strike-slip fault systems, some normal fault systems, and only a limited number of thrust faults (Chester and Logan, 1986; Shipton and Cowie, 2003; Flodin and Aydin, 2004; Kim et al., 2004). Although damage zones occur at all scales and in all lithologies, we concentrate on damage zone development within quartz-rich sandstone adjacent to a thrust fault system.

The development of faults and their associated damage zones in quartz-rich rocks, such as sandstone, are of particular interest because quartz-rich rocks are abundant in the upper crust (<8 km) and quartz often serves as a proxy for upper crustal rocks in tectonic analyses. In the uppermost crust (<3 km depth), deformation band development and sheared joint faulting are brittle processes that dominate damage zones (Aydin, 1978; Antonellini et al., 1994; Shipton and Cowie, 2001, 2003; Davatzes and Aydin, 2003; Crider and Peacock, 2004; Flodin and Aydin, 2004; Davatzes et al., 2005), with increasing depth in the upper crust (>3 km depth), faulting processes change in quartz-rich sandstones. Pretectonic porosity reduction from deeper burial and consequently increased compaction and cementation decreases the number of grain-to-grain point loads, altering the grain-scale stress state and creating a more homogenous stress distribution

* Corresponding author. Tel.: +1 865 974 4161.
E-mail address: wdunne@utk.edu (W.M. Dunne).

0191-8141/$ - see front matter
doi:10.1016/j.jsg.2006.02.007


(a)
80° W
79° W
78° W
39° N
SCALE
0
50
kilometers
Plateau
Valley and Ridge
MD
WV
VA
Allegheny structural front
Wills Mtn anticline
Broadtop synclinorium
Cacapon Mtn anticline
North Mtn thrust
Massanutten synclinorium
Cave Mtn anticline
Brown's Mtn anticline
Study Area
Synclinorium
Anticlinorium
Thrust Fault
State Line
Pennsylvanian and Mississippian
Devonian
Silurian
Cambro-Ordovician
(b)
N
S. Br. Potomac River
Damage Zone Exposure
A
A'
1200
1600
0
kilometers
1
Contour Interval = 200 ft
Devonian Shales
Devonian
Silurian
Oriskany Sandstone (DO)
Helderberg Group (DH)
Tonoloway Formation
Wills Creek Formation (STW)
Williamsport Sandstone
McKenzie Formation (SM)
Rosehill Formation (SR)
Tuscarora Sandstone (ST)
400
meters
0
syncline
anticline
thrust fault
strike/dip
26
(305°) A
A' (125°)
(c)
DAMAGE ZONE
100 Meters
Tuscarora Sandstone
shale interval - Tuscarora Sandstone
Stratigraphic marker (dashed where inferred)
Thrust faults (dashed where inferred)