Possible seismites of the upper Fairview Formation (Upper Ordovician) near Maysville, Kentucky

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INTRODUCTION

Holocene earthquakes of magnitude >5 sometimes cause deformation in unlithified sediment, creating water escape structures, neptunian dikes, sedimentary breccias, recumbent folds, sand blows, ball-and-pillow structures, and convolute bedding (Tuttle and Seeber, 1991; Pope et al., 1997). These syndepositional and early postdepositional, seismically induced liquefaction features are known as “primary seismites.” Primary seismites are sedimentary layers deformed *in situ* by a seismic event; secondary seismites are reworkings of older primary seismite deposits (Pope et al., 1997). Many of the same features diagnostic of primary seismites are, however, also produced by “soft sediment” deformation caused by slumping or loading of unlithified sediment (Mills, 1983).

Deformed beds are obvious in the upper Fairview Formation (Upper Ordovician) near Maysville, Kentucky, and have been described by others (e.g., Pope et al., 1997). However, new exposures are now found in recent road cuts which have not yet been described. This paper describes these beds and compares them to descriptions of purported seismites of different ages and locations. These include locally common features such as ball-and-pillow beds, slumps, and convolute bedding, as well as rarer features including folded bedding, centimeter- to meter-scale slides, and flame structures. This study investigated 1) relationships between lithologies and structures and 2) the possibility that these features are not seismites but are instead soft sediment deformation structures.

RESEARCH QUESTION:

I hypothesize that the structures I have observed in the field are, in fact, seismites. I also hypothesize that lithology, early cementation, and stratigraphic relationships are instrumental in the formation of these structures. These variables dictated not only whether or not deformational structures formed, but also which particular structures formed, their resultant horizontal and vertical extent, the scale of the features, and the deformation of surrounding beds.

BACKGROUND

Most deformation attributed to seismic activity is the result of liquefaction (Obermeier and Pond, 1999). Liquefaction results from the mobilization of sediment grains facilitated by an increase in pore-fluid pressure within loosely packed, water-saturated sediment (Fig. 1). This phenomenon can be the result of seismic shocking. In laboratory experiments performed by Weaver and Jeffcoat (1978), carbonate ball-and-pillow structures were created by striking the side of a glass tank containing wet lime mud overlain by carbonate sand under water. Other types of deformation commonly associated with seismic activity include convex-down stacking of shells, fault-grading, microfracturation, water-escape structures, recumbent folds, contorted bedding, various types of clastic dikes and sills, sand blows, some turbidites, submarine slumps and slump folds, debris beds, tsunami deposits, and homogenized beds (Seilacher, 1969, 1983; Tuttle and Seeber, 1991; Beck et al.; Pope, 1997; Bhattacharya and Bandyopadhyay, 1998).

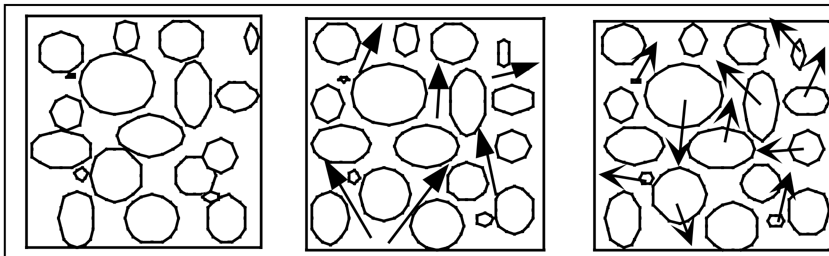

Figure 1. a) Sediment grains loosely packed, water in interstitial pore spaces. b) Increase in pore-water pressure, water begins to move "floating" grains. c) Grains themselves move, mixture flows.

However, attributing a definite seismic origin to deformational features can be problematic. Many features, such as dewatering, slumping, fault-graded beds, and turbidites, can be caused by other factors such as gravity-flow unrelated to seismicity. Liquefaction is frequently attributed to loading or storm- and tide-induced mechanisms so ball-and-pillow structures can be present in sediment which has felt no shaking.

METHODS

Three separate road cut localities were examined and these are herein referred to as Maysville West (MW), Maysville West Large (MWL), and Kentucky 11 (KY 11) (Fig. 2). The two Maysville sections are separated by 1.2 km while Kentucky 11 is approximately 6.9 km to the southeast of the Maysville West cuts. The existence of hardground and ball-and-pillow marker horizons allows for assessment of length scales of various deformation structures.

Sedimentological structures were carefully observed, sketched, and photographed in the field. Lithologies of deformed and undeformed beds were inventoried and sampled and a stratigraphic column representative of the selected section was drafted. Samples of packstones and wackstones from different deformational structures, as well as from undeformed areas within deformed horizons, were collected and thin sectioned for examination and comparison of cement. These thin sections were examined for evidence of early cementation (bladed and syntaxial cement).

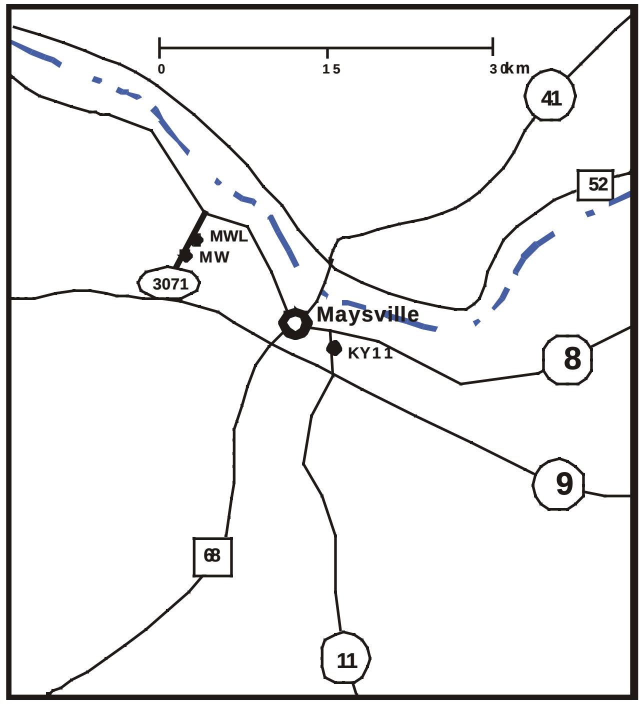

Figure 2. Location map showing study sites. MW=Maysville West, MWL=Maysville West Large, KY 11=Kentucky 11.

My results are compared to past studies on purported seismites observed in Ordovician, Pleistocene, and Holocene marine and lacustrine limestone, siliciclastic rocks, and glacial deposits from all over the world (Mills, 1996; Pope, 1997; Tuttle & Seeber, 1991; Weaver & Jeffcoat, 1978; Seilacher, 1984, 1969; Plaziat et al., 1988

RESULTS

Lithologies. The upper Fairview Formation is a mixed siliciclastic-carbonate unit. Siliciclastic lithologies include blue-gray calcareous shale and yellow-gray siltstone that locally grades to very fine sandstone. Neither siliciclastic lithology contains fossils although scattered bryozoans grew on the tops of some early-cemented siltstone beds at the sediment-water interface. Carbonate lithologies include skeletal packstone, skeletal wackestone, and micritic mudstone. The packstone is calcite cemented and exhibits syntaxial and bladed cement, both of which are indications of early cement. The wackestone is micrite cemented with very rare areas of pure sparry calcite. Mostly these areas appear to be cavity infilling, probably by precipitation out of infiltrating seawater. Micritic beds at the KY 11 cut are locally fossiliferous, but not at either Maysville West locality.

Early syntaxial and bladed cement is present in packstone and wackestone samples from areas within deformed beds as well as in samples from undeformed beds. Early cement is difficult to detect in ball-and-pillow structure samples as these are nearly all micrite.

Deformational Structures. Deformational structures observed at the Maysville West and Maysville West Large road cuts include ball-and-pillow structures, slides, folds, intrastratal slumps, substratal slide scars. Evidence of intrastratal removal of strata is present here on the scale of 10's of cm. Contemporary gravitational collapse and brittle deformation of overlying layers imply that the overlying beds were semi- or completely lithified at the time of deformation. Slump features are present at the Maysville West locality in the form of decimeter-scale folds. Areas are common at the Maysville West localities where beds of ball-and-pillow structures are overlain by laterally continuous beds of even thickness and sharp lower contacts. Locally overlying beds are thickened over ball-and-pillow depressions.

Ball-and-pillow structures, clay upwelling, and flame structures are present at all localities. Laterally extensive ball-and-pillowed horizons on the decimeter -scale, which are locally deformed to a much greater extent, are also present at all three localities. These areas of greater deformation consist of 1-2 meter-thick channel-like forms of approximately 10-50 meters width, which are observable on both sides of large road cuts.

Relationships. Synsedimentary deformation features of this study were analysed with respect to lithology and mode of deformation. Ball-and-pillow structures, clay upwelling, and flame structures are relatively *in situ* responses to shaking. Extremely minor or no lateral movement takes place in this type of deformation.

Some movement may have taken place along the edges of the ball-and-pillow channel forms to create the sharp truncation boundaries at the channel edges. However, deformation must have been largely *in situ* because of the absence of consistent asymmetrical load structures, which would have been produced by large-scale downslope movement.

All *in situ* deformation occurs in shale and carbonate mudstone. Ball-and-pillow structures occur mainly in micrite, although some structures contain widely spaced thin shell beds. Clay upwelling involved both siliciclastic mud and micrite. This structure is present where shale beds are overlain by micrite beds, the latter of which broke apart allowing clay to squeeze up between micrite fragments. (This local breakage of the micrite implies that some micritic beds were early cemented.) Flame structures and intrastratal removal structures also involve shale and carbonate mudstone (See Table 1). The association of ductile flow features with fine-grained lithologies is thought to reflect the high porosity and low permeability of this type of sediment.

Deformational structure	**Lithology involved**	**Interpretation**
Slides	Packstone/wackestone	Brittle failure and transport
Folding	All lithologies	*In situ* ductile deformation
Intrastratal slumping	All lithologies	Detachment, transport, ductile deformation
Substratal removal	Shale and micrite	Liquefaction and movement
Ball-and-pillow structures	Micrite w/ widely spaced thin shell beds	Liquefaction and loading
Clay upwelling	Shale and micrite	Injection of H_2O-rich mud
Flame structures	Shale and micrite	Injection of H_2O-rich mud

Table 1. Relationships between deformational structures and lithologies involved in the formation of these structures. Also processes interpretations.

Folds, slumps, slides, and intrastratal removal all involve some degree of movement. In the case of folding, this movement is very minor. In the case of slumps and slides movement took place over much larger distances. Both ductile and brittle deformation is recorded in these features. Slides occur only in the packstone and wackestone beds. This is to be expected as these beds show signs of early cement. If the sediment was already lithified or semi-lithified, it would have acted as a cohesive unit during deformation. Folding and intrastratal slumping were not limited to one sediment type and involved more than one lithology within individual features.

Deformational structure	**locality**
Slides	MW, MWL
Folding	MW
Intrastratal slumping	MW, MWL
Substratal removal	MWL
Ball-and-pillow	MW, MWL, KY 11
Clay upwelling	MW, MWL, KY 11
Flame structures	MW, MWL, KY 11

Table 2. Localities at which different deformational structures were observed; MW=Maysville West, MWL=Maysvillle West Large, KY 11= Kentucky 11.

The absence of certain deformational structures at KY 11 (Table 2) can be explained by the lack of packstone/wackestone beds within the deformed horizon at this locality. Those structures missing from Kentucky 11 are those which involve, either wholly or in part, the packstone/wackestone lithology. A possible explanation for the finer-grained succession at the more easterly road cut is that this section was deposited in deeper water. Stratigraphic position of this section relative to the Maysville West localities is unknown, but the Fairview Formation does thicken to the east (Cuffey, 1998) which implies greater accommodation space and a deeper depositional environment.

CONCLUSIONS

The presence of extensive, planar beds overlying ball-and-pillow structures as well as the thickening of these beds directly over ball-and-pillow paleodepressions implies that deformation occurred near the sediment-water interface, probably in semi-lithified sediment. Signs of early cement were found in deformed as well as non-deformed areas, so in some cases cementation probably took place after deformation. However, brittle deformation in surface and near-surface slide and slump features implies early cementation of the sediment involved. (Table 1) This occurred mostly in packstone and wackestone beds. Carbonate mudstone and shale beds show ductile deformation structures including abundant ball-and-pillow structures. This reflects the high porosity/low permeability of this type of sediment and therefore its susceptibility to liquefaction.

The seismic nature of these structures is unclear. Many of these features can be attributed to sources other than seismic shocking. However, most also clearly fit into many accepted models of earthquake-induced liquefaction and resulting deformation. The fact that deformation appears to have happened at or near the sediment-water interface tends to point more to seismically-induced liquefaction than to loading as a driving force behind the formation of ball-and-pillow structures. In addition, the generally accepted surface slope for this area during the Ordovician was probably extremely low (Pope et al.,1997), so gravity-driven sediment flows are not likely to have occurred. These factors point to a probable seismic origin of deformational structures at these localities.

REFERENCES CITED

Bhattacharya, N. H. and Bandyopadhyay, S., 1998, Seismites in a Proterozoic tidal succession, Singhbhum, Bihar, India: *Sedimentary Geology*, v. 119, p. 239-252.

Cuffey, R. J., 1998, Sampling the layer cake that isn't: The stratigraphy and paleontology of the Type-Cincinnatian: Geological Society of America, Annual Meeting Field Trip Guidebook no. 13, 3-4.

Lowe, D. R., 1975, Water escapes structures in coarse-grained sediments: *Sedimentology*, v. 22, p. 157-204.

Mills, P.C., 1983, Genesis and diagnostic value of soft sediment deformation structures - A review: *Sedimentary Geology*, v.35, p. 83.

Obermeier, S.F. and Pond, Eric C., 1999, Issues in using liquefaction features for paleoseismic analysis: *Seismological Research Letters*, v. 70, no. 1, p. 34-58.

Plaziat, J., Purser, B., and Philobus, E., 1988, Diversity of Neogene seismites of the northwest Red Sea (Egypt): a characteristic sedimentary expression of rifting: *Tectonophysics*, v. 153, p. 295.

Pope, M.C., Read, J.F., Bambach, R., and Hofmann, H.J., 1997, Late Middle to Late Ordovician seismites of Kentucky, southwest Ohio and Virginia: Sedimentary recorders of earthquakes in the Appalachian basin: *GSA Bulletin*, v. 109, no. 4, p. 489-503.

Seilacher, A., 1969, Fault-graded beds interpreted as seismites: *Sedimentology*, v. 13, p. 155-159.

Seilacher, A., 1984, Sedimentary structures tentatively attributed to seismic events: *Marine Geology*, v. 55, p. 1-12.

Tuttle, M. and Seeber, L., 1991, Historic and prehistoric earthquake-induced liquefaction in Newbury, Massachusetts: *Geology*, v. 19, p. 594-597.

Weaver, J. and Jeffcoat, R., 1978, Carbonate ball and pillow structures: *Geological Magazine*, v. 115, p. 245-253.