Thomas Hearon received a B.S. degree in geology from the University of the South (2003) and a M.S. degree in geology from New Mexico State University (2008). He is currently a PhD candidate in geology and a research assistant at the Colorado School of Mines, researching subsurface- and outcrop-based salt-sediment interaction in the Gulf of Mexico and South Australia, under the advice of Bruce Trudgill. From 2006-2008, he worked as a field geologist for Nautilus, a geoscience training company that specializes in high-quality, field- and classroom-based courses for the oil industry. Thomas specializes in salt-sediment interaction and has completed salt-related field mapping projects in Utah, Mexico, South Australia and Spain. He enjoys fishing and skiing throughout the western US.

Testing the halokinetic growth sequence model adjacent to allochthonous salt sheets and in deepwater depositional settings: Flinders Ranges, South Australia and northern Gulf of Mexico

INTRODUCTION

The current model for the formation of halokinetic growth sequences is mostly derived from outcrops of steep salt diapirs present in shallow water to subaerial depositional settings. The aim of this research project is to test this model in different depositional and structural settings from outcrops in the Flinders Ranges, South Australia and from a seismic dataset located in the northern Gulf of Mexico. This model has rarely been applied to outcrops in the Flinders Ranges, thus in-depth structural and stratigraphic analysis will provide better insight into the formation of halokinetic growth sequences. The following research questions will be tested: (1) in addition to passive diapirs, do halokinetic sequences also play a role in the evolution of allochthonous salt bodies?; (2) do the concepts of halokinetic sequence formation also apply to deepwater settings?; (3) is there a direct correlation between halokinetic sequences and depositional sequence stratigraphy?

GEOLOGIC SIGNIFICANCE

Elements of salt-sediment interaction have broad implications for the understanding of inherently complex structural and stratigraphic relationships present in passive margin, rift and foreland basin settings. A temporal and spatial understanding of salt movement can yield important insight into basin partitioning, sediment dispersal patterns and the evolution of crustal-scale basins and minibasins. In petroleum basins such as the Gulf of Mexico, sedimentary depocenters and sand distribution can be influenced by the topographic relief created by passive salt diapirs and allochthonous salt sheets. Additionally, stratigraphic geometries flanking passive salt diapirs and allochthonous salt sheets control reservoir geometry and trap configuration and influence hydrocarbon development, migration and seal. For example, the amount of upturn of hydrocarbon-bearing halokinetic sequences adjacent to salt diapirs can impact column heights and thus reservoir volumes (e.g., Wilcox Group, Gulf of Mexico).

Current understanding of allochthonous salt emplacement (i.e., lateral salt movement) is based on seismic, limited well data and numerical models (e.g., McGuiness & Hossack, 1993; Harrison & Patton, 1995; Fletcher et al., 1995; Harrison et al., 2004; Hudec & Jackson, 2006, 2009). Various theories invoke surficial glacial flow, advance above subsalt shear zones, or emplacement along tip thrusts (Figure 1). Because of the limitations inherent in subsalt seismic imaging and one-dimensional well sampling, however, there is a need for outcrop-based studies to test these models.

In contrast, the theory of halokinetic deformation is based entirely on outcrop studies of steep diapirs in La Popa Basin, Mexico (Giles & Lawton, 2002; Rowan et al., 2003; Giles & Rowan, 2012). Giles & Rowan (2012) characterized two geometrically-defined end-member types of composite halokinetic sequences (CHS), which stack vertically into different configurations (Figure 2). Conceptual sequence stratigraphic models for the formation of such sequences were developed based on the relative rates of diapir rise and sediment accumulation. Although this model for halokinetic sequence formation is directly applicable to provinces such as the Pricaspian Basin and the North Sea, which have diapirs and depositional settings analogous to those in La Popa Basin, there is a need to test whether this model is also useful in deepwater and sub-salt settings.

Halokinetic sequences have tentatively been linked to depositional sequence stratigraphy in shelf depositional settings (e.g., Giles & Rowan, 2012; Kernen et al., 2012). However, the lack of detailed biostratigraphic data makes the correlation of these sequences uncertain. One benefit of examining a deepwater diapir is that abundant biostratigraphic data from wells will allow the correlation to be tested and confirmed, thereby extending the usefulness of sequence-stratigraphic theories.

RESEARCH APPROACH

This is a multi-disciplinary project which integrates detailed outcrop mapping and structural analysis at the Pinda and Oladdie diapirs in the Flinders Ranges, South Australia, with subsurface data from the northern Gulf of Mexico. These diapirs contain structural and sedimentological elements that allow the interaction between halokinetic sequences and allochthonous salt to be tested. Outcrop exposures include subsalt and suprasalt strata, passive salt diapirs, allochthonous salt sheets, salt welds and stacked CHS.

High resolution satellite imagery and multispectral HyMap imagery will be utilized to delineate salt structures and halokinetic sequences at the Pinda and Oladdie diapirs. Combined outcrop mapping and structural analysis will enable the degree of halokinetic folding to be quantified, with emphasis on the transition between steeply-dipping diapir flanks and shallowly-dipping allochthonous salt sheets. Structural modeling and restoration will attempt to illustrate the evolution and dynamics of salt-related deformation and allochthonous salt breakout and emplacement, and the results will be compared to existing models.

A combination of the following possible indicators of salt-sediment interaction will be identified, if present, and analyzed: (1) conglomeratic to brecciated debris flows and diapir-derived detritus, which represent material shed off bathymetric highs; (2) angular unconformities and upturned growth strata, which represent development of halokinetic sequences adjacent to a salt body; (3) sub-salt stratal terminations and the angles at which strata intersect a salt body; (4) subsalt shear zones, thrusts or imbricate thrusts.

Interpretation of a wide azimuth 3D seismic dataset and associated well data from the Auger salt diapir in the northern Gulf of Mexico will test whether the halokinetic-sequence model is also appropriate in a deepwater setting and whether there are direct correlations between halokinetic sequences and depositional sequences. Well data and biostratigraphic data will help constrain horizon interpretation, depositional sequences boundaries and sediment-accumulation rates. The interpretation and analysis will be used to examine: (1) the vertical stacking trend of different CHS types; (2) any strike-parallel variations in halokinetic sequences around the diapir flanks; (3) the impact of sedimentation rates on salt growth and the development of different types of CHS; and (4) the degree of correlation between halokinetic-sequence boundaries and depositional-sequence boundaries.

REFERENCES CITED

Fletcher, R.C., Hudec, M.R. & Watson, I.A., 1995, Salt glacier and composite sediment-salt glacier models for the emplacement and early burial of allochthonous salt sheets, *In*: Jackson, M.P.A., Roberts, D.G., & Snelson, S. (eds), Salt tectonics: a global perspective: AAPG Memoir, v. 65, p. 77-108.

Giles, K.A. & Lawton T.F., 2002, Halokinetic sequence stratigraphy adjacent to the El Papalote Diapir, northeastern Mexico: AAPG Bulletin, v. 86, p. 823-840.

Giles, K.A. & Rowan, M.G., 2012, Concepts in halokinetic-sequence deformation and stratigraphy, *In.* Alsop, G.I. et al. (eds), Salt Tectonics, Sedimentation and Prospectivity, Geological Society, London, Special Publication.

Harrison, H. & Patton, B., 1995, Translation of salt sheets by basal shear, *In*: Travis, C.J., Harrison, H., Hudec, M.R., Vendeville, B.C., Peel, F.J. & Perkins, B.F. (eds.), Salt, sediment, and hydrocarbons: SEPM Foundation, Gulf Coast Section, 16th Annual Research Conference, p. 99-107.

Harrison, H., Kuhmichel L., Heppard P., Milkov A.V., Turner J.C., & Greeley D., 2004, Base of salt structure and stratigraphy Data and models from Pompano field, VK 989/990, Gulf of Mexico, *In.* Post, P.J., Olson, D.L., Lyons, K.T., Palmes, S.L., Harrison, P.F. & Rosen, N.C. (eds.), Salt-sediment interactions and hydrocarbon prospectivity: SEPM Foundation, Gulf Coast Section, 24th Annual Research Conference, p. 243-270.

Hudec, M.R. & Jackson, M.P.A., 2006, Advance of allochthonous salt sheets in passive margins and orogens: AAPG Bulletin, v. 90, p. 1535-1564.

Hudec, M.R. & Jackson, M.P.A., 2009, The interaction between spreading salt canopies and their peripheral thrust systems: Journal of Structural Geology, v. 31, p. 1114-1129.

Kernen, R., Giles, K., Lawton, T.F., Rowan, M.G., & Hearon, T.E., IV, 2012, Depositional and halokinetic sequence stratigraphy of the Neoproterozoic Wilpena Group adjacent to Patawarta allochthonous salt sheet, central Flinders Ranges, South Australia, *In.* Alsop, G.I. et al. (eds), Salt Tectonics, Sediments and Prospectivity Special Publication, The Geological Society, London.

McGuinness, D.B. & Hossack, J.R., 1993, The development of allochthonous salt sheets as controlled by the rates of extension: Sedimentation and Salt Supply, SEPM Foundation, Gulf Coast Section, 14th Annual Research Conference, p. 127-139.

Rowan, M.G., Lawton, T. F., Giles, K.A. & Ratliffe, R.A., 2003, Near-salt deformation in La Popa basin, Mexico, and the northern Gulf of Mexico: A general model for passive diapirism: AAPG Bulletin, v. 87, p. 733-756.

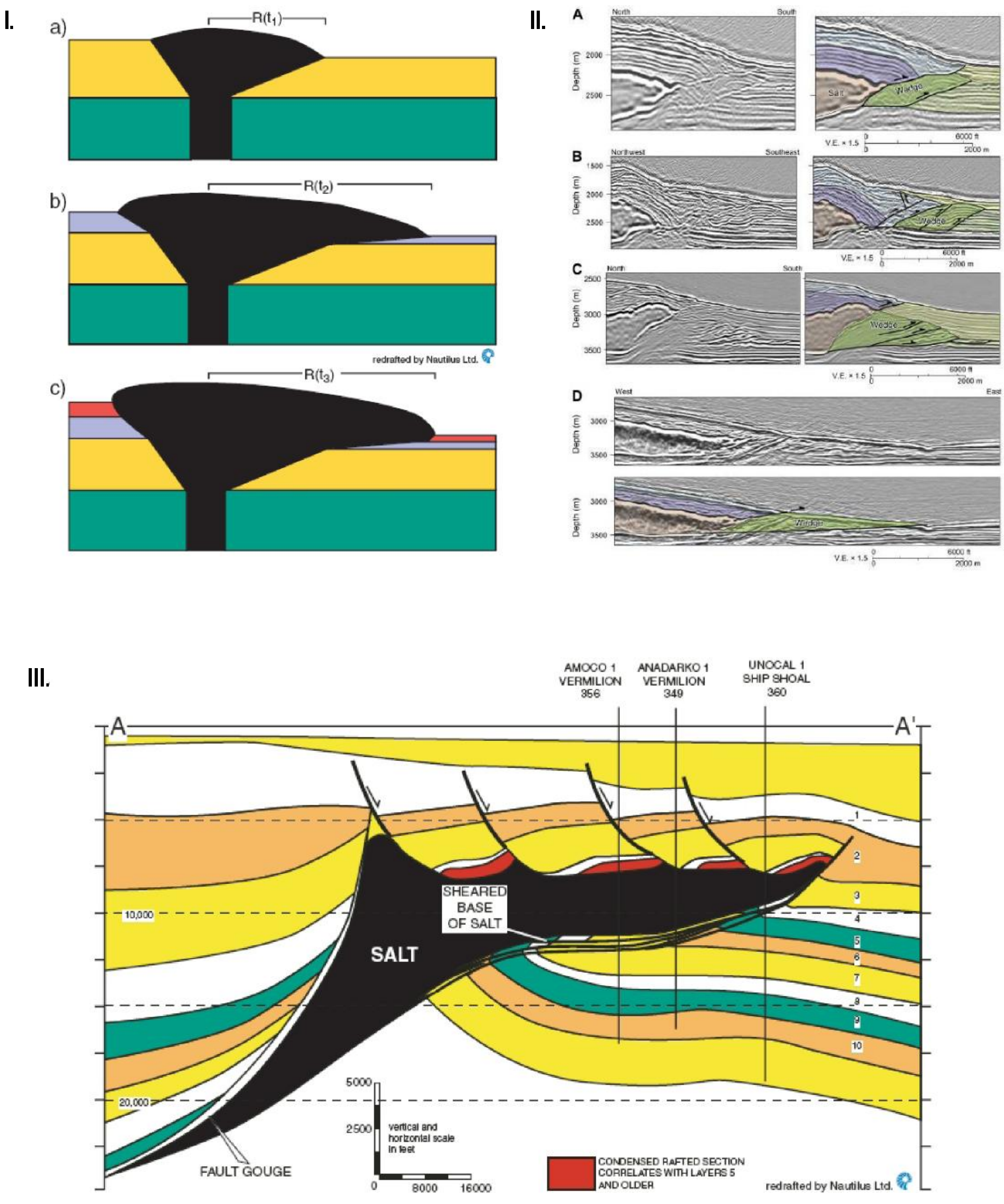

Figure 1. Allochthonous salt emplacement models: I) Surficial glacial flow (Fletcher et al., 1995); II) Emplacement along tip thrusts (Hudec and Jackson, 2009); III) Advance above subsalt shear zone (Harrison and Patton, 1995).

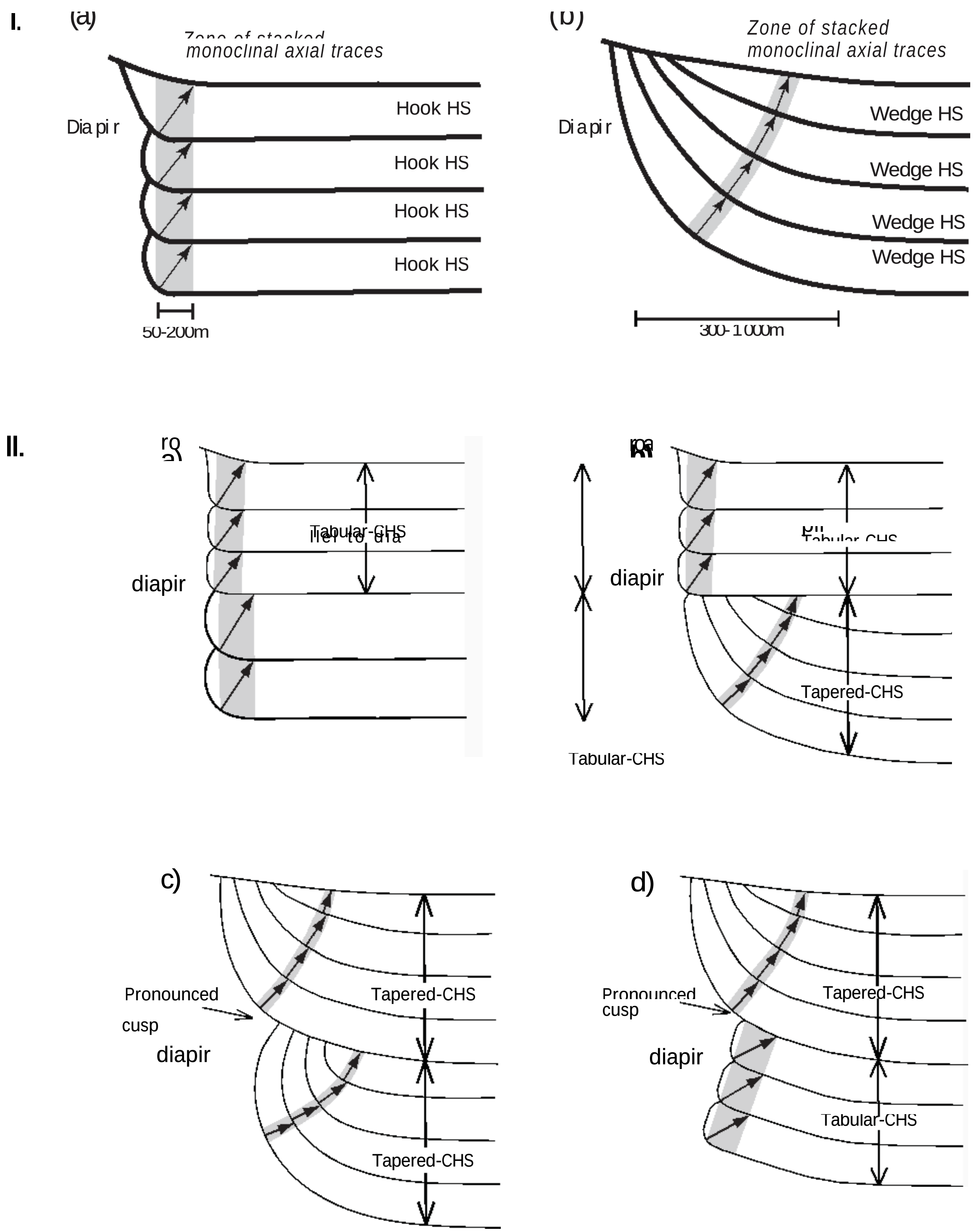

Figure 2. I) End-member halokinetic sequence types: a) individual hook halokinetic sequences stack to form a tabular composite halokinetic sequence; b) individual wedge halokinetic sequences stack to form a tapered composite halokinetic sequence; II) Geometric stacking patterns of tabular and tapered composite halokinetic sequence types (modified from Giles and Rowan, 2012).