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Study of Upper Albian rudist buildups in the Edwards Formation using ground-based hyperspectral imaging and terrestrial laser scanning

Diana Krupnik [a,*], Shuhab Khan [a], Unal Okyay [a], Preston Hartzell [b], Hua-Wei Zhou [a]

[a] University of Houston, Department of Earth and Atmospheric Sciences, United States
[b] University of Houston, Department of Civil and Environmental Engineering, United States

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ABSTRACT

Ground-based hyperspectral imaging is used for development of digital outcrop models which can facilitate detailed qualitative and quantitative sedimentological analysis and augment the study of depositional environment, diagenetic processes, and hydrocarbon reservoir characterization in areas which are physically inaccessible. For this investigation, ground-based hyperspectral imaging is combined with terrestrial laser scanning to produce mineralogical maps of Late Albian rudist buildups of the Edwards formation in the Lake Georgetown Spillway in Williamson County, Texas. The Edwards Formation consists of shallow water deposits of reef and associated interreef facies. It is an aquifer in western Texas and was investigated as a hydrocarbon play in south Texas. Hyperspectral data were registered to a geometrically accurate laser point cloud-generated mesh with sub-pixel accuracy and were used to map compositional variation by distinguishing spectral properties unique to each material. More calcitic flat-topped toucasid-rich bioherm facies were distinguished from overlying porous sucrosic dolostones, and peloid wackestones and packstones of back-reef facies. Ground truth was established by petrographic study of samples from this area. This research integrates high-resolution datasets to analyze geometrical and compositional properties of this carbonate formation at a finer scale than traditional methods have achieved and to model the geometry and composition of rudist buildups.

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1. Introduction

1.1. Overview

This work seeks to utilize ground-based as well as laboratory-based hyperspectral imaging (also referred to as imaging spectroscopy) to map mineralogical variation and facilitate the study of diagenetic features in rudist buildups and associated interreef and backreef facies. Carbonate minerals dominate these deposits with minor amounts of silica (Chen et al., 2016; Nelson, 1973).

Digital outcrop models, a recently developed technique for detailed geologic studies, are produced in this work. These methods can augment our understanding of hydrocarbon reservoir properties and enhance subsurface models by providing a realistic example of stratigraphic horizons, facies distributions, and compositional variation (Pringle et al., 2006). Integrated ground-based remote sensing techniques can provide information about compositional and textural variability of exposed rock (Kurz et al., 2013; Minisini et al., 2014). Observation of facies architecture at outcrop scale is useful for the purpose of observing diagenetic features and pathways for fluid flow.

Hyperspectral imaging is used to delineate compositional variation of exposed rock in regional studies using an airborne platform (Baugh et al., 1998; Bell et al., 2010; Bellian et al., 2007; Bowen et al., 2007; Roach et al., 2006), in the laboratory setting (Baissa et al., 2011; Greenberger et al., 2015), and more recently using close range ground based sensors (Kurz et al., 2012; Murphy, 2015; Okyay and Khan, 2016). While high resolution imaging can provide information from a distance, it lacks three dimensionality and contains some level of distortion. Light detection and ranging (LiDAR) has been used for several decades for purposes of surveying, atmospheric science, military, and many other applications, but only in the last decade has it gained popularity for the purpose of creating digital outcrop models (Pringle et al., 2006). The geometrically accurate data collected using a terrestrial laser scanner (TLS), a ground-based LiDAR system, can be augmented by hyperspectral data which contains reflectance values over a wide spectral range and can be used to distinguish between different minerals. In recent studies, three dimensional outcrop models have been generated by combining ground based hyperspectral and TLS data and were used to analyze compositional and geometric properties of exposed rock (Bellian et al., 2007; Snyder et al., 2016). Ground based hyperspectral and TLS sensors can be instrumental in producing a user-friendly interface for geological investigation.

* Corresponding author
E-mail address: diana.krupnik@yahoo.com (D. Krupnik).

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1.2. Regional and site geology

During the Cretaceous, a warm shallow marine environment led to the formation of several reef bodies including the Stuart City, Central Texas, and Devil's River reef trends the extent of which is shown in Fig. 1. These deposits produced an arcuate wedge of carbonate rocks which thickens toward the Gulf of Mexico and thins toward the northwest (Rose, 1974). Rudist buildups are found along the Central Texas and Devil's River Reef trends. The focus of this study is the Edwards Formation, which consists of about 90 to 105 m (300 to 340 ft) of limestone accumulated on the Comanche shelf (Rose, 1974). The study area is in close proximity to the Kirschberg Lagoon which is known to contain evaporate minerals (Fisher and Rodda, 1969).

High porosity and permeability of the Edwards Limestone create a pathway for fluid flow. It is an aquifer system which stretches for a distance of more than 290 km in south central Texas and provides water supply to over 2 million people (Johnson et al., 2009) and is a prolific hydrocarbon play as well (Fritz et al., 2000; Moredock and Van Ciclen, 1964). Rudist reefs and collapse breccias constitute permeable zones in the Edwards limestone (Maclay and Small, 1986).

In some parts of the world, rudist buildups are prolific hydrocarbon reservoir formations, examples include the Shuaiba Formation in northwest Oman (Borgomano et al., 2002), the Mishrif Formation in the Mesopotamian Basin in southern Iraq (Sadooni, 2005), and the Raman Field in Southeast Turkey (Keskin and Can, 1986).

Rudist bioherms are widespread in this area and diagenetic alteration is prevalent including but not limited to dolomitization, silicification, compaction, and dedolomitization. Fisher and Rodda (1969) noted varied dolomite fabrics in the Edwards, including stratal and massive dolomite. Stratal dolomite consists of poorly developed intergrown crystals less than 10 μm in diameter and has low porosity and permeability. Massive dolomite consists of loosely distributed euhedral (planar-e) crystals mostly larger than 30 μm and high porosity and permeability. It generally replaces fossiliferous limestones as evidenced by relict structures such as fossil molds and casts. Massive dolomite commonly is overlain by evaporite-solution units (Fisher and Rodda, 1969). Relation of dolomites with evaporate units as well as stable isotopic studies suggest that these dolomites resulted from metasomatic replacement of calcium carbonate as a result of contact with magnesium-enriched lagoonal brines, suggesting seepage reflux dolomitization (Fisher and Rodda, 1969; Tucker and Wright, 1990; Welch, 2001).

The present investigation took place in the Lake Georgetown Spillway (LGS) in Williamson County, Texas (Fig. 2), where rudist buildups of the Cretaceous Edwards formation outcrop along the relatively fresh surface of the spillway walls, constructed in 1979 (TWDB 2015). A transgressive-regressive depositional package containing the upper portion of the Edwards is exposed at this location, containing a rare three dimensional view of middle Albian rudist communities. Sullivan and Zahm (2005) observed a variety of carbonate facies above the floor of LGS including evaporitic back reef facies with thin beds of laminated wackestones and packstones, a 1 m bed of vertically burrowed brown dolomite, and rudist bioherms consisting of toucasid and caprinid-toucasid-radiolitid-chrondrodont buildups flanked by interreef debris deposits. Just below the floor of the spillway, caprinid mounds composed of packstones to grainstones can be recognized by their grainstone caps which are preserved due to their resistant nature.

These have been studied by means of three-dimensional ground penetrating radar and were found to be high porosity flat-topped bioherms with average heights of 2.5–3 m and basal diameter of 15–25 m and onlapping as well as aggradational reef flank strata observed to be prograding toward the south (Mukherjee et al., 2010; Mukherjee et al., 2012). Mud-dominated facies consisting of burrowed mollusc wackestones and chalky skeletal limestones overlying transgressive packages of wackestones and mudstones with low abundances of marine fossils are seen at the base of the sequence and are exposed in stream gullies (Sullivan and Zahm, 2005). Rudist buildups of each type observed in LGS are relatively uniform as most bioherms consist of a dominant group: caprinids, toucasids, and caprinid-toucasid-radiolitids (Mukherjee et al., 2012). Toucasia is a group of rudists which are the dominant constituent of bioherms. In the present investigation, two rudist buildups, comprised of toucasid fossil material are

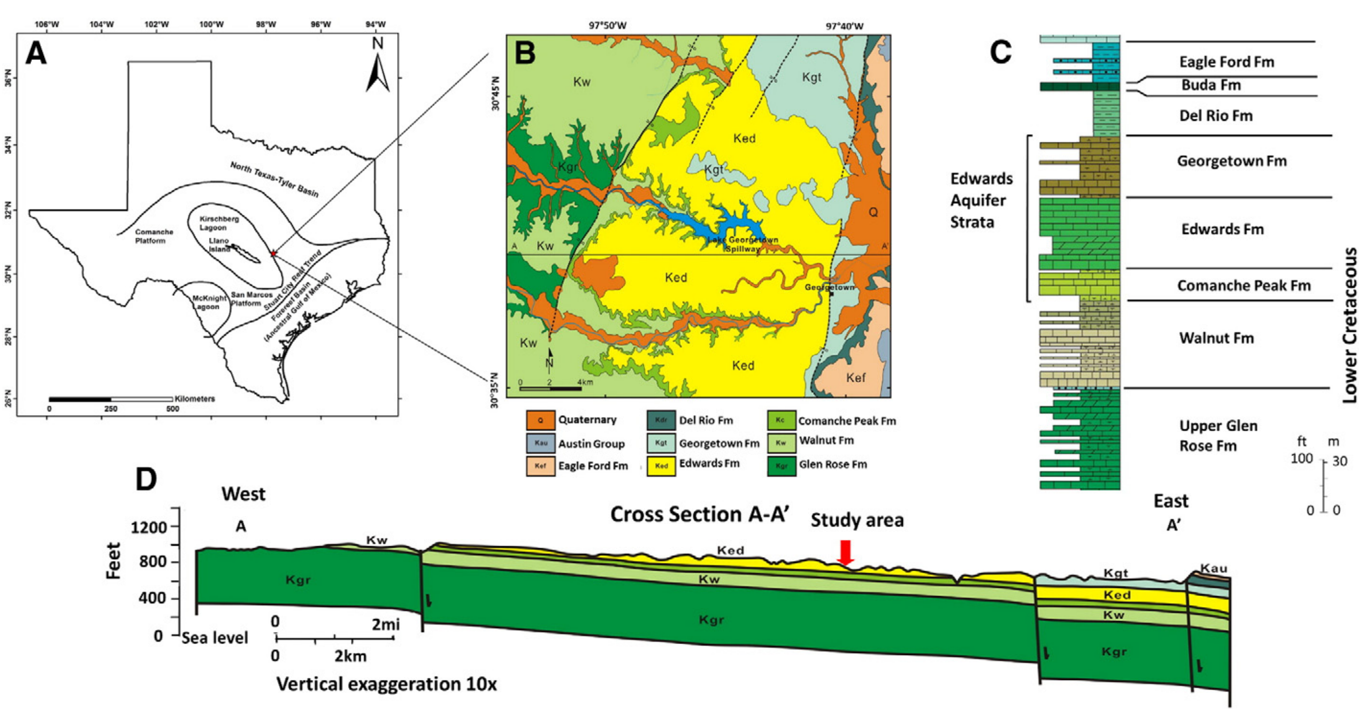

Fig. 1. (A) Cretaceous paleogeography of central Texas and surrounding areas after Damman (2011); Fisher and Rodda (1969); (B) geologic map, C) stratigraphic column, and (D) cross section of the Lake Georgetown area in Williamson County after Collins (2005) and Chen et al. (2016).