Marine and Petroleum Geology 80 (2017) 412–431

Contents lists available at ScienceDirect

Marine and Petroleum Geology

journal homepage: www.elsevier.com/locate/marpetgeo

Research paper

Re-sedimented deposits in the rift section of the Campos Basin

Karin Goldberg [a, b, *], Juliano Kuchle [a], Claiton Scherer [a], Renata Alvarenga [a], Patrycia L. Ene [a], Garibaldi Armelenti [a], Luiz Fernando De Ros [a]

[a] Instituto de Geociências, Universidade Federal do Rio Grande do Sul, Av. Bento Gonçalves 9500, Porto Alegre, RS, 91509-900, Brazil
[b] Department of Geology, Kansas State University, 108 Thompson Hall, Manhattan, KS, 66506, USA

ARTICLE INFO

Article history:
Received 10 March 2016
Received in revised form
23 November 2016
Accepted 26 November 2016
Available online 21 December 2016

Keywords:
Rift
Barremian-Aptian
Facies
Depositional model
Lacustrine carbonates
Campos Basin

ABSTRACT

An integrated petrologic-sedimentologic-stratigraphic-seismic study of the Lagoa Feia Group, rift section of the Campos Basin, has shown that rift sedimentation was dominantly intrabasinal (carbonate and stevensitic deposits), with siliciclastic deposits restricted to the proximity of graben border faults. The bivalve bioclastic rudstones ("coquinas") that constitute the rift reservoirs show commonly limited abrasion of the bioclasts, and were deposited both on basement highs and lows throughout the rift section. Although *in situ* deposits of stevensite ooids and peloids occur dominantly at the base of the succession, these particles are ubiquitous to the entire rift section, mixed in variable proportion with siliciclastic and carbonate sediments. The environmental conditions required for the formation of stevensite and the growth of bivalves are mutually exclusive, as stevensite forms only at pH greater than 10, while bivalves cannot tolerate pH greater than 9. The common mixture of well-rounded basaltic rock fragments with angular, granitic-gneissic rock fragments and feldspars in the sandstones and conglomerates indicates recycling of epiclastic deposits from the early rift section, combined with first-cycle contribution from the plutonic basement. The studied cores show no evidence of subaerial exposure, and there is a lack of bioturbation, suggesting harsh environmental conditions. The rift deposits are dominantly massive or faintly-laminated, with diffuse facies boundaries. Structures indicative of unidirectional or oscillatory flow are subordinate. Integration of seismic, sedimentologic and petrographic evidence indicates that the Campos Basin rift section is formed mostly by re-sedimented gravitational deposits. The onset of the rift sedimentation occurred in synformal depressions, where bivalve banks or stevensite ooids were formed in shallow lacustrine environments under variable alkalinity conditions. With the development of half-grabens and concentration of the tectonic activity along the border faults, recurrent tectonic events promoted the mixing and gravitational re-deposition of stevensitic, clastic and bioclastic sediments in deeper, fault-bounded troughs. Large-scale units, hundreds of meters thick, were generated by major tectonic events, whereas compositional variations in the scale of meters were possibly a product of lake-level climatic fluctuations. Thus, due to syn-rift and mainly to post-rift erosion (the Neo-Aptian unconformity), the preserved rift section of the Lagoa Feia Group comprises mostly sediments deposited in the central troughs of the half-graben structures. Marginal sediments were extensively eroded and re-sedimented as gravity-driven mixed deposits. This new model, constructed form the integration of seismic, stratigraphic, sedimentologic and petrologic data, diverges substantially from the presently accepted model for the sedimentation of the rift section, opening new possibilities for the exploration of Campos Basin, as well as of similar settings, as in the adjacent Santos Basin.

1. Introduction

The Campos Basin in eastern Brazil comprises an area of 100.000 km^2, with more than 2900 drilled wells (Guardado et al., 2000; ANP-BDEP, 2015). Before the recent discoveries of the voluminous pre-salt accumulations, the basin corresponded to more than 90% of Brazil petroleum reserves (Winter et al., 2007). The

* Corresponding author. Department of Geology, Kansas State University, 108 Thompson Hall, Manhattan, KS, 66506, USA
E-mail addresses: kgoldberg@ksu.edu (K. Goldberg), juliano.kuchle@ufrgs.br (J. Kuchle), claiton.scherer@ufrgs.br (C. Scherer), renatalvarenga@yahoo.com.br (R. Alvarenga), patrycia.n@gmail.com (P.L. Ene), armelenti@yahoo.com.br (G. Armelenti), lfderos@inf.ufrgs.br (L.F. De Ros).

http://dx.doi.org/10.1016/j.marpetgeo.2016.11.022
0264-8172/

Lagoa Feia Group, deposited in the rift and sag pre-salt phases, includes lacustrine organic-rich shales, which constitute the source rocks of the basin, and carbonate rocks, which correspond to the main reservoir rocks of the rift section. Despite of the huge number of wells, only a few cores were taken through the rift section of the Lagoa Feia Group. Excluding cored intervals with less than 3 m, cores of the rift section represent no more than 600 m across the entire Campos Basin, usually with 10–15 continuous meters, taken at the shallow part of the basin.

This work proposes a new depositional model for the rift section of the Campos Basin, based on petrologic, sedimentologic, stratigraphic and seismic data collected during an integrated study. This model offers new possibilities for the exploration of the Campos Basin, as well as of similar settings, such as the rift section of the adjacent Santos Basin.

2. Geological context

The Campos Basin was formed during the rifting process that led to the Gondwana breakup. Crustal fracturing started in the South Atlantic during the Jurassic and propagated to Santos, Campos and Espírito Santo marginal basins in the Neocomian (Milani and Thomaz Filho, 2000). The final breakup between the South American and African plates took place in the Aptian.

The basin is limited by the Vitória High to the north and by the Cabo Frio High to the south (Rangel et al., 1994) (Fig. 1), although there is no evidence that these highs were active during the rifting phase. The rift troughs, N to NE elongated, extended towards the Espírito Santo Basin at the north and the Santos Basin to the south. The basin infill can be divided into rift, transitional and marine stratigraphic megasequences (Dias et al., 1990). In the initial opening stages of the Atlantic Ocean, a SW-NE rift valley, with several half-grabens, was formed (Guardado et al., 1990). Early rifting was marked by intense volcanic activity, which formed the basaltic rocks of the Cabiúnas Formation, with ages between 122 and 134 Ma (Mizusaki et al., 1992, 1998). The Upper Neocomian to Barremian rift megasequence comprises the basal to intermediate interval of the Lagoa Feia Group (Winter et al., 2007). The base of this succession includes lacustrine deposits interbedded with volcaniclastic rocks of the Cabiúnas Formation, as well as alluvial conglomerates and sandstones, organic-rich shales and bioclastic rudstones and grainstones, previously called “coquinas” (Abrahão and Warme, 1990; Guardado et al., 1990; Rangel et al., 1994) (Fig. 2). The Aptian transitional megasequence comprises the upper Lagoa Feia Group, composed of a thick clastic package at the base, intercalated with lacustrine carbonates, formed during the sag phase of the Campos Basin (Grassi et al., 2004).

The first commercial discovery of oil in Campos Basin occurred in 1974 (Grassi et al., 2004). The main reservoir rocks are fractured basalts, rift-stage, bioclastic rudstones and grainstones (“coquinas”), Aptian lacustrine carbonates, Albian shallow-marine carbonates, and Cretaceous to Tertiary turbidites. Barremian rudstones and grainstones composed of bivalve and ostracod bioclasts constitute the main reservoirs of the rift section, exploited mostly in the Jubarte, Cachalote, Franca, Badejo, Linguado, Pampo and Bonito fields (Carvalho et al., 2000; Guardado et al., 2000; Castro, 2006). The oil window was reached in the middle Cretaceous, but only in the Miocene peak generation was achieved. Most of the source-rock succession is still in the oil window, and only in some of the grabens have these rocks reached the gas window (Mello, 2006).

3. Methods

The depositional model for the rift section of the Campos Basin was constructed integrating seismic, sedimentologic/stratigraphic and petrologic data. Available data for the study included 2D seismic surveys, well logs and 13 drill cores in the Campos Basin (Fig. 1). There are several limitations regarding rock data. Few wells were cored in the rift section, and the vertical distribution of those is very restricted. The spatial distribution of the drill cores is also restricted and concentrated mostly close to the producing fields, in the southern half of the study area. There are no wells drilled near the basin depocenters. Additionally, the cored intervals are below seismic resolution (15–30 m), what renders the log-seismic correlation difficult. Nevertheless, the data used in this study represent a rather complete data set for the rift section.

Delimitation of the study area was based on: (a) seismic coverage, with the best quality imaging in the rift section, along with the largest number of cored wells, and (b) the observation of the best rift structures, with a variety of half-grabens, a homoclinal ramp with alternate vergence, and some locally complex structures, such as full grabens, relay ramps and low-angle faults.

Seismic analysis included seismic stratigraphic interpretation of reflectors and terminations, seismic stratigraphic units, seismic facies and the construction of chronostratigraphic charts. The methodology follows the original work of Vail et al. (1977), including the definition of seismic patterns and seismic facies of Mitchum et al. (1977), the chronostratigraphic significance of reflections of Vail et al. (1977), and the procedures of Mitchum et al. (1977), as well as the re-visited concepts, models and procedures of Abreu (1998) and Neal and Abreu (2009). Adaptation of sequence stratigraphic concepts to rift basins was based on the work of Prosser (1993), Morley (2002), Bosence (1997) and Kuchle and Scherer (2010).

The sedimentologic-stratigraphic analysis was based on a comprehensive investigation that included the description of about 340 m of cores in 13 wells representative of the rift section. Core description at 1:50 scale, with information on grain size, grain composition, sorting, fossil content and sedimentary structures, was carried out with the aid of qualitative petrographic analysis of 197 thin sections from 9 wells. Depositional facies and facies associations were identified, and integrated logs were constructed. Facies codes were devised for the different lithotypes. For clastic rocks, the facies codes followed Miall's (1978), where the capital letter refers to the grain size (G = gravel, S = sand, F = fines) and the small letter to the structure (*e.g.* m = massive, t = trough cross-stratification), with the exception of heterolithics (Ht). For the carbonate rocks, the facies codes were adaptated accordingly; the capital letters refers to type of carbonate rock (GR = grainstone, R = rudstone, M = microbial) and the small letter to the structure (m = massive, h = horizontal lamination, b = bindstone). For stevensitic rocks, the capital letters refers to the grain size and composition (A = arenite, G = gravel, S = stevensitic) and the small letter to the structure (m = massive, h = horizontal lamination). Magmatic and hydrothermal rocks were given a special code (bas = basalt, Br = breccia, v = volcanic, h = hydrothermal).

Petrologic analysis included the quantitative petrographic description of 95 thin sections from 13 wells through the modal counting of 300 points per thin section, with detailed characterization and quantification of primary and diagenetic constituents, and pore types.

The results of seismic stratigraphic and petrologic analyses are the object of other publications (*e.g.* Armelenti et al., 2016) and thus will not be discussed in detail here. However, some of the data gathered in the integrated study that gave rise to these publications, entitled: *Integrated Stratigraphic-Sedimentologic-Petrologic Study of the Clastic Rift Sections of Santos and Campos Basins, Eastern Brazil*, are essential for the construction of the depositional model here presented, and thus will be discussed below.