

Petroleum Geology of Cameia Field, Deepwater Pre-Salt Kwanza Basin, Angola, West Africa*

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Abstract

Cobalt International Energy and partners discovered the Cameia field in 2012. The field is located in nearly 1700 m of water, and lies 100 km offshore in Angolan block 21. Cameia is a very large 4-way dip closure in an Aptian reservoir, located immediately below the base of salt. The discovery well, Cameia-1, found approximately 300 m of extremely high-quality reservoir in a mound-shaped biogenic build-up. The Cameia-2 well confirmed the presence of the mound reservoir, and also discovered potential reservoirs in the deeper synrift section. Extensive log and core data indicate the mound reservoir is a mixture of chert, dolomite and limestone. Microbial chert boundstone is a major reservoir type, and dolomite grainstones and packstones also comprise significant portions of the reservoir. Calcite-rich lithologies are present, but are commonly of poorer reservoir quality. Stacking patterns, structural position, and well and seismic correlations suggest the microbialites grew as amalgamated reefal complexes on a subaqueous lacustrine structural high. Textural evidence from core, and petrographic and isotope data, suggest the reef-building organisms secreted silica directly from lakes, which had water chemistries that were similar to modern East African rift lakes. Grainstones and packstones, along with carbonate mudstone, accumulated around and within the reef complexes. Much of the original boundstone porosity remains as vugs. The original mineralogy of the grainstones and packstones is uncertain, as most intervals have been heavily dolomitized. Nonetheless, many intervals retain good intercrystalline and interparticle porosity. Permeabilities, based on log, core and test data, are variable but can be very high, as demonstrated by the Cameia-1 drill stem test that reached a rate of 5010 stbopd and 14.3 mmscfd, with minimal pressure drawdown. Development planning for the Cameia field is progressing rapidly, and contemplates a Floating Production Storage and Offloading facility with subsea wells.

Regional Background

Cobalt International Energy and partners, Sonangol Pesquisa & Produção, Nazaki Oil & Gas, and Alper Oil, discovered the Cameia field in 2012. The field is located in approximately 1700 m of water and lies about 100 km offshore Angola in block 21 ([Figure 1](#)).

Block 21 lies within the mostly offshore Kwanza structural basin. The eastern boundary of the basin extends 150 km onshore Angola, where Lower Cretaceous siliciclastic rocks lie unconformably on Pre-Cambrian basement (Brink, 1974). The southern margin of the basin is marked by a line of sea mounts and volcanic rocks that separate the Kwanza basin from the Benguela basin. The northern margin of the basin is poorly defined where the Kwanza basin grades into the Lower Congo basin, and the pre-salt rocks are buried very deeply under the Tertiary clastic wedge. The western margin grades into a distal pinch-out of sediments onto the southern Atlantic oceanic crust.

The Kwanza basin, in turn, can be divided into Inner and Outer sub-basins, separated by a coastline-parallel chain of platforms, called the Atlantic hingeline, where salt is thin or absent (Hudec and Jackson, 2004). These authors interpret the Mesozoic sequence to be thickest in the Outer sub-basin, where the greatest amount of crustal extension took place during and after rifting associated with the separation of Africa and South America.

The sedimentary sequence beneath autochthonous Aptian-age salt is the current focus of deepwater exploration in the Kwanza basin. Similar sedimentary successions can be observed in the Campos and Santos basins offshore Brazil, where large volumes of oil and gas have been found in similar-age reservoirs below salt. Plate tectonic reconstructions suggest that the Kwanza basin, Campos and Santos basins had similar histories, with deposition of reservoirs and source rocks in close proximity before sea-floor spreading separated the basins during formation of the South Atlantic ([Figure 2](#)). These shared histories provide useful information on reservoir and hydrocarbon types found in the Outer Kwanza basin at Cameia.

To date, at least five billion barrels of oil equivalent have been found in the Brazilian Santos basin and Campos basin pre-salt reservoirs (Petrobras website, 2013), and the expected ultimate recovery in the entire Brazilian pre-salt province is estimated at 15 billion barrels of oil equivalent (Petrobras presentation, 2013). Hydrocarbon-bearing reservoirs of this age and structural position have been encountered in five discoveries operated by Cobalt in the pre-salt of the deepwater Kwanza basin to date; they give encouragement that this basin will be extremely prolific as well.

Structure and Geochemistry

The hydrocarbon accumulation at Cameia is contained in a four-way, dip-closed structural trap with at least 500 meters of closure ([Figure 3](#)). Seismic evidence indicates that the Cameia accumulation lies on a horst block that has been a positive structural feature for at least the last 125 million years. The elevated position established the Cameia structure as a focus for hydrocarbon charge from source rocks in the surrounding grabens ([Figure 4](#)). Geochemical modeling, based on Cameia well data, indicates that source rocks located in the pre-salt section have been generating and expelling hydrocarbons since at least 120 million years before present. Furthermore, these geochemical data suggest a cumulative charge over time that has resulted in a very high-yield, gas-condensate reservoir fluid.

Stratigraphy, Sedimentology and Reservoir Quality

Cameia pre-salt stratigraphy is based on recovery of ostracods and some palynofossils, such as algae and pollens. These fossils place the reservoir within the Aptian stage of the Cretaceous, with an absolute age of approximately 125 million years before present.

Cameia pre-salt sediments are principally interbedded chert, dolomite, and limestone. There are a number of lithologies, as shown in [Figure 5](#), but the most important depositional and reservoir facies is microbial boundstone ([Figure 6](#)). This microbial boundstone may be composed of chert, limestone or dolomite, or mixtures of these mineralogies. Textural evidence suggests that the microbial boundstones were precipitated as chert, limestone, or dolomite by bacteria in mounded organic buildups. Subordinate reservoir facies include dolomitic and calcite packstones and grainstones, which are interpreted to have been deposited around and between mounds. Non-reservoir facies are essentially all carbonate mudstone, which has occasionally been dolomitized. The interbedding of cherts, limestones, and dolomites is probably related to changes in lake water chemistry as various ion-bearing fluids entered through vents and springs along faults at the lake floor. Textural evidence from core and petrographic and isotope data suggest the reef-building organisms secreted silica directly from lakes, which had alkaline water chemistries that were similar to modern East African rift lakes.

Petrographic and isotopic evidence from Cameia indicates that diagenesis started early (before compaction) and continued through hydrocarbon charge. Petrographic study, as well as visual inspection and capillary pressure data, indicate that a number of pore types and ranges in pore sizes are present in Cameia reservoir. A spectrum of pore sizes, from nanopores (pore throat radius <0.10 microns) to megapores (pore throat radius >50 microns) are present ([Figure 7](#)). Numerous two- to four millimeter-sized vugs are visible in core and image logs as well. This range of pore sizes has a large impact on reservoir quality and well deliverability. In particular, the larger pore sizes are interpreted to provide the excellent well productivity observed in the Cameia-1 DST, which flowed at rates in excess of 5010 stbd and 14.3 mmscfd, with minimal reservoir pressure drawdown.

Development Planning

Development planning for the Cameia field is progressing rapidly and contemplates a Floating Production Storage and Offloading facility with subsea wells and wet trees. Cameia reservoir contains a rich gas-condensate fluid, with a liquid yield of 295 stb/mmscfd, which is one of the richest gas-condensates yet reported. The condensate has an API gravity of 39, is low in sulfur, and is indistinguishable from high-quality crude oil. Recovery of the condensate will be maximized by recycling of produced gas, and gas injection, along with water injection, is a fundamental element of the development concept. The current schedule calls for 1st oil from the Cameia field in 2017.

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Website

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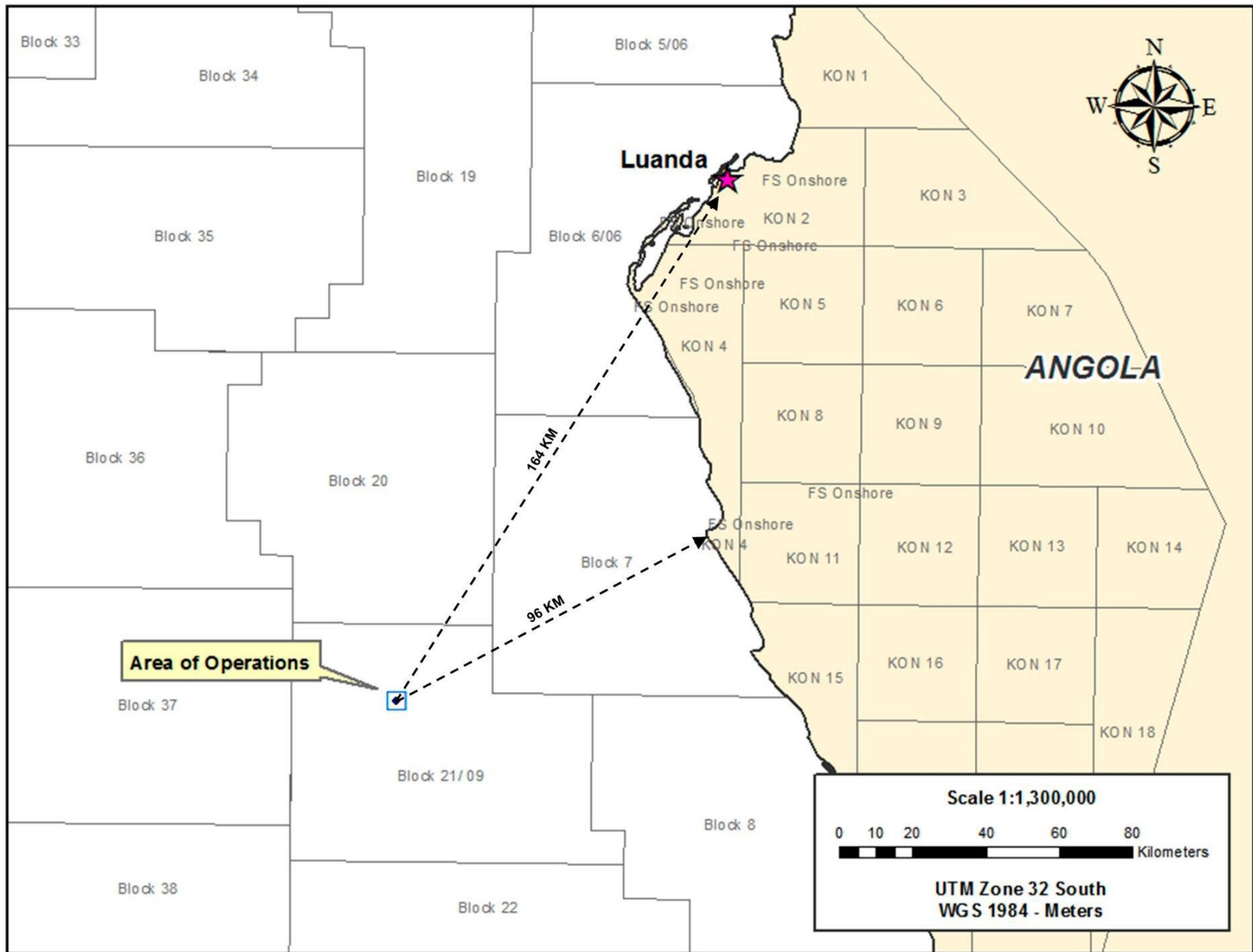


Figure 1. Cameia field location map.

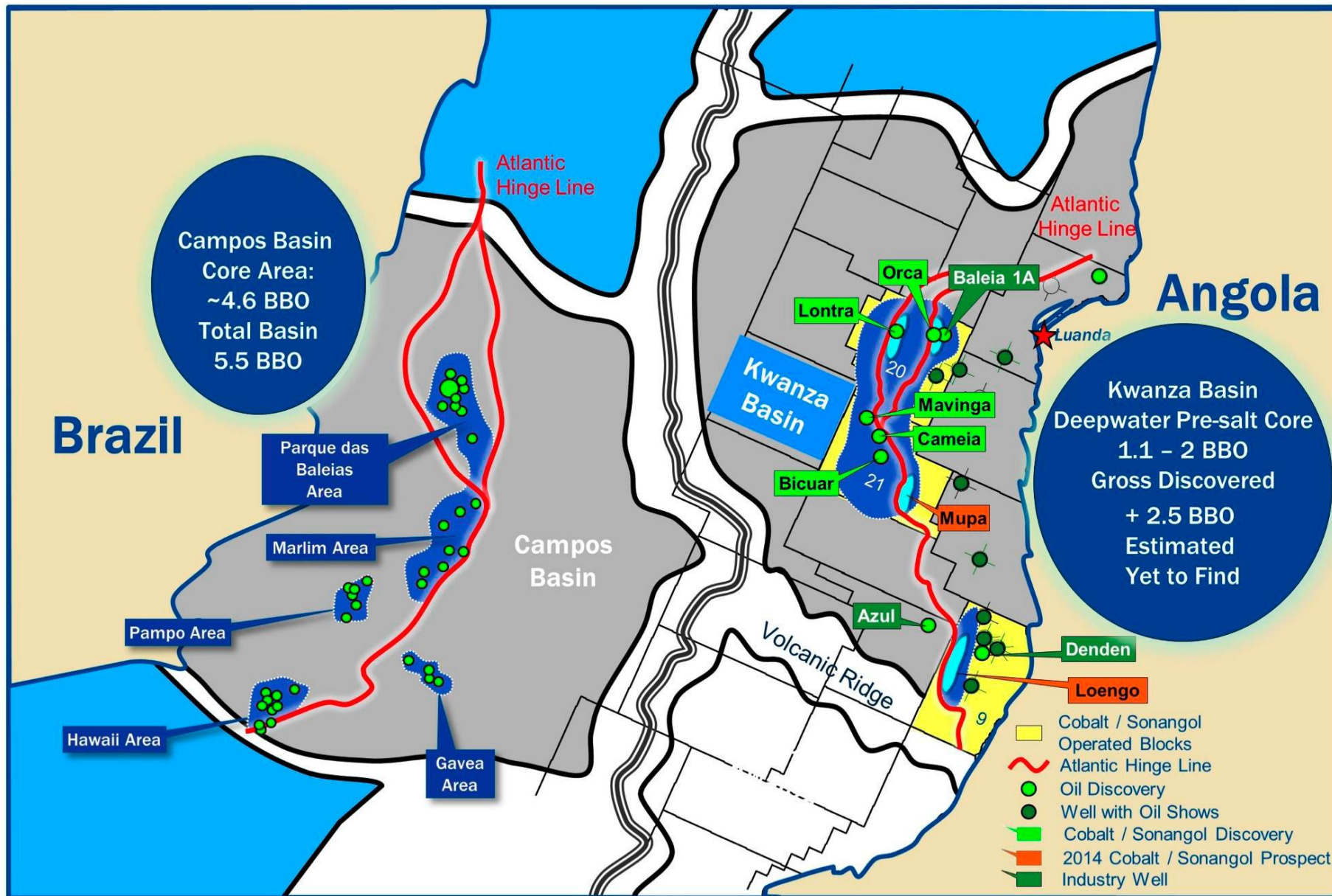


Figure 2. South Atlantic plate reconstruction at Aptian time.

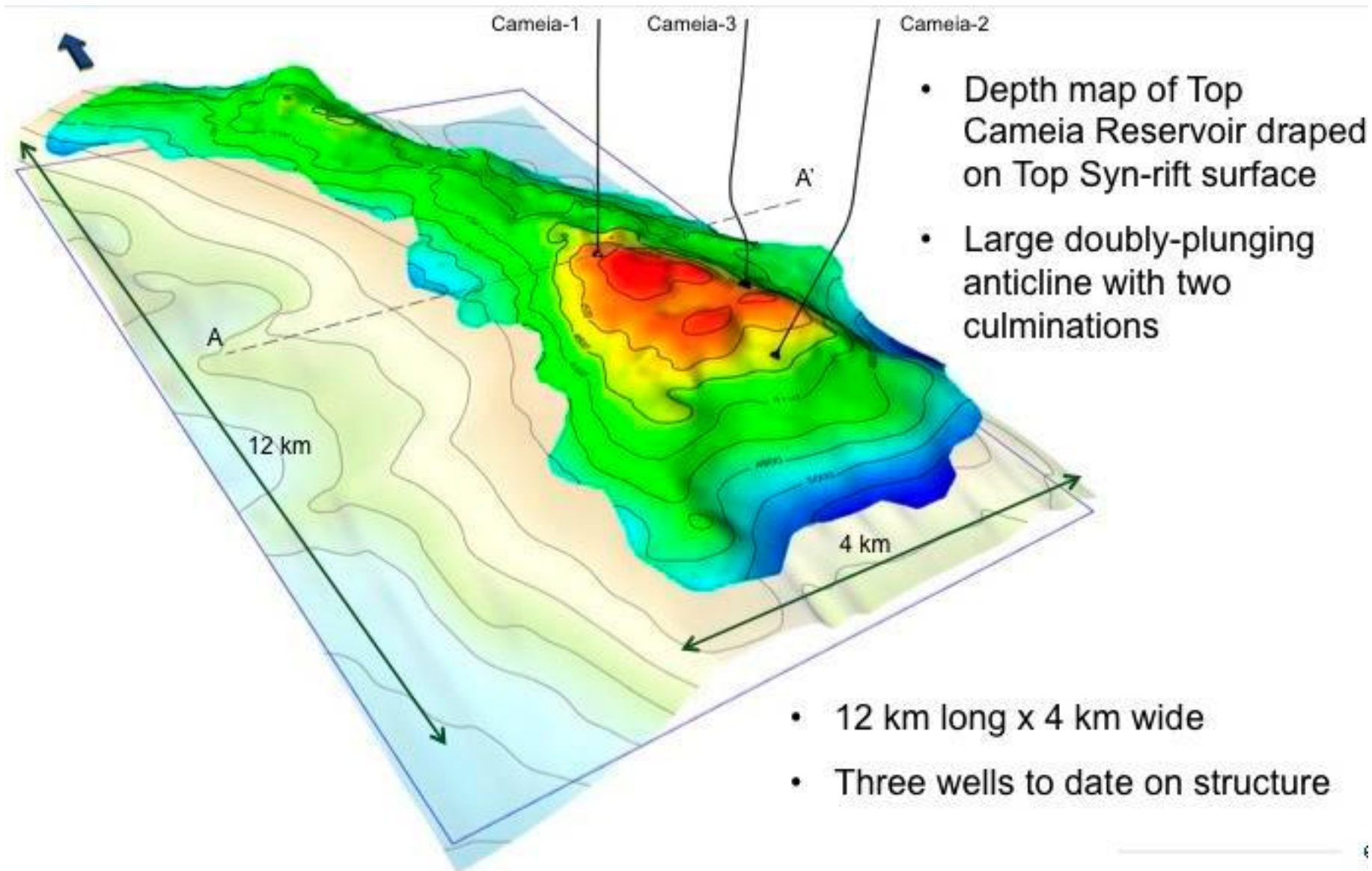
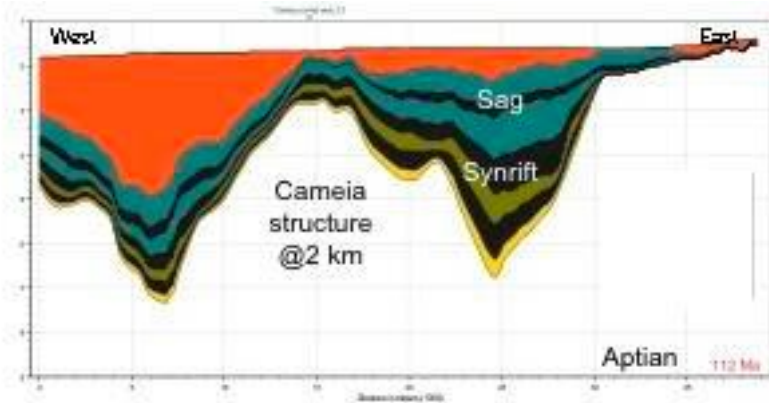
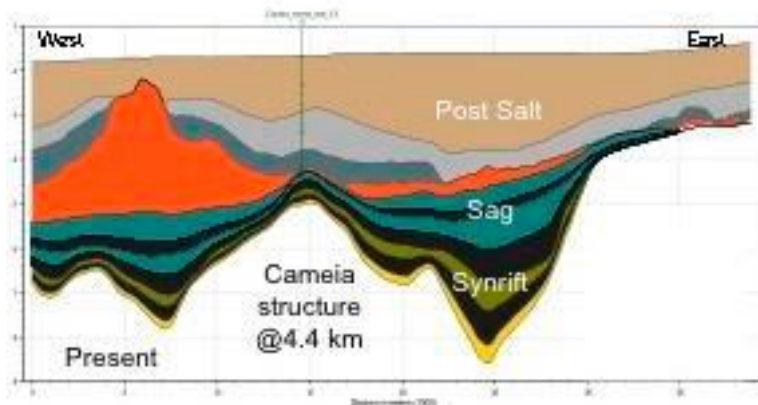
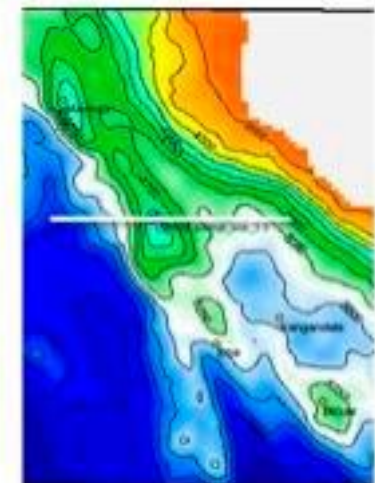
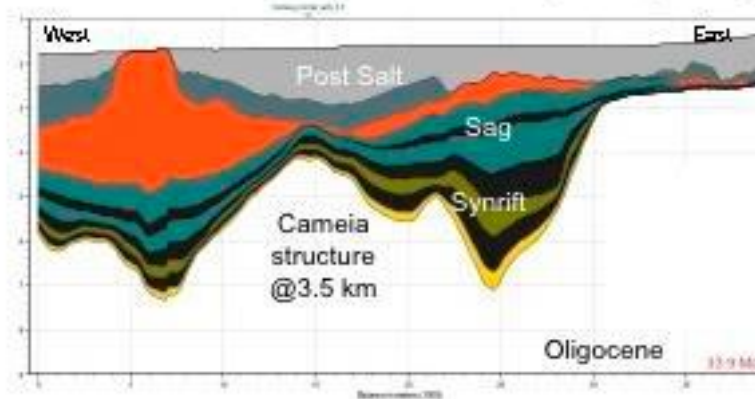


Figure 3. 3D perspective of Cameia structure, showing top Cameia reservoir depth structure draped on syn-rift depth structure. Depth contours in meters TVD SS; interval =100m. Note North arrow.

Structural configuration at time of salt deposition over top of Cameia structure. Deep evaporite basin to west



Onset of clastic wedge deposition from rivers to east. Salt diapirism begins

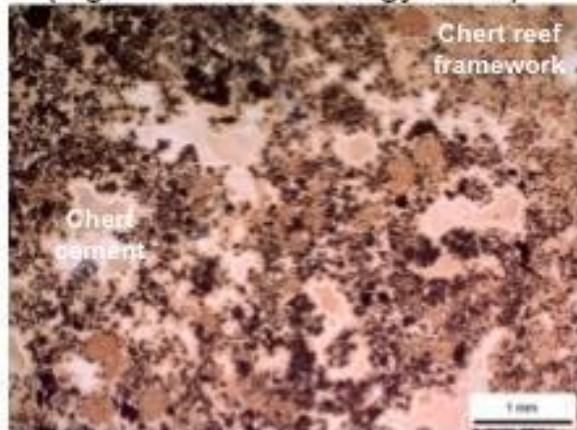


Miocene – Recent sediments fill in submarine lows. Salt withdrawal continues

Figure 4. Cameia burial history.

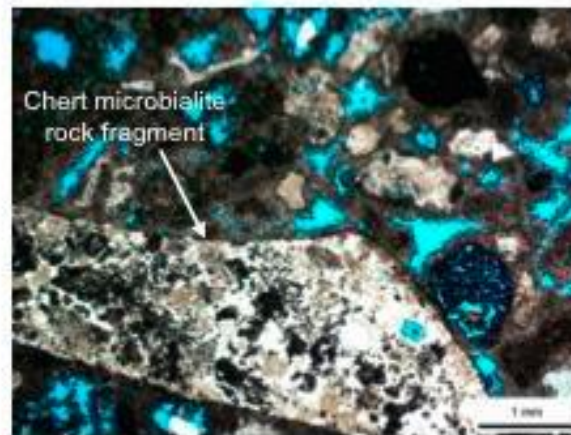
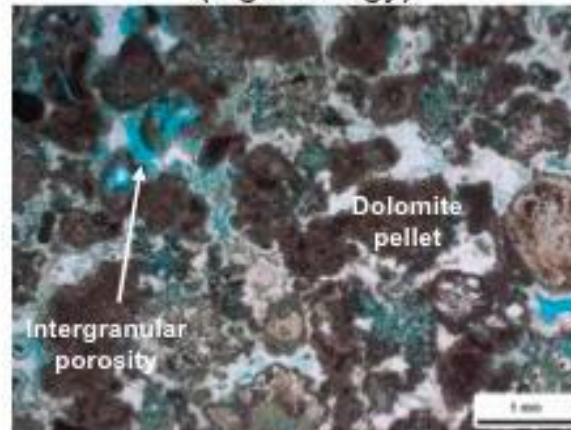
Microbial Boundstones

Chert and minor carbonate
(high – medium energy reefs)

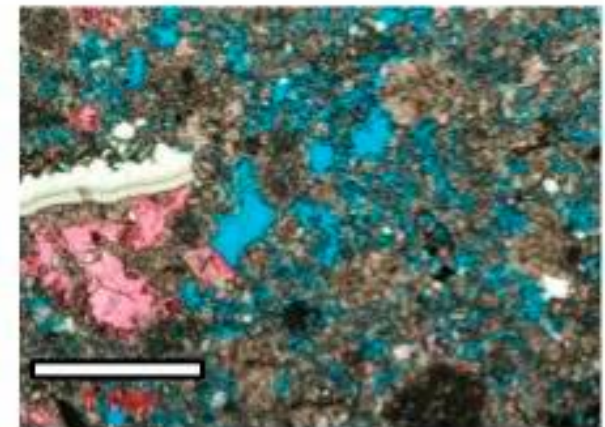


Grainstones

Limestones and Dolomites
(high energy)



Porous Dolomite



Mudstones (low energy)



- Cameia Mound reservoir is a mosaic of chert (microcrystalline silica), limestone and dolomite
- Pore types and sizes are variable, and typical of carbonate reservoirs, even though mineralogy may be silica
- Mineralogy and porosity is dependent on depositional environment and lake chemistry

Figure 5. Cameia mineralogies in thin-section.



Figure 6. Microbialite boundstone in core.

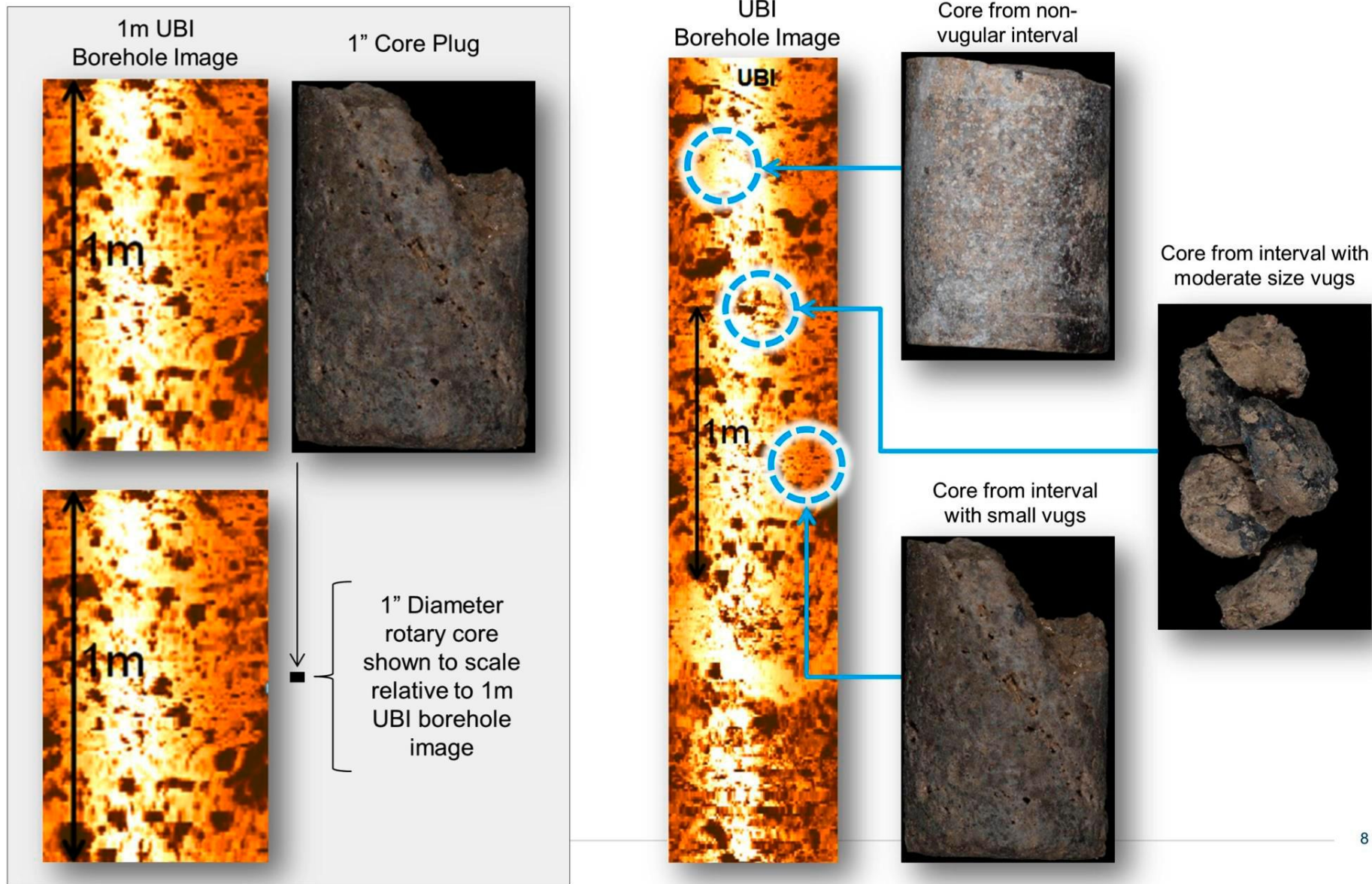


Figure 7. Pore systems showing vugs.