The Wildest Plays on the Planet

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Apparently wacky play ideas have already proved profitable, even resulting in the discovery of supergiant fields. There are probably many more unconsidered plays waiting to be discovered. Is it time to think outside the box?

The vast majority of the world's hydrocarbons have been discovered in what are termed conventional settings. These are primarily structural closures into which oil or gas has migrated, becoming trapped in layers of porous reservoir sandstone or limestone beneath an impervious cap rock. Stratigraphic traps, in which similar reservoirs are encased in shales, make up a smaller proportion of successful hydrocarbon plays, and recent years have seen the rise of a variety of unconventional plays. But beyond these accumulations lie a subset of truly unconventional, even wacky plays, where the geologist needs an open mind to appreciate the 'wildest plays on the planet'.

Ranging from astrobleme-hosted reservoirs to caves full of oil, and from hydrocarbon-filled granites to gas accumulations where animal sacrifices are the norm, there are some truly mind-boggling plays around the globe – and, potentially, in other parts of the solar system. There are also a variety of commercially viable, non-hydrocarbon gases, such as helium and nitrogen, which can be produced directly from the subsurface. Often discovered serendipitously, these plays are components of some of the world's largest fields. Examining their rich variety should provide those exploring for hydrocarbons with new insights and ideas.

Coming from Outer Space

The plays discussed here would probably have management laughing the exploration geologist out of the room, yet key features of many of them are the large reserve bases and high exploration success rates. Nowhere is this truer than in plays related to meteor impact craters. Around 40 commercial oil and gas fields have been discovered in craters, out of around 160 such structures identified worldwide, giving an impressive one in four discovery rate.

The largest (and most famous) is Chicxulub in the Mexican Gulf of Mexico, the remains of the impact event that may have wiped out the dinosaurs. Following the meteor collision at the Cretaceous/Tertiary boundary, the collapse of a carbonate platform deposited a series of coarse, shattered breccias, which form an excellent reservoir, complemented by the sealing ejecta layer. The resulting

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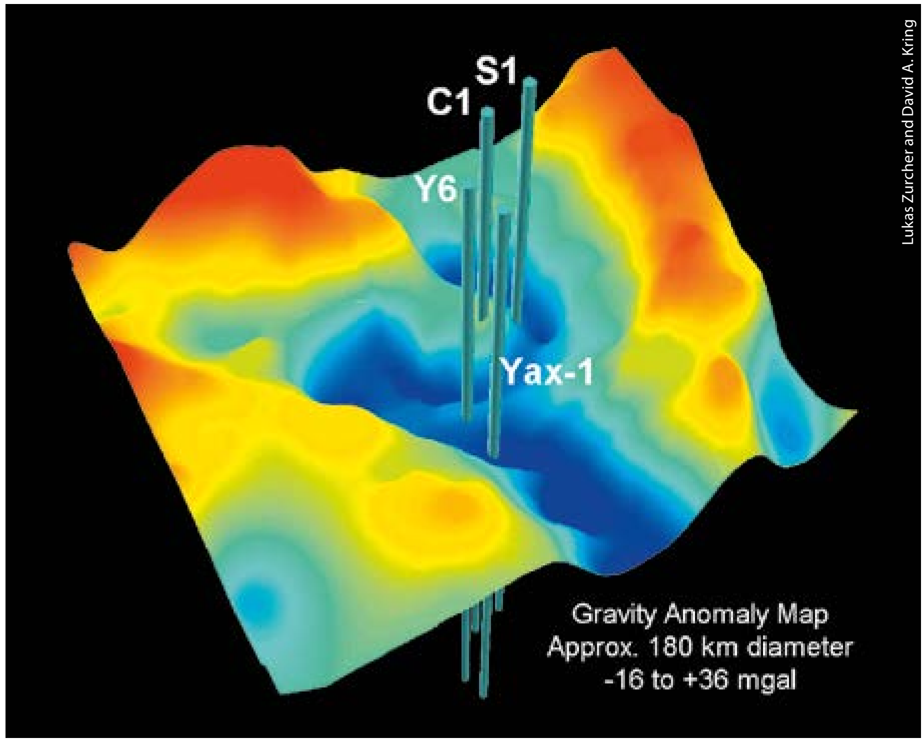
An astrobleme, the Barringer Crater in Arizona, also known as the Meteor Crater.

supergiant Cantarell field, discovered in 1976, delivered more than 2.1 MMbopd at peak production.

A further nine astroblemes are known to be producing in North America alone. One of these, the Avak Crater in Barrow, Alaska, was drilled by the army to fuel the military base there. The concussion that created the crater folded the surrounding rocks, trapping natural gas beneath impermeable cap rocks. The target reservoir comprises strongly deformed Ordovician and Silurian argillites. Overlying the crater are younger marine sandstones and shale seals, defined by gravity data.

Another such feature is the Ames Crater, which was discovered in the Sooner Trend in Oklahoma in 1991, based on some exceptionally productive wells. When examined, cuttings included brecciated granite with good shows, as well as shattered quartz and feldspar with cleavage faces. The crater is more than 10 km across, and following the meteor strike, it filled with fine sediments, ultimately producing a thick source rock interval and seal.

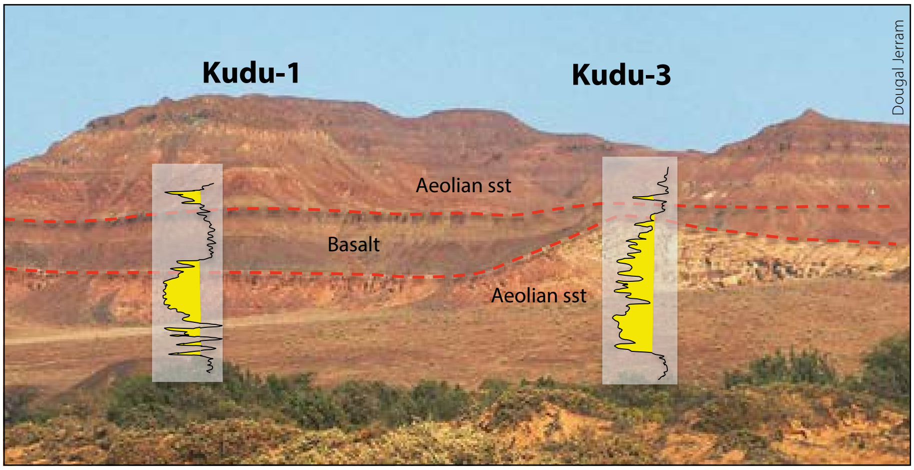


Gravity and borehole map of the Chicxulub crater, which is buried beneath Tertiary sediments. Gravity contrasts – between breccias created by impact-generated shattering of the rock and the denser rock resulting from melting of the Earth's crust – create a semi-circular anomaly in the gravity of the northern Yucatán Peninsula. S1, C1, and Y6 were exploration wells drilled by PEMEX in the '80s, and Yax-1 was drilled by the ICDP in 2002.

Other examples around the world include the Oblon crater, one of three potential astrobleme producers in central Ukraine, and the Viewfield field in Saskatchewan, which produces 400 bopd from fractured Mississippian carbonates. The Tookoonooka Crater in Queensland hosts several small oil fields.

Cracks in the Basement

Most people would not expect igneous rocks to host hydrocarbons, but more than 30 countries have fields that produce from igneous, volcanic or metamorphosed basement. The Suban Field in Indonesia, for example, holds more than 8 Tcfg in fractured granites, while fields in Thailand and Libya have also produced oil and gas from granitic basement.



An outcrop analog of the Kudu field, where volcanics form an important part of the petroleum system.

Production may exceed 20,000 bopd from extensive fracture networks. Generally, a high proportion of deep seated fractures in these rocks are subvertical, so horizontal wells can be key to unlocking these resources.

Typically basement reservoirs are considered more difficult to evaluate than conventional reservoirs, and are often discovered by chance rather than by design. However, several companies are now targeting basement plays, with both Russia and Thailand drilling into crystalline basements. As discussed on page 62, Hurricane Energy has drilled several such wells in the West of Shetland area.

Volcanic rocks are also associated with the Kudu Field in Namibia (*GEO ExPro* Vol. 8, No. 6), where the Cretaceous Twyfelfontein Sandstone hosts gas in aeolian deposits that are 'frozen' beneath outflowing basalts. These volcanic rocks were formed as the Atlantic opened.

In several Chinese basins such as Bohai and Songliao, the volcanic sediments can act as reservoirs (when fractured), as seals and as trapping mechanisms. Porosity is usually preserved because the rocks are strong enough to resist compaction. Lava tubes filled with gas have reportedly been identified in the subsurface in the Xingcheng gas field.

Caves Filled with Oil

A significant proportion of laymen still believe that oil is sucked from underground caverns using pipes. In the Rospo Mare Field, in the Gargano region of southern Italy, this is literally the case. Oil is trapped in vugs, fractures and subterranean caverns in Cretaceous karstified wackestones. Emergence of the limestone platform at the end of the Cretaceous allowed the development of caves, which were later onlapped by transgressive Tertiary carbonates and (sealing) evaporites. The field has an estimated recovery of 94 MMbo. The oil has been produced from the karstified interval using horizontal wells since 1982, one of the first fields ever to use this now commonplace technology. Production from a single well may exceed 3,000 bopd.

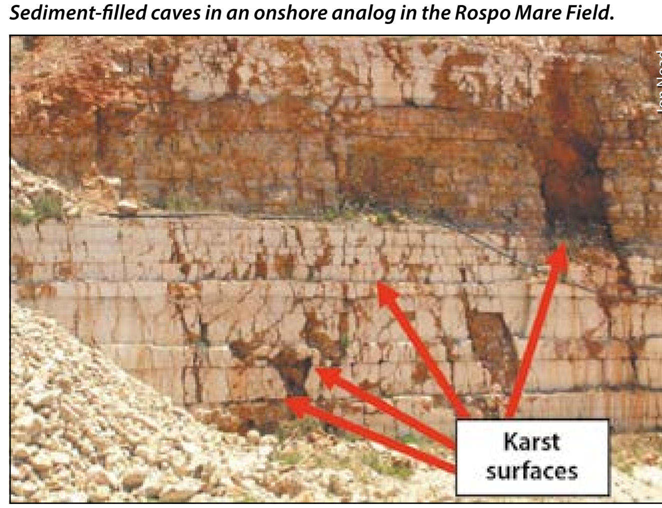
End Member Hydrocarbons

Several types of hydrocarbons do not fit the standard blueprint, including gas hydrates, a naturally occurring, crystalline, ice-like substance composed of methane hydrate gas molecules. They are constrained by a narrow range of high pressure and low temperature, with the vast majority located on oceanic continental slopes. Typically stable around 300m below the seafloor, the main controls are the reservoir lithology and available methane. Gas hydrates are usually recognized on seismic data through bottom-simulating reflectors, and the estimated resource potential worldwide may exceed 40,000 Tcfg, although they have yet to be produced commercially (see http://www.geoexpro.com/collections/6/).

Gilsonites are natural, resinous hydrocarbons, in the form of 'frozen' oil left after the volatiles have evaporated. They form vertical seams many kilometers long and up to 500m wide, filling existing fractures, and are mined in Utah and Kermanshah, Iran. In Utah the source of the gilsonite is the Green River Formation, which hosts the world's largest oil reserves (though currently not commercially viable). The brittle, jet-black gilsonite was used in the lacquer applied to Model T Fords, and is now a key component in photocopy black and in newsprint.

Tar mats are immobile, heavy oil deposits similar to pyrobitumens. They are common in carbonate reservoirs

Sediment-filled caves in an onshore analog in the Rospo Mare Field.



Natural gas emanating from disassociation of natural gas hydrate, Monterey Bay Aquarium Research Institute.

in the Middle East, and are often located close to the oil-water contact in a reservoir, accumulating due to biogenic activity, gravitational settling or to increases in solution gas. They can be potential reserves, and also provide excellent seals, as in the Orinoco Petroleum Belt in Venezuela, the world's largest single accumulation of heavy crude. A tar mat cap seals the Bolivar Coastal field, one of the world's largest conventional fields.

Other Molecules

The Kabir Kuh field in north-west Iran is 220 km in length, and 85% of the fill is nitrogen. Possible explanations for this unusual deposit include an underlying hot spot, a volcanic source rock or basement rocks with a nitrogenic component. The gas occurs in Ordovician and Permian carbonates, and could replace the Haber-Bosch process in providing feedstock for fertilizers.

There is often a link between high nitrogen and helium values, which is important because experts suggest that the world has only 25 years' remaining supply of helium. It forms from the breakdown of uranium, radon and thorium, usually found in basement rocks, and is then trapped in overlying natural gas reservoirs. The minimum commercial concentration is only 0.3%. The US produces around 40% of the world's helium, the majority from Kansas and from the Hugoton Panhandle on the border of Texas and Oklahoma.

Several gas fields in Arizona have high concentrations of helium, such as the Dineh-bi-Keyah oil field, which is 6% helium, sourced from black shales, occurring in a fractured syenite sill reservoir. The Holbrook Basin hosts the St. John's carbon dioxide and helium field, with up to 10% helium, and Kinder Morgan are reportedly planning to exploit this resource. Further resources have been identified in Canada in Saskatchewan and Alberta, with several projects actively exploring.

A recent project in South Africa is targeting helium dissolved in groundwater in former gold mines. The helium was generated from the breakdown of uranium, which is associated with gold deposits (see below), and then goes into solution in groundwater, which is transported along faults towards the surface. The helium occurs in association with methane sourced either from coal-bearing Karoo-age rocks or produced at depths by microbes.

The La Brea tar pits are near Los Angeles, California.

Finishing on a High

Among a cavalcade of extraordinary hydrocarbon plays, a few stand out. The Witwatersrand of South Africa has produced around 50% of all the gold ever mined on Earth, around 40,000 metric tonnes. Much of the gold is found in association with kerogen, thought to represent cyanobacterial remains some 2.2 billion years old. The gold has been locally remobilized, forming an amalgam with the carbon, which has been produced by the baking of the bitumen over time. Gold grades may reach kilograms per tonne in these Archaen, carbon-rich hydrocarbon reservoirs, which equates to hundreds of thousands of dollars per barrel.

Pammukkale, in south-western Turkey, is a UNESCO World Heritage Site because of the stunning travertine deposits and hot springs found there. It is also the site of Pluto's Gate, famous in biblical times as a place of sacrifice. Animals were driven into a cave by priests, and expired in the poisonous carbon dioxide atmosphere within. Their bodies were later removed using long ropes. The cave was rediscovered in 2013, partly due to the number of dead birds surrounding its entrance. The gas is emitted from a deep cleft in the rocks, through which fast-flowing hot water passes, degassing before feeding the hot springs in the area.

Finally we turn to the 'Door to Hell', in Turkmenistan. The location was originally drilled for oil in 1971, but intersected methane in the shallow subsurface. The small field collapsed to form the Darvaza crater. Russian geologists set it on fire to prevent the spread of methane gas, expecting it to burn for a few weeks, but 50 years later it is still aflame and has become a popular tourist attraction despite a government edict in 2010 to extinguish the fire. A member of the Explorers' Club of New York, clothed in a heat-resistant suit, reached the bottom of the crater in 2013, and collected a variety of extremophile bacteria.

What Can We Learn?

At first glance, many of the plays above appear of little more than academic interest. Yet almost all of them have proved profitable, and several have resulted in the discovery of supergiant fields. The Cantarell Field is considered the world's sixth largest oil field, Bolivar Coastal the eighth largest, and arguably the world's largest oil reserves lie in the Green River shales. Production has often required new technologies that can later be applied to less obscure plays. Many other fields continue to produce hydrocarbons from unusual plays, often discovered by chance.

This should encourage young exploration geologists to keep an open mind, and to look for evidence of unexpected shows and play elements. It only takes a single, repeatable play opportunity (that may have sat unrecognized for decades) to change the fate of a company. And not only on Earth: it is only a matter of time before a geologist convinces their manager that the next test should be carried out on the hydrocarbon lakes of Titan.

Now that is definitely thinking outside the box. ■

Natural gas burning at the 'Door to Hell', Darvaza Crater, Turkmenistan.

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