

Jamaica's petroleum potential prompts a first licensing round

A first formal licensing round of offshore and onshore blocks has focused industry attention on the petroleum geology of the West Indian island of Jamaica. Chris Matchette-Downs of JEBCO Seismic and Simon F. Mitchell, senior geologist at the University of West Indies Mona, describe the background.

The Government of Jamaica's Ministry of Science, Commerce and Technology (with Energy) and the Petroleum Corporation of Jamaica last November officially launched a first ever formal licensing round, to include four onshore blocks, Negril, Santa Cruz, Portland, and Windsor, and blocks 1 to 20 offshore. The round opened on 1 January with applications due in by 15 July.

The majority of the blocks offered lie in modest water depths in areas which contain numerous recently identified leads. There are strong indications that multiple Petroleum Systems may be present, with mixed oil and gas prone source potential. In addition to the potent source rocks there are individual structures which may have billion barrel and/or multiple TCF potential. There is high demand for new energy sources both in Jamaica and nearby in the USA. A detailed new report on the petroleum potential of Jamaica has recently been completed and is available in both digital and paper format.

Following a first phase review of the petroleum potential of Jamaica and announcement of the first licensing round, JEBCO Seismic is moving to the next phase of a plan for Jamaica by transcribing the national archive of 16,126 line km of seismic held in Houston onto modern media, along with reprocessing the Greater Walton Basin seismic and Pedro Bank datasets (11,140 line km).

Geological History of Jamaica

The geological history of Jamaica can be conveniently divided into depositional phases separated by changes in tectonic stress

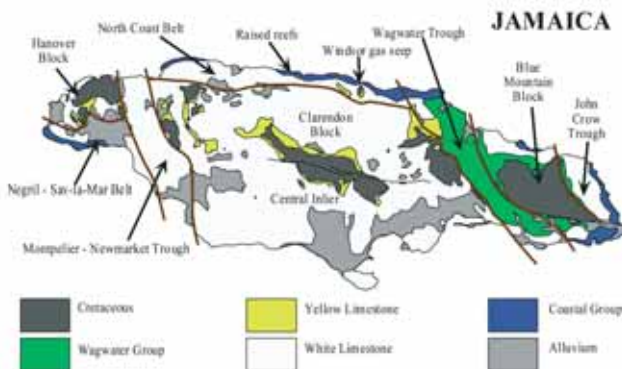


Figure 1. Simplified geology showing location of Central Inlier and other areas of interest in Jamaica

regimes and/or tectonic events (Draper, 1987; Mitchell, 2004a). The major event now recognized is the Late Campanian collision of the Chortis Block/Nicaragua Rise with the Yucatán Block. This event created northward dipping thrusts in the Central Inlier (Mitchell, 2004a) and accreted at least three separate structural units with different geological histories to form Jamaica. These three blocks are the Cornwall-Middlesex Block (probably including the Walton Basin and Pedro Bank), the North Coast Block and the Blue Mountains Block (Fig. 1). The geology of central Jamaica typifies this geological evolution and exposes rocks similar to those expected in the Walton Basin south of Jamaica.

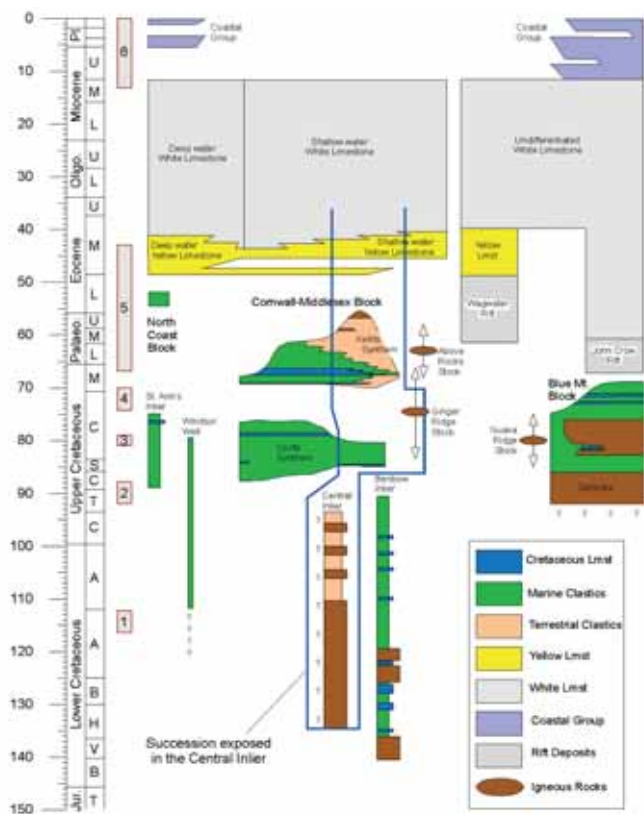


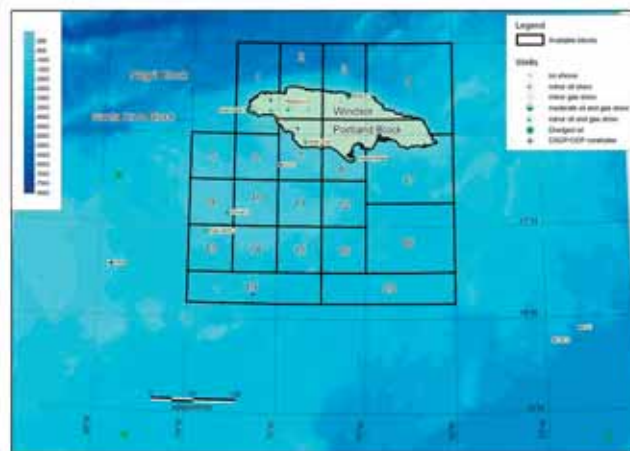
Figure 2. Simplified geological succession in Jamaica. Succession in the Central Inlier outlined in blue. 1 to 6 are tectonic events that have affected Jamaica (See Cameron et al., 2004 for details).

Petroleum Geology

Geology of the Central Inlier

The rocks of the Central Inlier (Figs 2-3) have been divided into four packages (Mitchell, 2004a): an older unit of volcanics (Arthurs Seat Formation); an older Cretaceous sedimentary sequence (Crofts Synthem); a younger sedimentary sequence (Kellits Synthem); and a cover of Tertiary limestones and clastics (White and Yellow Limestone Groups). The Arthurs Seat Formation represents a thick, unprospective volcano-sedimentary succession intruded by dykes and small plutons (Mitchell, 2004a). It is overlain by the Crofts Synthem (Mitchell, 2004a), a Santonian-Campanian sedimentary succession consisting of tight rudist limestones (Peters Hill and Dry Hill Formations) and overlying shale and turbiditic sandstone-shale sequences (Back River and Dawburn Content formations), both of which are also largely unprospective.

The Kellits Synthem (Fig. 4) is a major transgressive-regressive cycle (Mitchell and Blissett, 2001; Mitchell, 2004a). The basal unit, the Slippery Rock Formation (150 to 175 m thick), consists of red, brown or grey pebble conglomerates in poorly-defined beds up to several metres thick. The conglomerate beds have sharp, erosive bases, may have tabular and trough-cross bedding, and some show nodular calcretes at the top. The amalgamated conglomerate beds pass upwards into discrete conglomerate beds alternating with poorly-sorted pebbly sandstones and red siltstones with nodular and peloidal calcretes. In the western part of the inlier, the Slippery Rock Formation is succeeded by the Thomas River Formation. This consists of up to 175 m of red and grey



mudstones. At the base is a thin sandy limestone (Black River Member) with oysters. The red mudstones are unfossiliferous, but contain thin horizons of nodular calcrete. The grey mudstones contain thin beds of ripple cross-laminated sandstone showing bidirectional palaeocurrents, and are arranged into fining upwards packages (usually 10 – 50 cm thick, but sometimes up to 2 m thick) that show a transition from flaser to wavy to lenticular bedding. A few thin widely spaced marine limestones are present and contain a rudist-coral fauna. Organic debris is very widespread in the grey mudstones which yield mixed marine–freshwater faunas (gastropods and bivalves) and floras (charophytes: Kumar and Grambast-Fessard, 1984). They are interpreted as tidal flat deposits.

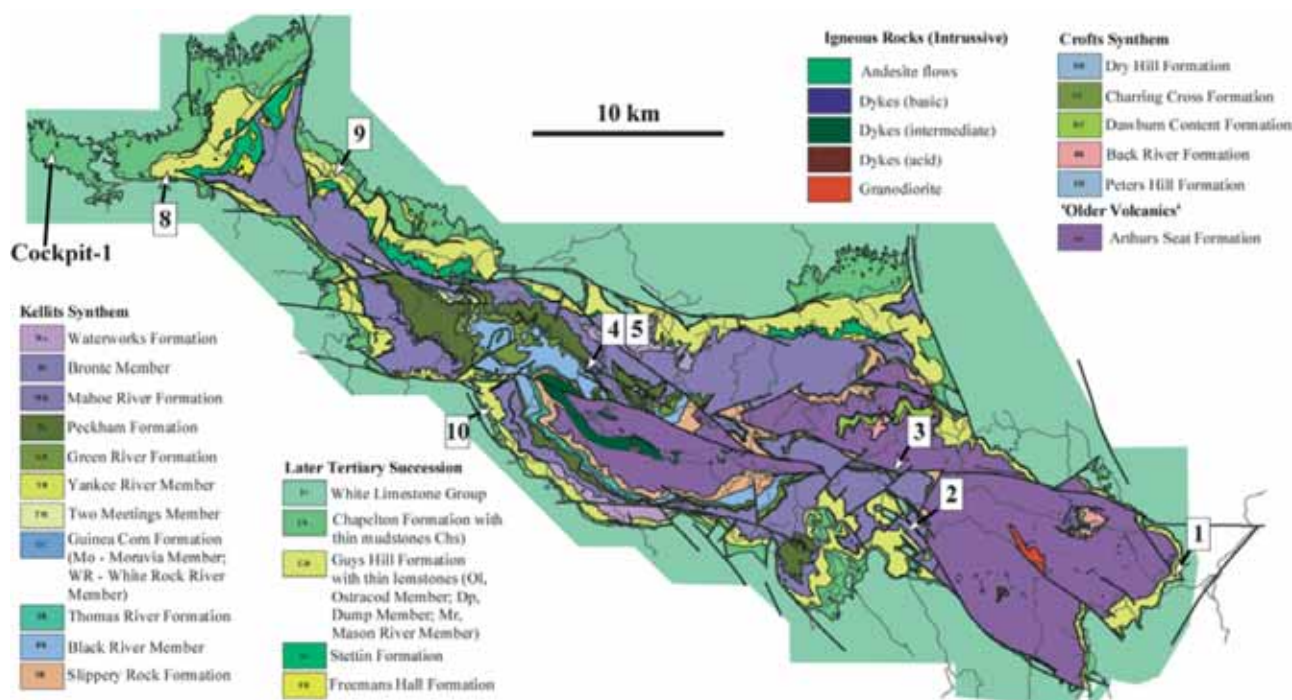


Figure 3. Geology of the Central Inlier (From unpublished map). Locations 1-5, 8-10 shown.

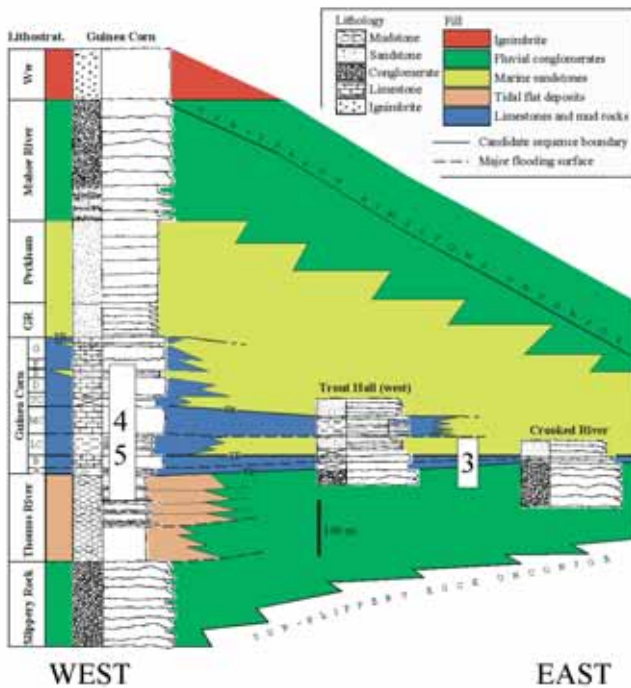


Figure 4. Simplified lateral distribution of Kellits Synthem with approximate positions of sections (3-5) studied

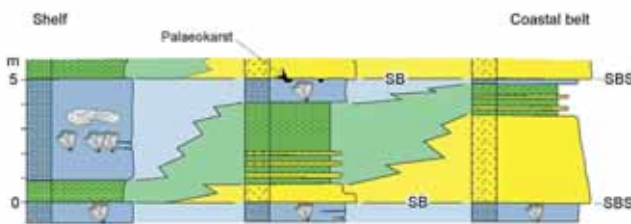


Figure 5. Idealized model for 5th-order Sequences in the Guinea Corn Formation

The Guinea Corn Formation is up to 250 m thick and rests on the Thomas River Formation in the west, the Slippery Rock Formation in the middle, but is absent in the eastern parts of the inlier. The formation consists of rudist-bearing limestones varying from massive to thinly bedded to nodular (Coates, 1965; Kauffman and Sohl, 1974; Mitchell, 1999). The limestones alternate with fossiliferous siltstones and mudstones with graded sandstones, forming rhythms (Mitchell, 2002). Rudist bivalves are abundant in the limestones and include *Titanosarcolites*, *Praebarrettia*, *Bournonia*, *Biradiolites*, *Antillocaprina* and *Thyrastylon* (e.g., Kauffman and Sohl, 1974; Mitchell, 1999, 2002). The limestones thin to the northeast and are replaced by paralic mudstones. Fossiliferous siltstones are interbedded with the limestone in the lower part of the succession. In the upper part of the succession, mudstones with graded sandstones, similar to the sandstones of the overlying Green River Formation, are pres-

ent (Mitchell, 1999). Four major limestone intervals are recognised in the Guinea Corn Formation and represent fourth order sequences. These sequences are built of fifth order sequences (the rhythms of Mitchell, 2002), which are separated by brief periods of emergence (Fig. 5). The siltstones and mudstones are organic-rich with lignitic mudstones up to 20 cm thick. A late Maastrichtian age is indicated by the fauna (e.g., Underwood and Mitchell, 2000) and ages derived from strontium isotope values (Steuber et al., 2002).

The Guinea Corn Formation (or Slippery Rock Formation where the Guinea Corn Formation is missing) is succeeded by the Summerfield Group consisting of a shallowing-upwards succession of marine to terrestrial volcanoclastic sedimentary rocks (Mitchell and Blissett, 2001). The lower part consists of mudstones with normally graded sandstones (Green River Formation – 60 m thick) that pass up into massive sandstones (Peckham Formation – 150 m thick). The overlying Mahoe River Formation (210 m thick) consists of thickly-bedded, pebble and boulder conglomerates with rounded clasts that have well-developed imbrication. Matrix-supported conglomerates are rarer, and sandstones are interbedded with the conglomerates in the lower part of the succession. The Mahoe River Formation is succeeded by up to 150 m of ignimbrites (Waterworks Formation). Mitchell (2000) interpreted this shallowing-upwards succession as a progradational volcanoclastic braid-delta, associated with a newly emergent volcanic centre.

A single fission track age from apatites from the Waterworks Formation indicates the earliest Eocene (55.3 ± 2.8 Ma; Ahmad et al., 1987). The succession drilled in the Cockpit Borehole (Fig. 3) can be directly correlated with the succession developed in the northwestern part of the Central Inlier. In both sections, the Guinea Corn Formation is divided in two by a thick mudstone sequence and overlain by the Summerfield Group. A shale unit with limestones at the base below the Guinea Corn Formation represents the Crofts Synthem.

Petroleum Geology

Source Rocks. The littoral and lacustrine deposits of the Thomas River and Guinea Corn formations in the Central Inlier are potential source rocks. These rocks are widespread across the surface exposures of central and western Jamaica. Analyses of oils recovered from the Retrieve-1 well (Cameron *et al.*, 2004) suggest a littoral setting (neutral CV) approaching a lacustrine environments (high tricyclic terpane C26/C25 ratio of 1.16) consistent with the palaeoenvironment of the Thomas River and Guinea Corn formations.

Reservoir Rocks. Rudist-bearing limestones (such as the Guinea Corn Formation) represent the most attractive reservoir rocks in the Cretaceous succession. The Guinea Corn Formation penetrated in the Cockpit-1 well had high porosities. Seals are provided by interbedded and overlying mudstones and shales.

Petroleum Geology

Tertiary Succession (Yellow and White Limestone Groups) Early Palaeogene rifting in Jamaica resulted in the formation of a block and trough topography defined by NW-SE and E-W fault sets (Fig. 1). During the Eocene to Middle Miocene the Yellow and White Limestone Groups were deposited (Robinson and Mitchell, 1999; Mitchell, 2004b); deep-water successions in the troughs, and shallow-water successions on the blocks. The rocks of the Yellow Limestone Group are now the prime hydrocarbon objective in Jamaica and contain source rocks, reservoir rocks and seals.

The Yellow Limestone-lower White Limestone can be divided into two major deposition cycles, the Stettin Cycle (Freemans Hall and Stettin Formations) and the Chapelton-Troy Cycle (Guys Hill, Chapelton and Troy Formations). The latter cycle (Fig. 6) will be examined in central Jamaica which represented a mixedclastic-carbonate platform succession with ramp-type margins. This succession is very similar to deposits penetrated in Content Well-1, and may be typical of Yellow Limestone deposition in the Walton Basin.

The Guys Hill Formation consists of a succession of sandstones, mudstones and thin limestones. The sandstones are well-sorted, uncemented quartz-bearing arkosic arenites and occur in 2-4 m thick beds with low angle cross bedding

(Fig. 7). They are interpreted as crevasse splay fluvial systems; thicker, coarser-grained sandstones may represent the channel systems themselves. In the lower Guys Hill Formation, the channel sandstones rest on mottled mudstones with occasional crayfish burrows and nodular calcrete horizons that are interpreted as interchannel palaeosols. Mudstones in the upper Guys Hill and lower Chapelton Formations contain low-diversity assemblages of oysters and gastropods and contain many lignitic and bituminous shale horizons. Discrete lignite bands are up to 1 m thick. The mudstones are interpreted as representing estuaries or interdistributary bay fills associated with a delta-system built across the platform from the south.

The carbonates of the Chapelton-Troy Cycle show a distribution related to their position relative to the edge of the Clarendon Block. In the protected interior platform, the impure foraminiferal and molluscan wackestones and packstones of the Chapelton Formation were deposited in protected 'lagoonal' environments and are succeeded by peritidal, poorly fossiliferous micritic limestones, dolomites and sucrosic dolomites of the Troy Formation (Mitchell, 2004b). Along the platform margin, foraminiferal-alpeloidal grainstones of the Swanswick Formation accumu-

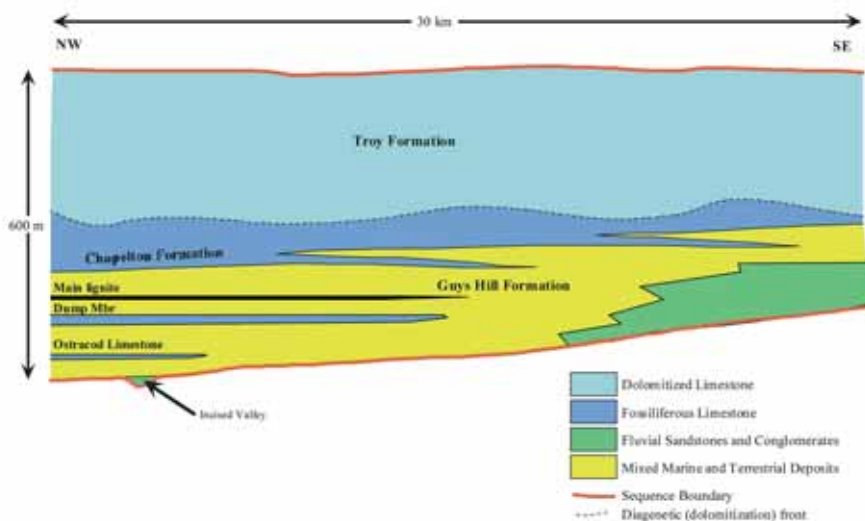


Figure 6. Model for the development of the Chapelton-Troy sequence of the Yellow Limestone Group



Figure 7. Crevasse-splay sandstone channels (left) with mottled palaeosols between (right), Mountain River (Stop 1)

lated in high-energy shoals. These deposits pass into evenly bedded wackestones and marlstones of the deeper ramp margin.

The majority of the White Limestone Group of central Jamaica is represented by carbonates deposited on the shallow-water blocks. On the north coast, the edge of the carbonate platform (Duanvale fault zone) is exposed with deep-water pelagic carbonates to the north of the fault. The existence of previous extensive Miocene reef tracks along this fault is indicated by coral-rich blocks preserved in talus deposits adjacent to the fault (Mitchell, 2004b), although the reefs themselves have been eroded away.

Coastal Group The rocks of the Coastal Group were deposited as a fringe around the edge of Jamaica (Fig. 1). In eastern Jamaica they consist of hemipelagics, sandstones and limestones. Similar deposits are likely to be developed in the Walton Basin with the sediments sourced from the Central Inlier as it was uplifted. These rocks would act as seals and subsidiary reservoir rocks.

On the north coast of Jamaica, the Coastal Group consists of reef limestones (Hopegate Formation, late Pliocene age; Falmouth Formation, late Pleistocene) that grew on the foot-wall of the North Coast Fault. These are analogous to the reefs that developed on the foot walls of normal faults surrounding the White Limestone platforms.

Petroleum Geology of Tertiary Succession

Source rocks. The Guys Hill Formation and base of the overlying Chapelton Formation contain lignite-rich shales and organic-rich mudstones and shales (cover picture). These rocks are best developed in the central and western parts of the Central Inlier and appear to become a major part of the succession in the westernmost exposures. Oils collected from the Content-1 well belong to a Middle Eocene sourced oil family with a clastic source rock (high oleanane values [OL/H>1]; high diasterane contents, moderate C29 norhopane/C30 hopane and low C35/C34 hopane ratios: Cameron et al., 2004) and probably originated from Guys Hill type source rocks. These source rocks are regionally widespread (e.g. Punta Gorda Formation, offshore Nicaraguan), and are likely to be present in the Walton Basin (onshore sections appear too immature to have generated significant hydrocarbons).

Reservoir rocks. Two principal reservoir rocks are recognized in the Tertiary section: channel and crevasse-splay sandstones in the Guys Hill Formation, and carbonate reefs in the White Limestone Group. The Guys Hill sandstones are well-sorted and have high porosities (23%). Seals would be formed by interbedded marine mudstones or muddy palaeosols. Carbonate reefs are the major reservoir rocks in the White Limestone Group (analogous to the Pliocene reefs of the north coast of Jamaica). Seals would be hemipelagics in the overlying Coastal Group (marlstones and mixed lime-

stones-claystones similar to those developed in the Coastal Group exposed in southern part of the parish of St. Thomas).

Field trip 2005

As an early component of Jamaica's first formal licensing round JEBCO organised a field trip for interested oil companies to view potential source rock, seal and reservoir analogues thought to exist offshore (20 blocks available) in the greater Walton Basin and Pedro Bank areas and to examine the potential of the onshore (4 blocks available).

The field trip promoted the examination of :-

- Organic-rich source rocks in Maastrichtian (Cretaceous) paralic mudstones
- Lignitic and bituminous source rocks in Eocene mudstone sequences
- Reservoir rocks in Eocene sandstones with clay seals.
- Reservoir rocks in Cretaceous rudist limestones with siltstone seals
- Coral build-ups analogous to those expected in the Walton Basin
- An active hydrocarbon gas seep.

The sites investigated on this trip were relevant to exploration both onshore and offshore. Potential reservoirs,



Petroleum Geology

source rocks and seal/cap rocks were seen both in the Upper Cretaceous and Tertiary. As with any humid tropical country, good exposures were few and far between, subject to deep weathering and, as we were told, of an ephemeral nature. Despite this several impressive localities across this 17,790 km² mountainous island were visited.

Guys Hill sandstones in Mountain River: A tall section in the Guys Hill Formation with alternating arenites and mudstones was viewed in a river bend. Arenitic units up to 2 m thick, uncemented with low-angle accretion surfaces and ripple cross-lamination may be seen. The mudstones displayed mottling, have occasional burrow systems (interpreted as crayfish burrows) and layers of nodular calcrete. The arenites (potential primary reservoir objective) were interpreted as crevasse splay deposits, the mudstones (top seals) as palaeosols.

Stettin Limestone at Pindars River bridge: The Stettin Limestone, part of the Yellow Limestone series, consisted of packstones and thin grainstones with late (post-compactional) sparite cements. The Stettin Limestone has a top seal of Guys Hill mudstones, and with sufficient porosity could perhaps be considered as a secondary reservoir objective. This area was characterized by small-scale NW-SE anticlines and synclines.

Organic-rich mudstones in Pindars River: Marginal facies of the Guinea Corn Formation are exposed in the banks of Pindars River. The succession consists of thin rudist limestones, volcanoclastic sandstones, and 12 m of fossiliferous, lignitic and sandy mudstones. Some parts of the mudstone succession contain diverse molluscan and solitary coral faunas suggesting moderate levels of oxygenation at the sea floor, whereas other parts of the succession consist of laminated or blocky unfossiliferous organic-rich mudstones suggesting periodic anoxia. This organic-rich (spot TOC value of 1.76%) sequence overlies fluvial conglomerates and associated overbank mudstones of the Slippery Rock Formation and represents the initial marine flooding of this part of the basin.

Rudist Limestones at Cabbage Hill: The rudist limestones of the Guinea Corn Formation are well-exposed in the Rio Minho at Cabbage Hill. Rudists are abundant and occur in rudstones and growth frameworks, they have high porosity and again could be considered as having reservoir potential. The rudists include *Macgillavryia nicholasi* (Whitfield), *Chiapasella trechmanni* (Mitchell & Gunter), *Titanosarcolites giganteus* (Whitfield), *BiracUolites jamaicensis* (Trechmann), and *Bournonia*.



Tidal flat deposits at Grantham: The Thomas River Formation shows small-scale tidal-flat cycles showing flaser-wavy-lenticular bedding, alternating with poorly fossiliferous, laminated mudstones. Fossil assemblages in impure limestones are of low-diversity and dominated by brackish water elements including oysters and the bivalve *Perucardia*. The mudstones contain rare gastropods and locally abundant gyrogonite charophytes indicating fresh or brackish water conditions. Plant debris is abundant and the rock splits along surfaces due to its abundance. The low diversity faunal assemblages, the abundant plant material, and the tidal flat sequences, suggest that the succession accumulated in an estuary with a strong fresh-water influence.

Gas seep at Windsor: The Windsor gas seep is one of three gas seep known in Jamaica at the time of the field trip. The gas is mostly methane (98.8%) with traces of ethane, propane, and butane, and carbon isotopes suggest that the gas is thermogenic. The nearby Windsor-1 well and corehole had many oil shows. Biomarker and stable carbon isotope analysis of two oils suggests an affinity with the Oxfordian Smackover source of the US Gulf of Mexico and Belize. The St. Ann's Great River gas seep is also interpreted as originating from this source. At the time of writing (23/02/05) several new onshore gas seep localities have been discovered in the Retrieve and Marchmont areas which will need investigation.

Raised reefs on North Coast: Some of the youngest rocks on the island flank the coast. These Mio-Pliocene limestones could just from shallow reservoir objectives offshore as they do elsewhere. This road cut limestones and dolostones of the Pliocene Hopegate Formation. Abundant reef corals could be seen, with their skeletons dissolved out leaving high-mouldic porosities. These reef limestones were formed on the foot wall of the North Coast Fault and are analogous to reefs expected to be developed on the foot-wall of faults in the Walton Basin.

Organic-rich shales in Hectors River: The Guys Hill Formation is exposed intermittently along a stretch of Hectors River. It consisted of alternations of impure limestones with low-diversity oyster-dominated molluscan assemblages and organic-rich mudstones. Organic-rich (spot TOC value 3.93%) mudstones make up much of the succession in this part of the basin indicating the likelihood for the development of large thicknesses of source rocks in the pro-deltaic environments of the Guys Hill Formation.

Crevasse-splat sandstones and inter-distributary bay organic-rich mudstones at Litchfield: A 12m interval of the upper part of the Guys Hill Formation, the total thickness being about 290 m in this area, was viewed. The lower part of the section is made up of crevasse-splay sandstones with up to 23% porosity. Above the sandstones are organic-rich mudstones (spot value TOC 12.67%) with concretions containing a low-diversity oyster-gastropod assemblage, and lignite horizons.

Organic-rich shales at Broomwell: At Broomwell, well-developed lignitic shale (spot TOC value 5.57%) can be seen in



the hillside. The junction of the shale and overlying sand forms a spring line. These shales are similar to those seen at Litchfield. This shale contains concretions with abundant small molluscs. The alternation of organic rich mudstone and thin shell beds indicates either transported shells or alternating conditions of oxygen-rich and oxygen-poor waters.

PCJ Core Store: The Core Repository and Analytical Laboratory of the Petroleum Corporation of Jamaica were opened in 1980. The facility also houses a small Petrological

Petroleum Geology

Laboratory. Efforts are currently underway to improve the long-term storage of the material as well as to implement a user-friendly database for the retrieval of storage information. Perhaps of particular interest is the well preserved Content # 1 core. Several hundred metres of shales with enhanced TOC and associated high HI values may be viewed. In 1983 Rodrigues recorded values as high as 15% with corresponding HI reading of 500 for the Eocene Chapelton formation, indicating the presence of a very potent source rock. The Content # 1 is situated on the flanks of the Walton basin.

Latest seeps

During the 1980s gas emanating from a river in the Marchmont Inlier was collected. It was analysed to establish whether it was biogenic or thermogenic gas. One analysis suggested the former, although a current reinterpretation of the values suggests the latter. Over time, the exact location of the seep had become uncertain. An excursion was conducted in February this year to investigate the location of any seeps in the inlier. From the data gathered, it would appear that gas seepage from the Cretaceous rocks of the Marchmont Inlier is fairly widespread in the areas surrounding Bruce Hall and Retrieve.

Intermittent bubbling from the sediment was observed, on approach, at several localities while walking in the riverbed. This was probably due to small pockets of slowly accumulated gas trapped beneath the impermeable sediment (hence the bubbling was not observed until pressure was placed on these pockets). However, locals of the area also reported active seeps from sediment. Two of these leads were investigated and confirmed to be areas of active gas seepage.

At both localities (Yaws House and Blue Hole), over the course of about five minutes, gas was observed to emanate intermittently from diverse spots in the riverbed while standing on the riverbank. All the bubble trails observed lasted roughly 3-4 seconds. However, two locals reported that at times a single trail could be observed for periods of a minute or more. The largest gas bubbles were estimated to be roughly 3 cm in maximum diameter standing roughly 5 m or so away. In addition to these two localities, a further three have been reported by locals (one with persistent bubbling) and await investigation.

The Great River, which delineates the border between the parishes of St James and Westmoreland, is considered relatively well oxygenated. Bedrock is exposed along much of the riverbanks in the area and the alluvial cover is relatively thin. The overall data make us confident that these localities will be confirmed as areas of thermogenic gas seepage, upon collection and reanalysis of the gas.

References

Ahmad R., Lal, N., and Sharma, P.K. [1987] Fission-track age of ignimbrite from the Summerfield Formation, Jamaica. *Caribbean Journal of Science*, **23**, 444-448.

Cameron, N., Milsom, J., Mitchell, S.F. [2004] *The realisation of the hydrocarbon potential of Jamaica. Phase 1: setting the scene*. The JEBSCO Alliance.

Coates, A.G. [1965] A new section in the Maestrichtian Guinea Corn Formation near Crawle River, Clarendon. *Journal of the Geological Society of Jamaica (Geonotes)*, **7**, 28-33.

Draper, G. [1987] A revised tectonic model for the evolution of Jamaica. In: Ahmad R. (Ed.), *Proceedings of a Workshop on the Status of Jamaican Geology*. Geological Society of Jamaica, Special Issue, 151-169.

Kauffman, E.G. and Sohl, N.F. 1974. Structure and evolution of Antillean Cretaceous rudist frameworks. *Verhandlungen Naturforschenden Gesellschaft Basel*, **84**, 399-467.

Kumar, A. and Grambast-Fessard, N. [1984]. Maastrichtian charophyte gyrogonites from Jamaica. *Micropaleontology*, **30**, 263-267.

Mitchell, S.F. [1999] Stratigraphy of the Guinea Corn Formation (Upper Cretaceous) at its type locality between Guinea Corn and Grantham (northern Clarendon, Jamaica). *Journal of the Geological Society of Jamaica*, **33**, 1-12.

Mitchell, S.F. [2000] SS03 Facies analysis of a Cretaceous-Paleocene volcanoclastic braid-delta. *GSTT 2000 SPE conference proceedings*, 1-9.

Mitchell, S.F. [2002] Palaeoecology of corals and rudists in mixed volcanoclastic-carbonate small-scale rhythms (Upper Cretaceous, Jamaica). *Palaeogeography, Palaeoclimatology, Palaeoecology*, **186**, 237-259.

Mitchell S.F. [2004a] Sedimentary and tectonic evolution of central Jamaica. In: Bartolini, C., Buffler, R.T., and Blickwede, J.F. (Eds). *The Circum-Gulf of Mexico and the Caribbean: Hydrocarbon Habitats, Basin Formation, and Plate Tectonics*. *American Association of Petroleum Geologists, Memoir 79*, 605-623.

Mitchell S.F. [2004b]. Lithostratigraphy and palaeogeography of the White Limestone Group. *Cainozoic Geology*.

Mitchell, S.F. and Blissett, D. [2001] Lithostratigraphy of the late Cretaceous to ?Paleocene succession in the western part of the Central Inlier of Jamaica. *Caribbean Journal of Earth Science*, **35**, 19-31.

Robinson E. and Mitchell, S.F. [1999] Upper Cretaceous to Oligocene stratigraphy in Jamaica. In: S.F. Mitchell (Ed.), *Contributions to Geology, University of the West Indies Mona*, **4**, 1-47.

Steuber T., Mitchell, S.F., Buhl, D., Gunter, G., and Kasper, H.U. [2002] Catastrophic extinction of Caribbean rudist bivalves at the Cretaceous-Tertiary boundary. *Geology*, **30**, 999-1002.

Underwood C.J. and Mitchell, S.F. [2000] *Serratolamna serrata* (Agassiz) (Pisces, Neoselachii) from the Maastrichtian (Late Cretaceous) of Jamaica. *Caribbean Journal of Earth Science*, **34**, 25-30.