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The origin of Canada Hill — A result of strike-slip deformation and hydraulically powered uplift at the Pleistocene/Holocene border?

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Abstract: Canada Hill, located in the centre of Miri City in Sarawak, is roofed by terrace deposits of Pleistocene/Holocene age, which implies a very young uplift of this complex anticline. The present-day Canada Hill structure is explained by strike-slip deformation, in conjunction with a semi-liquid pillow of Setap Formation clay. Horizontal pressure acting in NW-SE direction, and the likely presence of a strike-slip system with late inversion triggered a 'diapiric' remobilization of the clay reservoir. The flow of liquefied clay was refocused upwards, namely in direction of the lowest pressure. Miri Formation remnants, the roof of forming clay pillow, and overlying Quarternary terrace deposits, were subsequently uplifted and emerged from the Pleistocene peneplain. However, the adjacent country rock, including the main part of the Miri Field, was hardly affected.

Assuming a hydraulic uplift in the order of 400 feet and a lithostatic pressure gradient of 0.9 psi/foot, lateral pressure above the 360 psi equilibrium pressure would have prompted the clay core to move. It is noted that all current oil seepages in the hill area are related to fault systems that were reactivated at the Pleistocene/Holocene border, and an extinct mud volcano of the Canada Hill was also sighted at Tanjong Lobang, this being an obvious indication that overpressured fluids had escaped from the centre of Canada Hill. In addition, other potential areas of hydraulic uplift located in Brunei and Sabah, particularly the well-documented Jerudong and Belait Anticlines are also discussed for comparison with the observations derived from Canada Hill to support the new structural model proposed in this study.

Keywords: Pleistocene, Holocene, Borneo, tectonics, diapirism

INTRODUCTION

Borneo, being part of Sundaland and a 'continental promontory', as coined by C.S. Hutchison, lies wedged between the mighty Indo-Australian and the Pacific Plate, as well as a retinue of smaller plates, and is hence surrounded by compressive margins. The continental crust of Sundaland saw, under sustained lateral pressure, periods of compression. The tectonic pressure has left a strong imprint on areas in Borneo, such as oroclinal bending of the Rajang/West Crocker folded mountain belt (Hutchison, 2010). Furthermore, tectonic inversion is also seen in many areas within and surrounding Borneo (e.g., Morley *et al.*, 2003). Within an area of strong lateral compression it appears logical to assume that soft, mobile and often *quasi* semi-liquified basin constituents such as clay would be the first to react to crustal tectonic pressure. In this article, we would like to examine this hypothesis in the context of the NW Borneo foredeep area, in particular focusing on Miri and linking results to selected potential areas of similar hydraulic uplift in Brunei, as documented in the literature.

It is also worth mentioning that we defined clay diapirs as relatively mobile masses that intrude into pre-existing sedimentary rocks that commonly intrude vertically through more dense rocks because of buoyancy forces associated with relatively low-density rock types, such as shale, which form clay diapirs. The process is known as clay diapirism. By pushing upward and piercing overlying rock layers, the diapirs can form anticlines and other structures capable of trapping hydrocarbons.

REGIONAL TECTONIC SETTING

Canada Hill is located in the western portion of the subsiding Baram Delta Block, which is offset against the stable Central Luconia Block by a network of faults called the Baram Line. Two morphologically prominent areas are recognized: Bukit Lambir and the Canada Hill. Both features are suggestive for inversion tectonics that may have affected the area since the Pliocene. The shape of the Baram Line has recently been revised by Kessler (2010, Figure 1).

Canada Hill forms a segment of the seismically prominent Siwa-Seria fault zone, characterized by elements of reverse faulting, and strike-slip movements. On its south-western extremity, the fault zone merges with the main branch of the Baram Line west of Siwa; towards the NE, the fault lines up the Miri Field, Asam Paya/Rasau Fields, and finally the Seria Field (Figure 1). Within this regional trend, however, Canada Hill is the only feature uplifted above sea-level.

Based on limited data, tribute goes to von Schumacher (1941) for recognizing differences in facies on either side of Canada Hill, with the Miri Formation west of Canada Hill containing thicker and better developed sands. This observation, if further corroborated by results of recent drilling campaign by Nippon Oil, might form an additional argument for pro strike-slip movements.

THE CANADA HILL - STRUCTURAL MODEL AND RECENT STUDIES

The Canada Hill is a unique and somewhat mysterious tectonic feature: some 7 km long but less than 2 km wide, it emerges from the coastal plain, and there is no apparent recent tectonic deformation in its further-than-immediate surroundings. The inner core of the Canada Hill can be described as an elongated sliver of mildly folded sandstone, bounded by the Shell Hill Fault (indicated as normal fault on older data) and the Canada Hill Thrust – both faults are inferred to have large throws (Figure 2).

However, data used for the von Schumacher (1941) model from the Miri area suffer from a bias in the data. During the exploration, development and production of the Miri Field, 612 wells were drilled on the NW side of the Canada Hill, but none on the eastern side (Kpg. Lopeng, Figure 3). Only shallow core holes were available on the SE side, plus several small and temporary outcrops. The latest well drilling campaign by Nippon Oil conducted in late 2011 to early 2012 saw the drilling of two exploration wells that reported oil and gas shows, with good reservoir sands encountered. Failure to find commercial accumulations of hydrocarbons is attributed to likely lateral fault seal failure.

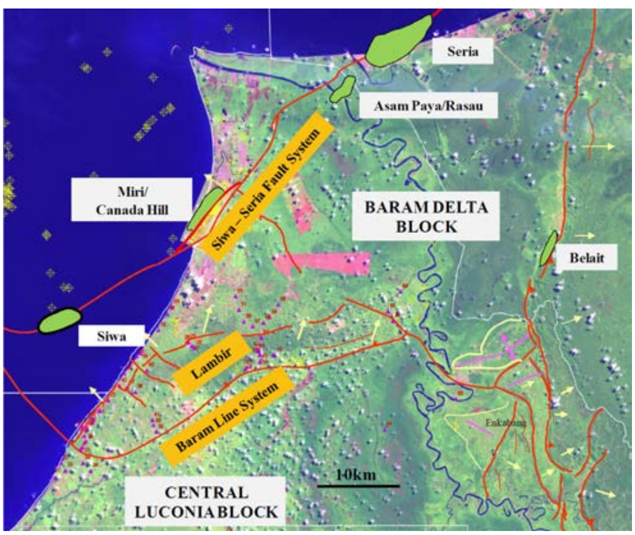

Figure 1: Satellite imagery of northern onshore Sarawak with key structural elements and fields along the Siwa-Seria and Belait structural trends. The stable Central Luconia Block is located to the south of the Baram Line System, with the subsiding Baram Delta Block to the north.

To help address this shortfall in data, in 2010-2011, Curtin University carried out a systematic remapping of the Miri area, an effort in which some 60 students participated – partly as two consultancy projects funded by Nippon Oil, partly as independent research. Work also included gravimetric measurements over some 49 km^2, clay gauging studies, reservoir petrography and petrology, as well as oil sampling, oil typing, plus the generation of a new geological map.

Nonetheless, the interpretation of geology of the Miri area remains challenging. W.S. Pollock, a structural geologist correlating wells and mapping the then-existing surface tectonic features at the height of the Miri Field output, from *ca.* 1920 to1930, came up with a field cross section model of downwards converging faults, later updated by von Schumacher (Figure 2 - Miri Field cross section). This 1941 model, created during a period of unstoppable production decline, however, suggests predominantly extensional tectonism (= normal faults) in the Miri Field, and compressive tectonics on the SE (Kpg. Lopeng) flank, in immediate vicinity of the normal faults. This model, consisting of both map and section, was widely copied and re-drafted. A summary of the von Schumacher model was published by Tan *et al.* (1999), and Hutchison (2005, p. 125 – 129) (Figure 2), which suggests an asymmetric anticline, characterized by normal faulting on the NW leg, and several, largely parallel thrusts on the SE leg. This model/interpretation, however, is mechanically impossible, as it invokes extension and thrusting to occur at the same time. However if normal faults and thrusts originated at different times, one would have to infer a fairly complex phasing of tectonic events, which is also somewhat unlikely.

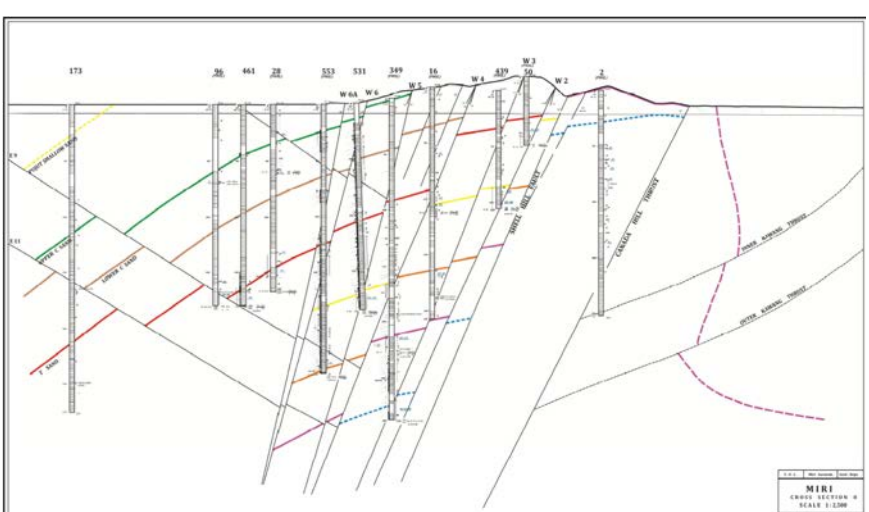

Figure 2: Redrawn Miri Field cross-section by W.S. Pollock with adaptation by von Schumacher, 1941. Note that faults are projected as straight lines into older, undrilled formations – a curved shape appears to be more likely, given experience gained later during the Baram Delta exploration (seismic and drilling) campaigns, and more recently from the 2D seismic data acquired over Miri by Nippon Oil in 2010.

Also recently, structural evidences from outcrops studies conducted by Ulfa *et al.* (2009, 2011) in Miri area suggest that a set of normal faults that head in the opposite direction to each other and rotational movements on the competent sediment of the Miri Formation may have formed due to the space created during the deformation periods. Meso-structures of the outcrops support this rotational movement, explains the existence of a very big contrast of thick sequence of vertically dipping section with a sub-horizontal or gently dipping sequence situated side-by-side. The change in orientation of the anticline from symmetrical-upright to asymmetrical with axial plane dipping to NW and then to SE direction and trending to NNE-SSW in the middle but swing to NE-SW in the northern and southern parts suggests that it was influenced by regional NNW-SSE force probably related to the strike slip faulting in the region (Mazlan, 1999). The 2011 study also highlighted the absence of a drag fold in the field and the presence of a very short contact zone for a very big contrast between a thick sequence of vertically dipping section with a sub-horizontal or gently dipping sequence situated side-by-side suggests there is a serious weakness in the structural model that was proposed by von Schumacher in 1941, a common view shared in this study.

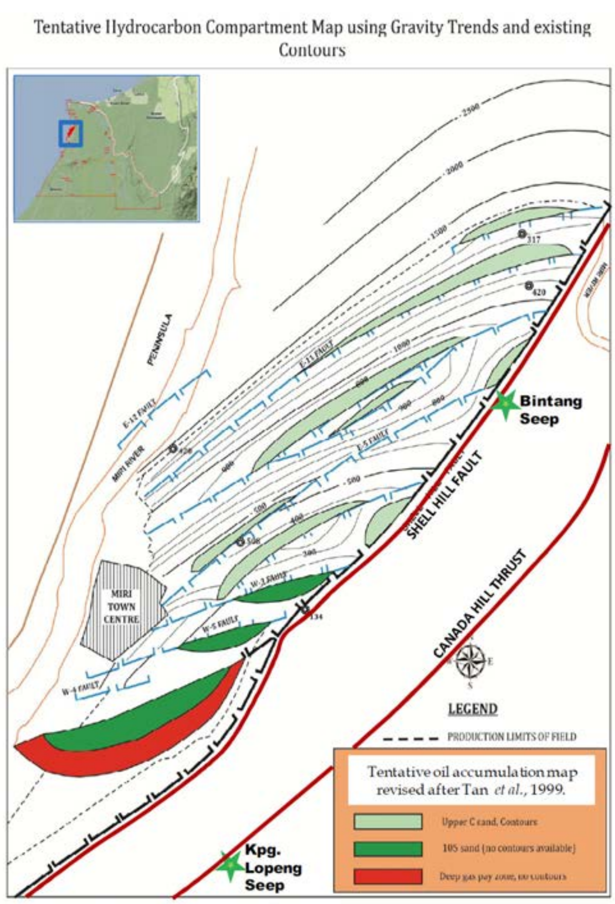

Figure 3: Simplified map showing oil and gas accumulations of the Miri Field and discussed seep locations (modified after Tan *et al.*, 1999).

In disputing the dated von Schumacher's model, further evidence is also provided in Figure 4, which compares outcrop geology, (land) Bouguer gravity and, last but not least, the most recent seismic data acquired over Canada Hill by Nippon Oil in 2010. Overall, the three sources of data are in good agreement, in particular on the SE flank of Canada Hill, where the Miocene rocks of the Miri Formation are seen rising in NW direction. The seismic data also suggest the presence of a fault pattern, likely of a strike-slip system with inversion feature, instead of the inferred planar faults indicated in the previous geological mode (Figure 2). The shallowest section, namely the outcropping Canada Hill, is of particular complex internal architecture, and is summarized in three cross-sections shown in Figure 5.

In light of the presented data and recent work by other workers, it appears more logical to suggest that the Shell Hill Fault and Canada Hill Thrust belong together as a conjugated pair of faults, being part of the same strike-slip tectonic regime, and were both reactivated at the same time. In Miri, Canada Hill is elevated up to almost 300 feet above mean sea level, and is formed by sandstones

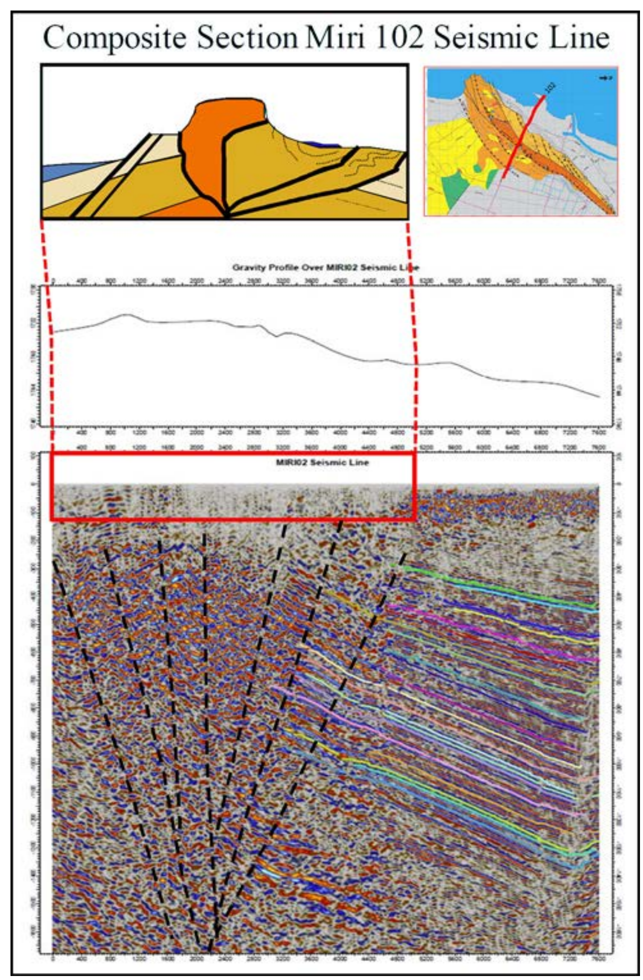

Figure 4: A comparison of outcrop geology (above), a Bouguer gravity high (middle), and the subsurface seismic profile (below) of Canada Hill indicating the likely presence of a strike-slip system with late inversion, instead of planar faults suggested in the previous geological model.

of the Miri Formation; remnants of terrace deposits are seen on the flanks and even on the top of hill, deposited above the eroded Miri Formation sandstones. It is also noted that there are no Tukau Formation outcropping on Canada Hill, either due to non-deposition or erosion, and even the upper part of the Miri Formation is eroded. This could imply that Neogene sediments (upper Miri Formation and Tukau Formation) had been eroded ahead of the latest uplift. Radiometric C-14 dating of terraces both present on the top and the hill flanks (Kessler & Jong, 2011) puts the emergence of the hill as early as 28,570± 230 years BP, but is very likely much later, around 8,170 ± 50 years BP.

More regionally, a schematic evolution model of a NE–SW-striking inversion anticline over a counter-regional fault depocentre associated with active clay diapirism, where a detached style of deformation is dominant was also proposed by Morley *et al.* (2003) based on studies of the Seria, Miri and Ampa Anticlines (Figure 6).

OIL OCCURRENCES AND PRESSURE REGIME

Both Seria and Miri are regional high zones, which explain the relatively large oil accumulations in these areas. Minor oil accumulations are seen in the Asam Paya/Rasau Fields, located roughly in the middle between Seria and Miri. It is noted that the mentioned fault system runs orthogonally to the regional fracture trend, which is 120° (range between 110° and 130°, own studies and Tingay *et al.*, 2009). Fracture orientations were measured by the authors in Batu Gading, Niah, and the Lambir areas.

Some (unfortunately incomplete) pressure information is available from several Miri Field wells, which is summarized in Figure 7. One of the older wells in the field was drilled through the central Canada Hill and found strongly overpressured soft clay. Given the poor pressure controls of the time, the well had to be plugged and abandoned. Most wells drilled into the 105 reservoir sand sequence (Figures 3 and 7) had encountered overpressures and are devoid of a proper water drive. GOR in these wells is in the order of 600-4000 (scf/bbl).

The deeper oil-bearing Miri sequence also yielded some overpressure information. Well 604 hit an overpressured gas/condensate-bearing zone of some 400 ft with the Setap Formation at a depth of 5850-6250 ft. The reservoir was described as discontinuous lenses of fine sands, and possibly of turbidite origin (Shell internal report). Apart from the central clay core, it is believed that the above mentioned overpressures were relatively mild (several hundreds of psi ?), but there are no good data to either support, or reject this speculative assessment.

In a marked contrast, the shallow reservoirs (above 105) are on a hydrostatic regime, and produced heavy oil with a

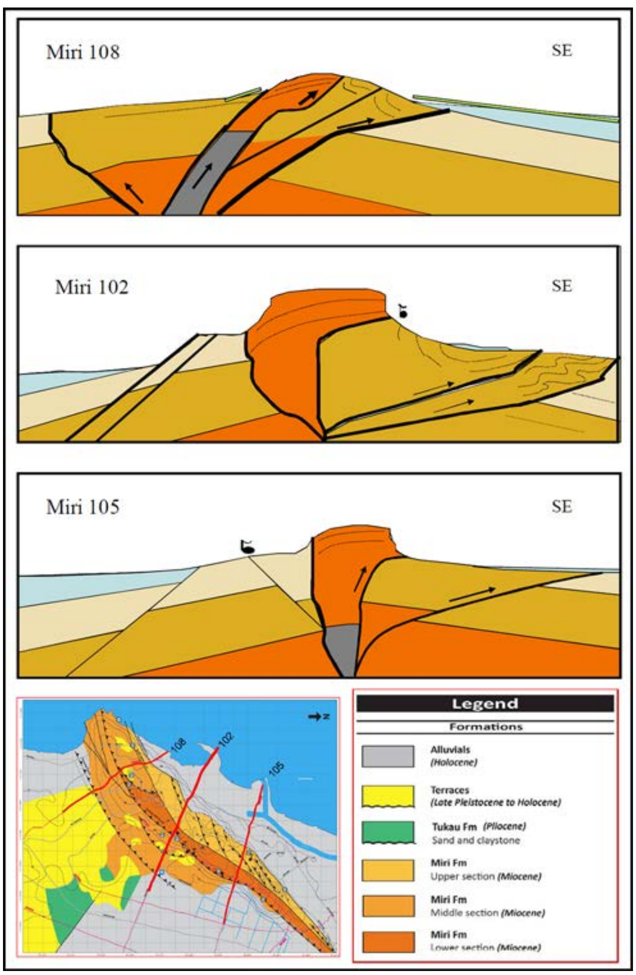

Figure 5: Three geological cross-sections through Canada Hill, drawn based on data from field geology and seismic interpretation. Symbol denotes locations of oil seepages.

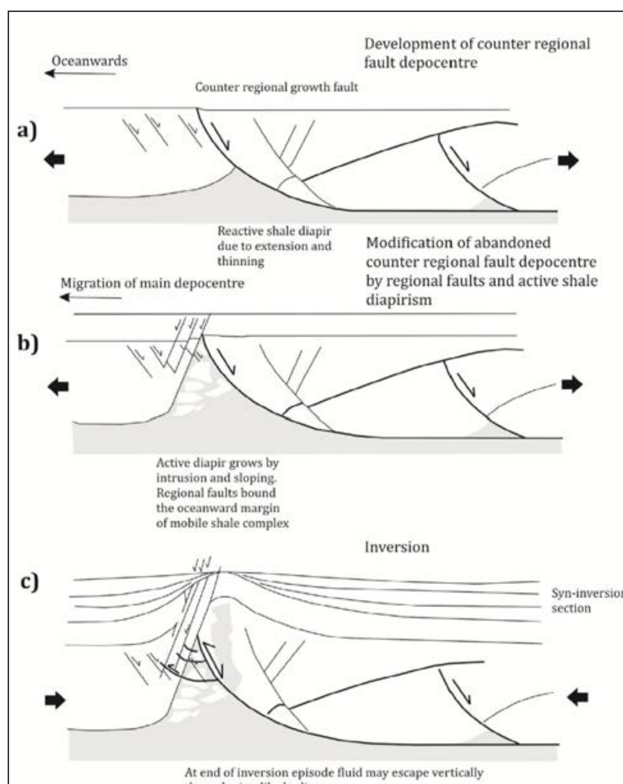

Figure 6: Schematic evolution of a NE–SW-striking inversion anticline over a counter-regional fault depocentre associated with the offshore area, where a detached style of deformation is dominant. Based on the Seria, Miri and Ampa anticlines (Morley *et al.,* 2003).

GOR of 400-500 (scf/bbl). The Shell geologist W.S. Pollock (Shell internal reports) was probably the first to realize that all shallow Miri oil accumulations were heavy, and that the signature of these biodegraded oil levels could be used for block-to-block correlation purposes. This very substantial observation suggests internal Miri structural elements, as well as the Canada Hill, originated after biodegradation had started to affect Miri oil in a substantial way.

TECTOGENESIS OF CANADA HILL

As outlined by Hutchison (2005, p. 128), we can discriminate two compressive events in the Miri area; according to recent research in Curtin University, there might be even three events (Figure 8), as here proposed. The latest tectonic event seems to have affected the Canada Hill area only, and the new radiometric C-14 data demonstrate that this third compressive pulse is much younger than previously thought (Kessler & Jong, 2011), and also very limited in lateral extent. The three compression events bear the following characteristics (Figure 8).

Compression, pre-dating the deposition of the Tukau Formation, hence near the Miocene/Pliocene border; this tectonic event is well developed in the Miri area, given the Tukau Formation is seen wedging-out against the folded Miri Formation in the outskirts of Miri. It may have also affected areas of Lambir. In the Miri area, the tectonic event may have led to a simple anticline, characterized by a thrust fault in the SE and inversion of older extensional faults in the NW. After the tectonic event, we see Canada Hill emerging, and becoming a shoal. The timing of the tectonism is uncertain, possibly intra-Pliocene in absence of good age dating.

Compression, post-dating the deposition of the main part of the Tukau Formation, as seen in the Lambir foot hills. Unlike in Miri-Kpg. Lopeng, the Tukau Formation here is folded together with the underlying Lambir Formation, and so-far the data suggest the contact between Lambir and Tukau Formations is either entirely or nearly concordant (Hutchison 2005, p. 111 Figure 42). The tectonic event that folded the Lambir Formation has not been seen or cannot be separated from the older event in the Miri Area.

Compression affecting the Miri Area during the Quarternary (Kessler & Jong, 2011) at the end of the Pleistocene, the current Canada Hill area was a peneplain, with Tukau Formation sediments onlapping onto an elliptical, domal structure, characterized by central SW-NE hading faults and radial cross patterns; in the center of the feature, the Miri Formation had been eroded by some 1500 – 2000 ft, and Lower Miri Formation sands lay at the surface, covered only by some 3 – 7 ft of sandy and lignitic terrace deposits (Figure 9). Although it is not clear what triggered this sudden pulse of tectonic activity, it must be explained by a build-up of compressional stress targeting the Miri area only. Situated at a high node of a regional fault system, with Late Miocene sediments covered by little or no overburden, the Miri area naturally qualified as an area of tectonically induced clay diapirism.

CANADA HILL AND POTENTIAL SIMILAR FEATURES IN BRUNEI

The idea of a buoyant clay core in the centre of Canada Hill is not entirely new. Whilst this article was prepared, the "Geological Excursions Around Miri Sarawak" by Wannier *et al.* (2011) reached the book shops; this beautiful compilation of recent and older research (Shell, PETRONAS, literatures) results does contain relevant data material pertinent to this topic, which are cited below:

- On Page 50, an interpreted seismic line from the Miri/Tudan area showing a pillow of mobile Setap Shale;
- On Page 66, a picture of an extinct Canada Hill (Tanjong Lobang block) mud volcano; this being an obvious indication that overpressured fluids escaped in the centre of the Canada Hill;
- On Pages 69 and 70, a normal? faults with an intruding clay core (Shell Hill fault?) in Tanjong Lobang; it shows that mobilized clay moved along the fault plane;
- On Page 118, a block model of Canada Hill with a 'diapir' in its centre.

There remains, however, the question what provoked the (renewed) movements within the inferred clay core in the centre of the Canada Hill. Possibly, during the last tectonic compression pulse at the border between Pleistocene and Holocene, the overpressured and semi-liquid clay core beneath the hill responded by pushing the roof formed by the semi-eroded Miri Formation upwards to an elevation of almost 300 ft above sea-level (Kessler & Jong, 2011). In the model presented here, the hydraulic uplift affected mostly the central part of the Canada Hill, and to a much lesser degree the neighboring blocks on either side, that saw merely a steepening of dip (Figures 10 & 11). Evidence for the uplift is shown in Figure 9; a slightly tilted (10-15° SW) terrace deposit dated Pleistocene-Holocene is seen outcropping on the southern tip of the Canada Hill.

Assuming a hydraulic uplift in the order of 400 feet and a lithostatic pressure gradient of 0.9 psi/foot, the lithopressure may have been in the order of at least 360 psi at a palaeo-depth of 400 ft. Without additional pressure, however, the clay would not have moved. In order to render the clay mobile, one would expect additional pressure in the order of several hundreds of psi. Although this additional pressure is believed to have been tectonically driven, hydrocarbons (gas) may have played an additional role in increasing the pressure within the clay core.

Across the border in Brunei, clay diapirism and related upwarping of the overlying strata has also been widely observed (Figures 12 & 13), with the flow of clay is largely in the direction of the lower pressure gradient. The Jerudong and Belait Anticlines (Figure 13) are good example of clay-cored hydraulic push-up ridges (Sandal, 1996). Mudstone intrusions in the Jerudong area represent natural hydraulic fractures developed above an inferred mobile mudstone diapir sourced from the Middle Miocene Setap Formation. Intrusion geometries are strongly influenced by pre-existing weaknesses, in particular normal faults (Figure 14; Morley, 2003). The core is deeply eroded and exposed

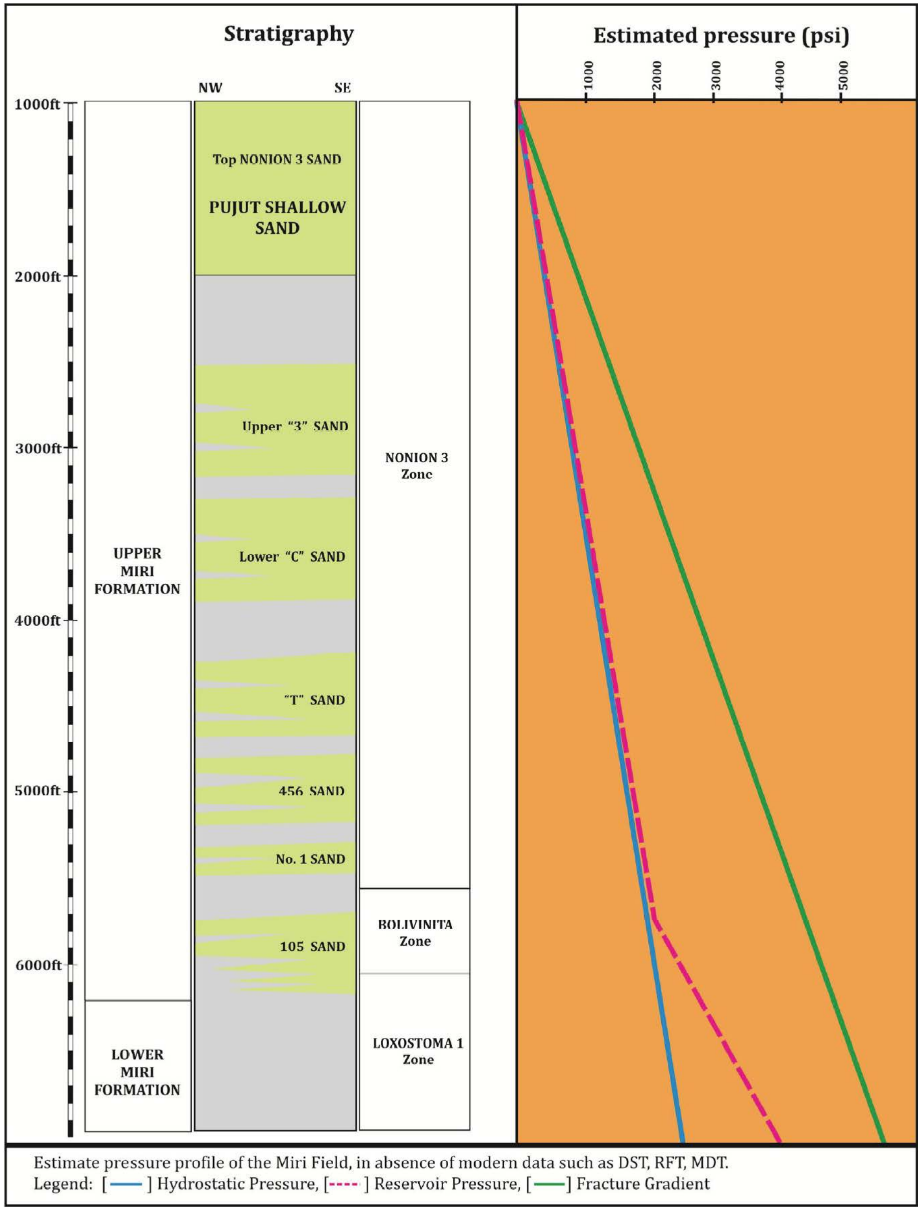

Figure 7: Estimated original (virgin pressure) gradient in the Miri Field, with stratigraphy based on older Shell data.

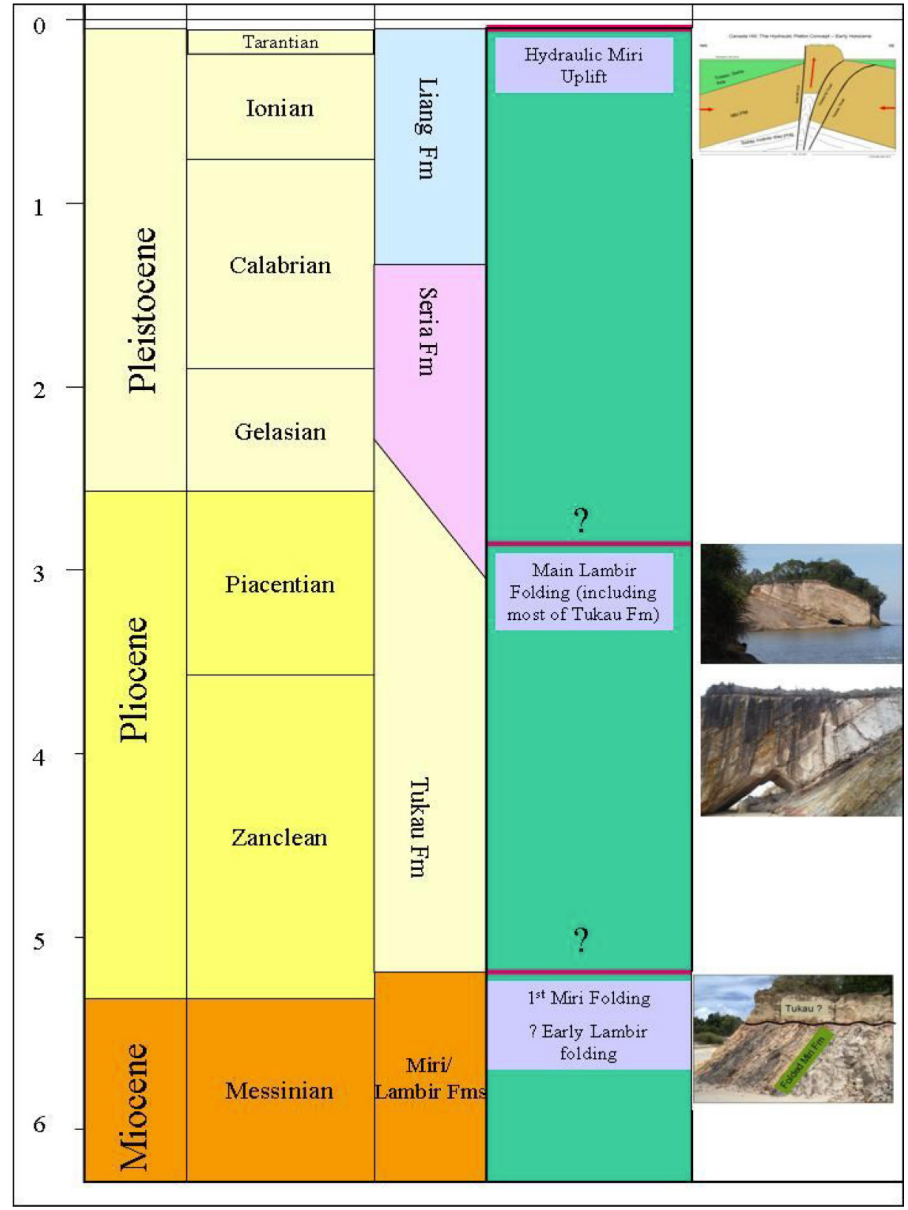

Figure 8: Phases of tectonism in the Miri area (vertical scale in millions of years). There remains age uncertainty in respect of the two Neogene folding events.

at the present-day surface. The deep erosional truncation over the crestal areas of clay-cored push-up structures has probably allowed the bleeding-off of a large part of the entrapped, overpressured formation water (or hydrocarbon accumulations).

Continuing from the directly adjoining parts of eastern Brunei, these clay-cored-push-up ridges are also well known in SW Sabah (e.g., Levell, 1987). The ridges are relatively steep and narrow, separate by wide, flat synclinal basins.

DEFORMATION AND CLAY MOBILIZATION

The classic model addressing intrusion of mobile sedimentary material was proposed by Trusheim (1960). Salt structures (classified as salt pillows, walls, and stocks) in the Saxon Basin (NW Germany) were attributed to autonomous, isostatic movement (halokinesis) of intruding salt rather than to compressional tectonic forces. Trusheim used the term 'diapir' for intruding salt features, and also described stages in the development of structures. Since then, there is a debate to which extent material properties (e.g., salt, overpressured clay with gasses and water) are activated by density contrast and load, or, alternatively through compressive stress in the context of basin dynamics.

Interestingly, all the listed localities in Brunei discussed in the previous section used for a comparison with Canada Hill are either situated in a strike-slip environment, or could be considered expressions of reverse faults/overthrusts, or even a combination of both. It is possible that either of these mechanisms might have played a role in mobilizing clay within Canada Hill. Nevertheless, it appears unlikely that Canada Hill could have been uplifted in the context of strike-slip tectonics and/or overthrusting alone; in either of the processes one would expect further evidence of similar post-Pleistocene uplift features along the Siwa-Seria fault zone, but this does not appear to be the case. Consequently, Canada Hill is considered a unique tectonic feature.

When attempting to offer a discrete description of the Canada Hill (and other) clay core architecture, the overriding observation is the lack of reliable data. The reason of the ambiguity being clay cores (Canada Hill and many others) are commonly not well imaged on seismic – a result of short cable acquisition, insufficient velocity analysis or perhaps even sub-optimal migration techniques. Accordingly, a chaotic nature of postulated clay cores in Miri and elsewhere might be at least partly a result of bad seismic imaging, and the zone of mobile clay might be smaller than the currently available seismic suggests. An exception to this would be the well explored area in Brunei such as the Seria and Champion Fields, both complexly faulted structures, albeit covered by modern 3D seismic data and tested by many appraisal and development wells, with some encountered mobile shale. *Morley et al.* (2003) also commented that during the Latest Miocene to Early Pliocene, folding of regional faults in the Champion area was resulted by the upward movement of clay diapir (Figure 15).

CONSEQUENCES FOR OIL ACCUMULATIONS

The presented model would suggest oil and gas escaping on the flanks of these rather recently mobilized blocks; this being indeed the case, the current oil seeps (Figure 3) opposite the main road in the Bintang Plaza area, as well

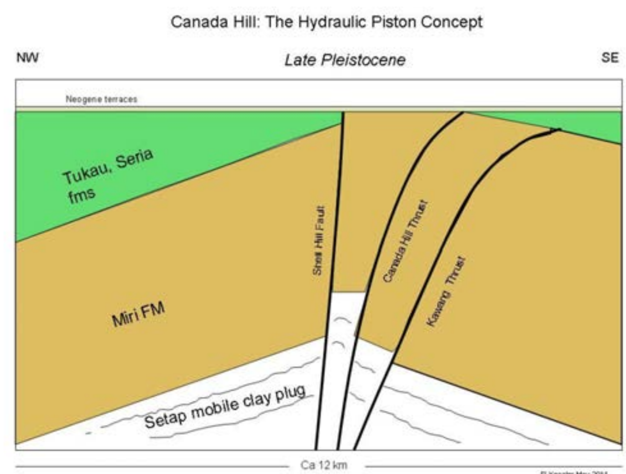

Figure 10: Reconstructed structural setting of the Canada Hill before the Pleistocene.

Figure 9: Uplifted Pleistocene – Holocene terrace deposit at the Government Guesthouse near Tanjong Lobang, Miri.

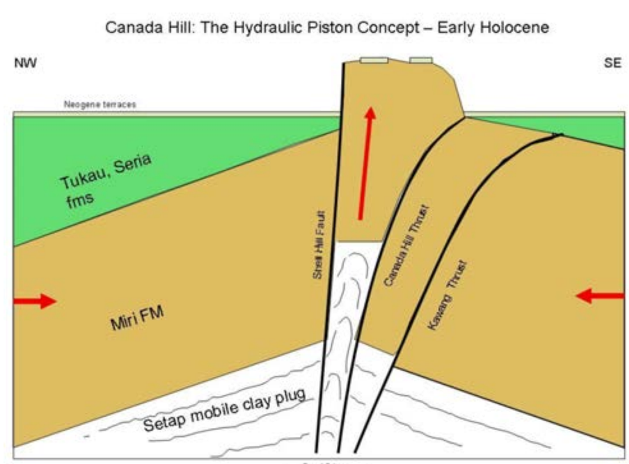

Figure 11: The Canada Hill is uplifted at the end of the Pleistocene, possibly even later.

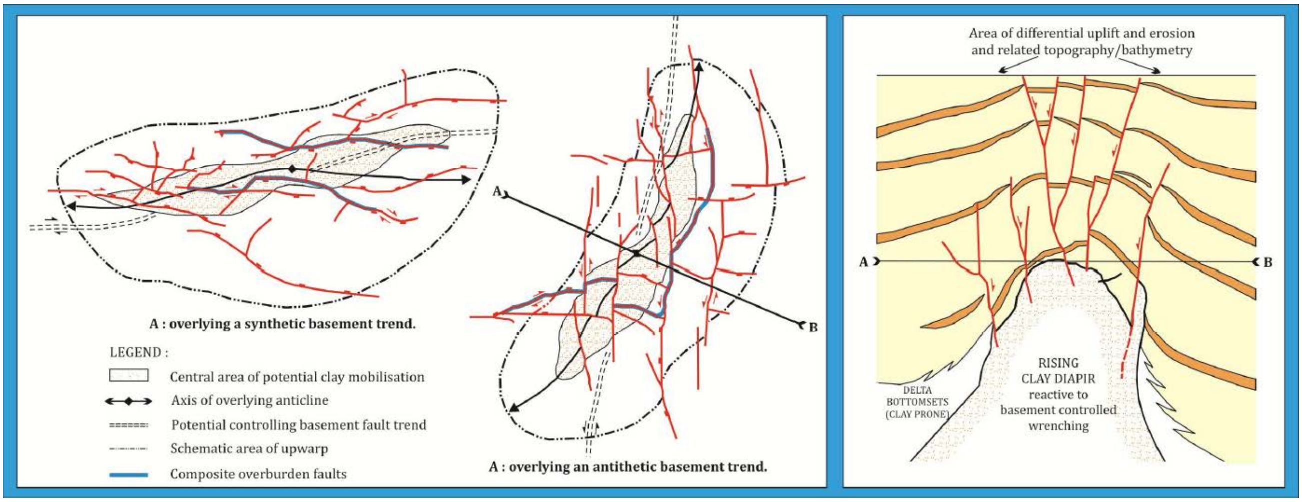

Figure 12: Characteristics of composite (basement controlled/deltaic) deformation styles in Brunei (Sandal, 1996)

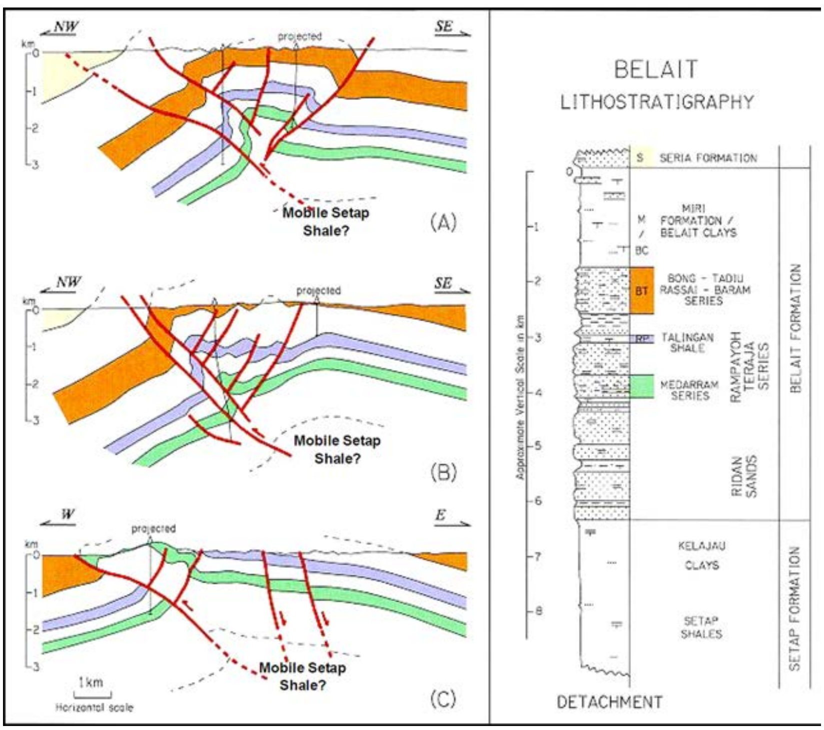

Figure 13: Three geological sections and a simplified stratigraphy through the complex Belait Field near Labi hills area, Brunei, suggesting the presence of a clay core - mobile Setap Shale? (modified after Sandal, 1996).

Figure 14: Injection of clay along a fault exposed in the east flank of the Jerudong Anticline (Sandal, 1996).

as the gas and oil seepages along the Canada Hill thrust in the General Hospital (Kpg. Lopeng) area belong to fault systems that laced the central Canada Hill block. Old Shell sources (fragmented) are suggestive of many oil springs in the Miri town area that can be tied to faults. Hence, faults are predominantly leaky, and oil migration along fault planes is proven. It can be argued that many fault systems acted temporarily as oil carriers, and temporarily as seals depending on the pressure regimes and cross-fault lithology. In view of the relatively young age of Canada Hill, it can be argued that the uplift may have decimated parts of the Miri Field.

Such recent tectonics could have split the Miri oil accumulation into three segments: (i) The Western Block, where Miri is located, the oil field *sensu-stricto*; (ii) the Central Block of the Canada Hill, a tectonically uplifted segment with minor reservoirs supplying well Miri No. 1, “The Grand Old Lady”, and (iii) the Eastern Block of the field in Kpg. Lopeng, only somewhat influenced by the recent uplift tectonics, in the sense that these may have led to a breaching of seals and watering-out of previously oil bearing reservoirs (e.g., Miri East-1/ST1 by Nippon Oil in 2011).

Recent oil seepage forms the tail-end of oil spillage prompted by the hydraulic uplift of Canada Hill. Recent

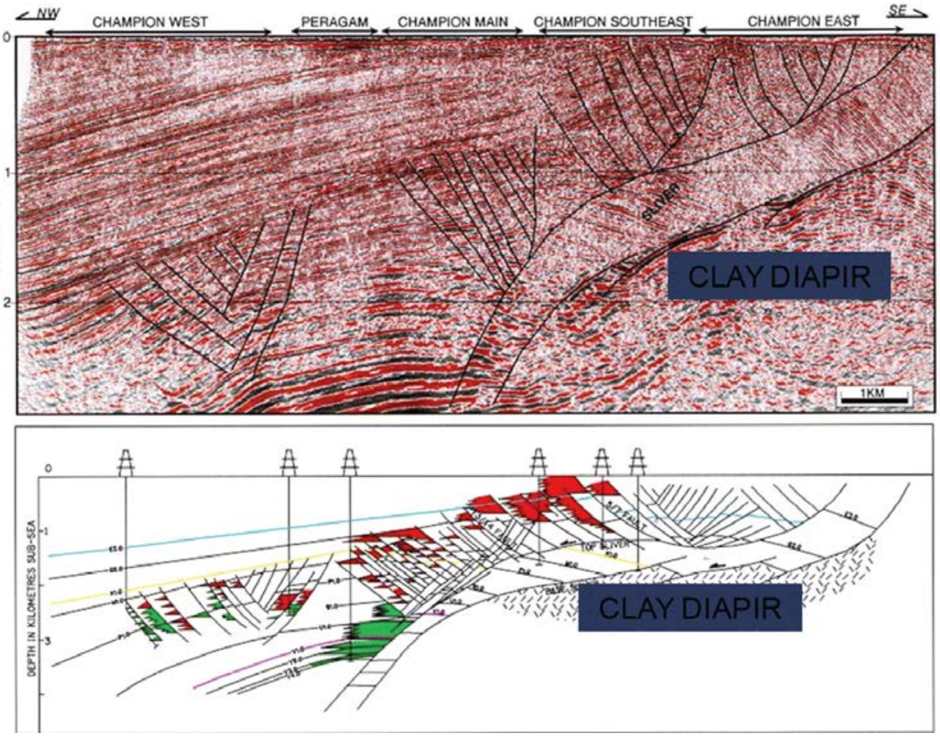

Figure 15: An example of Champion Field's seismic and geological cross-section indicating a clay- cored structure below the prograding Champion Delta (modified after Sandal, 1996).

analysis of seepage oils in Curtin University are suggestive that a very strong biodegradation process had taken place.

Hydrocarbon movements along faults in the Miri Field may also be a function of reservoir pressure - since the middle of the 20th century, most if not all historical oil springs have stopped flowing, in relationship with continued draw-down of reservoir pressure. All faults in the Miri area offer variable degrees of clay gouging, offering good lateral sealing capacity in clay-dominated segments, and poor pressure retention in sand-dominated units. Within the latter, maximum clay-gouging pressure retention (=reservoirs sub-cropping against faults) may be in the order of 100 psi, and possibly up to 300 psi in the deeper, clay-dominated reservoir compartments. Hydrocarbon columns could possibly be longer beneath reverse/thrust faults given the expected thicker gouging clay material as a function of fault displacement. Long columns can also be expected in the deep 105 sand, provided overpressure is not excessive. The Miri Field itself suffers from strongly layered sandstone reservoirs, leading to a high horizontal permeability values, but very low vertical permeability values. It is suggested that future completion should address this issue with horizontal completions and long gravel pack sections, if the Miri Field were to be revived.

CONCLUSIONS

In this article, the structural weakness of the von Schumacher (1941) model for Canada Hill area was highlighted based on outcrop mapping, interpretation of new seismic data and findings of recent research conducted by other workers. The young (reactivated) Canada Hill tectonics are here explained by hydraulic pressure onto a semi-liquid pillow of Setap Formation clay. Inferred Quarternary horizontal pressure in NW-SE direction, in combination with strike-slip tectonics, plus some overthrusting, triggered a diapiric remobilization of the mobile clay pillow beneath the Canada Hill. The diapiric flow was refocused upwards, in direction of the lowest pressure. As a result, the sequence above the Setup Formation clay, parts of the Miri Formation, were uplifted and emerged beyond the Pleistocene peneplain. Assuming a hydraulic uplift in the order of 400 feet and a lithostatic pressure gradient of 0.9 psi/foot, additional lateral pressure above the 360 psi equilibrium pressure would have prompted the clay core to move. Both cited and described Malaysian (Miri, Sabah), and Bruneian (Jerudong, Belait) locations suggest that post-Tertiary clay mobilization is a common feature of NW Borneo, and produces pop-up structures. The uplift negatively affected the Miri Field, effectively splitting it into a Western, Central (Canada Hill) and Eastern (Kpg. Lopeng) Block segments, the latter probably depleting due to fractured lateral seal. It is also noted that all current oil seepages in the hill area can be related to fault systems that were reactivated at the Pleistocene/Holocene border.

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