What Will it Take to Bring a Renaissance to Gulf of Suez Exploration: Has the Time Arrived to Try Some Unconventional Source Rock Plays?*

John Dolson[1]

Search and Discovery Article #11153 (2018)**
Posted December 10, 2018

*Adapted from extended abstract based on oral presentation given at AAPG Geoscience Technology Workshop, Alexandria, Egypt, May 20-23, 2016
**Datapages © 2018 Serial rights given by author. For all other rights contact author directly. DOI:10.1306/11153Dolson2018

[1]DSP Geosciences and Associates, Delonex Energy, Coconut Grove, Florida (John.Dolson@delonexenergy.com)

Abstract

The Gulf of Suez is a prolific rifted hydrocarbon province, but one whose creaming curve peaked around 1989 with generally only small field discoveries and extensions made since that time. Sub-salt seismic imaging remains the most significant barrier to finding new traps but exploration also needs some new ideas to pursue beyond simple 3-way fault and 4-way closures. There remains much to learn about the petroleum system in the basin, despite a number of good regional syntheses published in the last 15 years. It is also clear that the 11 BBO so far discovered is the product of multiple source rocks, with much of the emphasis given to the Cretaceous Brown Limestone and Eocene Thebes Formation.

These formations have many of the characteristics required for successful unconventional exploration, with brittle layers interspersed with high quality, mature source rocks. Fractured Thebes production has long been noted in the basin or in oil shows in dry holes. The resource potential in the source rocks plays may be substantial, but there are serious economic and technical hurdles required to make unconventional plays work.

Perhaps it is time to openly discuss ways to overcome these barriers and see if some of that potential can be unlocked. With large areas of ramp structural dip in the deep kitchens untested, the potential for large new plays exists. In the spirit of an AAPG GTW, this presentation is designed to generate ideas, look at gaps in understanding and question old paradigms. The author recognizes that many more detailed, and more accurate maps exist in the confines of proprietary work in many oil companies, and presents these interpretations from the best available public data, sparse as good detailed maps may be.

Introduction

The Gulf of Suez is an Oligocene-Miocene rift formed largely by northeast-southwest extension. The exploration history is covered briefly (Wescott et al., 2016) and the structural geology best summarized by (Patton et al., 1994). Additional information on fields, syn-rift sedimentation and petroleum geology is contained in (Alsharhan, 2003; Dolson et al., 1996; Jackson et al., 2006; Matbouly and Sabbagh, 1996; Moustafa, 1996; Ramzy et al., 1996; Salah and Alsharhan, 1996; Shagar, 2006; Younes and McClay, 2002; Young et al., 2002; Younes, 2012).

Structurally, the rift cross-cuts deeper Syrian Arc inverted Jurassic basins. These deeper fabrics create accommodation zones across them which segment the basin into a series of half grabens where the direction of tilt reverses from basin to basin (Figure 1).

There are multiple half-grabens in the Gulf of Suez, and their dip direction switches direction in major accommodation zones. The zones are controlled by Syrian-arc related Jurassic inverted rifts which underlay the Oligocene-Miocene rift. These deeper structural grains, at nearly 90 degrees to the Tertiary rifting, exert a strong control on where transfer faults are located (Figure 1).

The stratigraphy of the basin is summarized in Figure 2. Multiple source rocks occur, but can broadly be grouped as Miocene age syn-rift and Cretaceous pre-rift stratigraphy. Much of the production is attributed to pre-rift source rocks, but in deeper grabens, there is evidence of syn-rift Miocene shale contributions (yellow colors on the Van Krevelan diagram on Figure 2).

While the Miocene source rocks are more localized, deposition of Eocene and Cretaceous limestones and shales covered much of the basin prior to rifting (Figure 3). These strata are thus far more extensive than the Miocene shales and were deposited during global sea-level rises associated with 'hot house' climates.

Exploration History

The creaming curve shown in Figure 4, shows that the 'golden era' of Gulf of Suez exploration occurred between 1961 and 1989. Since that time, only small fields have been found, despite extensive drilling. The biggest problem in bringing forth new reserves is that the plays have remained the same for over 60 years, with the industry searching for ever-diminishing fault blocks.

The exploration growth shown in a more detailed creaming curve (Figure 5) from 1955-1989 was spectacular, with success from exploration offshore for sub-salt fault blocks. The Italian forerunners of IEOC opened up the rift plays with the 1955 and 1961 discoveries of Belayim Land and Belayim offshore fields. Amoco Production Company opened an office in Cairo and drilled the giant Morgan discovery in 1965, sparking a rush to develop the rest of the basin, with remarkable industry success. A more detailed look at that story is chronicled in (Wescott et al., 2016). Figure 6 pays tribute to the vision of Jim Vanderbeek, who fought conventional wisdom and envisioned a giant petroleum province at a time of political upheaval in Egypt (Figure 6). A little-known fact is that Amoco, after earlier failures in the GOS was ready to exit the country, but Vanderbeek staked the Morgan discovery well as a mandatory 'water well', since, by contract, in the event of failure, the company was obligated to at least drill some water wells. Fortunately, this 'last ditch' resulted in discovery of a more than one billion barrel recoverable oil field.

One of the definitions of insanity is the idea of 'doing something over and over the same way and expecting different results. This more or less depicts the status today of exploration in the Gulf of Suez (Figure 7). It is highly unlikely additional large fault blocks will be found with the existing quality of seismic data in the basin. New concepts and technology are needed.

Pre-Rift vs. Syn-Rift Reserves

The ‘plumbing’ of the petroleum system is not as well understood. With most of mature and widespread source rocks in the pre-rift section, it is surprising that syn-rift reservoirs account for more than half of the proven reserves in the basin (Figure 8). This is shown in map view (Figure 9) where the number of syn-rift fields far out-weigh the pre-rift traps. This requires fairly efficient migration pathways to charge a variety of syn-rift reservoirs. Those migration pathways are not well understood. Some of this has been addressed in El-Ghamri et al., 2002; Khavari-Khorasani et al., 1998a, b; and Khavari-Khorasani et al., 1998c.

The challenge to finding more fields is the poor quality of the seismic data (Figure 10). Over 20 layers of interbedded salts, anhydrites and sandstones lie above the sub-salt reservoirs. These layers generate many seismic multiples which subsequently mask the deeper reflectivity. Some of the older 3D vintage seismic has resolution as low as 10 hertz in the prospective section. Even when multiples are removed and depth seismic sections compared to dipmeters in wells, only rough shapes are often possible to map.

Demonstrating the decrease in field size and repetitive nature of the exploration for only fault traps can be demonstrated in a series of maps over distinct periods of growth and decline shown on the earlier creaming curves. The major growth period in exploration can be seen in stages (Figure 11, Figure 12, Figure 13).

As is typical in many basins, the largest fields were found early and the overall shape of the basin understood by 1981, when field size discoveries began to fall. Well control shown in Figure 11 is concentrated almost exclusively on the highs. The depths to the deep basins, where source rock is the most thermally mature, are largely undrilled.

From 1982-1994 (Figure 12) the number of dry holes increased and field sizes found decreased. In a three-year period from 1990-1993, for instance, Amoco drilled 32 dry holes in a row. Most companies, by 1994, were starting to shoot large 3D seismic surveys in the hopes of better defining structural and stratigraphic features. The creaming curve did not, however, change substantially, but more economic wells were drilled as integrated seismic, log, oil show and other data were better integrated to reduce risk. The value of such efforts (1994-2009 time period) was documented by Dolson et al., 1997 and Hughes et al., 1997. Ultimately, the Saqqara and Edfu fields, discovered in 2003, resulted from careful data integration and seismic reprocessing (Figure 12 for location).

The maps and well penetrations on Figure 13 show that the basin has long ago entered its mature phase, with most discoveries as step-out exploration, with virtually no new play concepts. Well control remains focused around the high blocks, with flank tests less common and virtually no tests purely into the syn-rift synclines. Small companies like Transglobe have made additional small discoveries onshore or in very shallow water on small sub-basins that can be more cheaply drilled and tested.

Field size distributions can give an idea of basin maturity. The field sizes in the Gulf of Suez (Figure 14) are dominated by fields smaller than 25 MMBO, with a large number less than 5 MMMBOE. The largest reserves lie in a relative handful of large fields and a few giants. There are large gaps between the 614 fields of 5 MMBOE or less and the big fields with more than 100 MMBOE. This suggests there are large numbers of intermediate size fields left to be found, but they will probably not come from the traditional plays made in the past.

Growth in Rift Plays: Other Possible Rifts in Egypt

Two areas of lightly tested rifts are known in Egypt. The first is the obvious extension of the GOS southeastward into the Red Sea (Figure 15). An additional rift at Kom Ombo was discovered in 1998 in Upper Egypt. Both these areas lack infrastructure and pipelines for development.

A good overview of the Red Sea potential is that of Gordon, 2012; Gordon et al., 2011; and Gordon et al., 2010, summarized on Figure 16 and Figure 17. Oil was recovered in the NRS 1-5 area while drilling into a high basement block, but reservoir was absent. The extent of the Red Sea Rift, shown with an image of the gravity response (Dolson et al., 2001), is comparable to the Gulf of Suez in size, as is the lightly tested Kom Ombo Basin. More importantly, these lightly tested rifts are comparable in size to the Gulf of Suez, but will require substantial investment and better imaging to explore effectively.

Drilling in the Kom Ombo Basin has resulted in low permeable reservoirs (Figure 18), but excellent Lower Cretaceous source rock. Early information released and published in Dolson et al. (2001) identified the rift as Jurassic in age. Further biostratigraphy work, however, and 3D seismic coverage over the main field, confirms the deep source rock is Lower Cretaceous in age (Dolson et al., 2014). In 2012, a down-thrown fault block in the Al Baraka-16 well encountered better permeability and flowed naturally. It is unlikely this large basin has been fully tested with its sparse well control, but its remote location and lack of pipeline have discouraged exploration. Figure 19 summarizes the seismic and petroleum system.

While recognizing large potential growth in these remote basins, the question remains as to how to extract new reserves in the old Gulf of Suez Basin, where adequate infrastructure already exists to produce and market any new reserves. Discoveries in the Kom Ombo and Red Sea areas, in contrast, have no pipeline or infrastructure and thus require huge new reserves to become economic.

Use of High-Resolution Gravity and Seismic Imaging

Throughout the last 15 years, BP has tried to acquire high resolution gravity data (Figure 20) and innovative seismic processing to unlock new structural traps. This effort, has, unfortunately, yielded little new resources, with the play continuing to be ever decreasing size of structural traps. The publication by Peijs et al. (2012), however, is a must to read for anybody working in this basin.

Stratigraphic Trap Potential

Stratigraphic and combination traps are proven in the Gulf of Suez, as shown in Figure 21. Most of the fields classified as stratigraphic are only small accumulations, and located in flank positions to the high blocks. There is virtually no exploration in the synclinal basins.

It is certainly likely that large stratigraphic traps, particularly in the deep syn-rift grabens, must exist but are virtually impossible to identify with existing seismic technology. An example of a giant stratigraphic trap over-looked in the North Sea rift is that of the Buzzard Field (Figure 22).

Interestingly, the Buzzard acreage was initially picked up by Amoco and British Gas in the mid 1990's, but dropped when BP merged with Amoco in 1999. The paradigm at the time, in the newly merged company was that "strat traps are always small because they have single zone pays and require multiple seals". Hence, Buzzard Field was overlooked and later discovered by Pan Canadian and Encana in 2001.

The value of 3D seismic in de-risking these traps of traps where seismic imaging is of high quality is substantial. A review of world-wide giant field discoveries through 2017 shows that the stratigraphic and combination trap component of giant discoveries has jumped in the last 15 years from an average of 10-15% to over 50% or recently discovered giants. We now have many tools to image reservoirs and seals, but remain challenged on data quality in the Gulf of Suez.

Petroleum System, Unconventional Play Assessment and Data Challenges

So, what is left? There are abundant, rich source rocks in the Pre-rift of the Gulf of Suez. Understanding their maturation level, however requires multiple of high-quality maps, something that is difficult for new-basin entry companies, or even long-established smaller companies, to make. In addition, current unconventional source rock plays are made in cratonic basins with much simpler 'somewhat layer-cake' stratigraphy where horizontal drilling does not have to deal with extensive faulting. Yet as unconventional shale exploration matures, increasingly difficult structural trends and other basins, such as rifts, will undoubtedly be explored.

One of the major challenges to developing strategies to unconventional source rock plays in the GOS is simply the lack of readily available, widespread seismic, logs and geochemical information. It is very difficult for a small operator hoping to explore anywhere in Egypt to obtain good databases without years of trading with other companies or forming partnerships with groups that can pool their diverse data sets. There are, for instance, almost no published structure maps beyond those shown in Dolson et al. (2014) and Dolson et al. (2001) and the author readily admits these maps provide good shapes, but the depths to the synclinal areas are extrapolated and could be greatly approved with more data. The maps should only be considered gross approximations compared to those in companies with a long history in the basin and large seismic and well datasets.

Regional geothermal gradients and burial histories (particularly on the flanks, where there has been some basin uplift and erosion) are only grossly understood. Good basin models require multiple high-quality structural maps at numerous levels, and these are largely missing except in companies that have explored in the basin for over half a century. The best geothermal gradient map is that of Alsharhan (2003), digitized and gridded to provide input into a basin model (Figure 23).

In addition, 'ground truthing' petroleum systems models require calibration of the test, show, field, reservoir and geochemical data such as vitrinite and source-to-oil correlations test predictions made from any model. Historical test and oil field data is shown on Figure 24 and Figure 25 with pre-rift fields. A Trinity (www.zetaware.com) software basin model was used with the gross Eocene structure map, gross approximations of Eocene thickness, other available published isopachs at other levels and the geothermal gradient map. A resultant maturity maps on the base of the Eocene limestone is shown in Figure 25.

The author stresses that these maps are crude approximations to results that would be obtained with higher quality input, but there is, however, a fairly good fit to the pre-rift oil shows and shows in the Eocene, Sudr and Brown limestone formations. This suggests the shapes are grossly correct and the patterns of generating kitchens reasonable.

Structural levels near the Base of the Matulla are even more uncertain, but again, maturation maps seem to reasonable fit the known accumulations of pre-rift fields. If the absolute value of the maturation maps is not correct, the trends probably are close enough to high-grade areas of interest.

Syn-rift reservoir distribution, however, is much broader than indicated by the Eocene level maturation maps, suggesting complex migration and charge from the deeper source rock into the syn-rift sections. This can occur from fault juxtaposition of mature pre-rift sources against syn-rift reservoirs. A good case study is that of the October Field in the northern Gulf of Suez (El-Ghamri et al., 2002). Alsharhan (2003) shows significant source rocks in the Lower Rudeis and these have undoubtedly contributed to syn-rift strata, but most modeling indicates that the syn-rift kitchens (Figure 27, right diagram) and not extensive. Hence, uncertainty in the kerogen kinetics, regional and local structure maps and sparse, scattered available data make de-risking source rock plays difficult.

There are, however, ways to further test the validity of the maturation maps shown in this study. Trinity model estimates of the API gravity generated at the base of the Eocene structural level shows widespread low API oil areas (dark green in Figure 28). These would be caused by relatively immature source rocks and early, heavy oil generation. The lighter green shades shown on Figure 28 are higher API gravity kitchens. The API gravities posted for the Eocene and Sudr formations in existing field show fairly close agreement with the predicted model. Hence, areas of potential lighter oil can be identified on this map.

Likewise, the calibration of Eocene, Sudr and Brown Limestone shows and fields correlates well with the location of mature source rocks at the Brown Limestone level, despite the crude nature of the gross structural geometry used. More importantly, just taking one small kitchen on this map and using the original HI and TOC values shown for a Class B marine source rock, a Trinity model estimates a 700 square kilometer kitchen as shown could generate 25-64 million barrels of oil per square mile. The author acknowledges this is a crude estimate, but it speaks to the possibility of having a rich source rock available to exploit in that area. Much more work would need to be done to establish accurate estimates of potential. The same kind of analysis of generation potential is shown for the base of the Eocene (Figure 30), again with substantial volumes predicted.

Even with a crude regional structural model and geothermal gradient maps, it is clear that mature source rocks (.9 % Ro) generally lie between 3500 and 4500 meters (Figure 31). Many other factors such as brittleness, stress directions, natural fractures and matrix porosity in the shales and carbonate sources are necessary to derisk an unconventional play. But at some point, as has been proven in the United States over the last decade, these kinds of plays will need to be tested. Some of the deeper structures would allow horizontal testing now, where there is adequate control and the source rocks already mature. Much of the existing Eocene, Sudr and Brown Limestone production is already from fractured carbonates, so the production from these formations is proven. The challenge remains to go into the deeper basins and attempt some horizontal drilling and multi-stage hydraulic fracturing.

Challenges Ahead

Ultimately, the courage to attempt a play like this will lie in the potential economic return. Rifts have not yet been exploited fully for their source rock potential, with most unconventional plays in cratonic basins. Hydraulic fracturing, offshore, is also potentially far into the future. Abundant tight oil in conventional reservoirs exists in the basin, but hydraulic fracturing technology has not been widely applied in the past, although horizontal drilling has. Some of the incentives that need to be put in place are summarized in Figure 32. The Egyptian petroleum industry must make more data available to smaller companies, solve current fiscal issues of money owed for existing production share and move to a more open data access environment. A much higher percentage of discoveries should go to companies attempting to open up unconventional plays. Better terms may drive some innovation.

Oil companies, in contrast, must foster new ideas, drop their opposition to trying new things and try to develop some truly new plays. Great oil finders in some companies frequently take a ‘back seat’ to staff who prefer to try to save money by killing plays instead of taking bold risks to try new things. We need to invest heavily in the next generation of geoscientists and foster and participate in more workshops like this AAPG Geotechnical Workshop where new ideas can begin to flourish.

The author looks back in astonishment what Jim Vanderbeek, at the young age of 35, accomplished when he positioned Amoco in Egypt in the early 1960’s. He had a vision of a new, giant oil province located between the productive basins of Libya and the Saudi Arabian. At a time when the basin shapes were not even understood, when there were few rigs to work from, no pipeline and only a very small and antiquated oil industry, he took a risk. He took that risk shortly after a country-wide revolution and stayed with exploration in Egypt through the 1967 and 1974 Arab-Israeli wars. He worked tirelessly and collaboratively with the Egyptian government, its universities and the local governates. He managed to keep the El Morgan Oil Field flowing during the war years of 1967-1973 by negotiating successfully with President Nasser and the Israeli government, at the same time that IEOC had its fields seized and produced by Israel at the loss of 220,000 BOPD from its fields (Sayed Matbouly, personal communication).

It is time to find a few more explorers of that caliber, and of many of the other innovators who helped build the Egyptian oil industry. Status quo and old paradigms will not find new, big, reserves. The future belongs to the innovators and companies who nurture them and take bold steps to try new things.

Selected References

Alsharhan, A.S., 2003, Petroleum geology and potential hydrocarbon plays in the Gulf of Suez rift basin, Egypt: AAPG Bulletin, v. 87, p. 143-180.

Ayyad, M.H., and M. Darwish, 1996, Syrian Arc structure: A unifying model of inverted basins and hydrocarbon occurrences in North Egypt, in M. Youssef, ed., Proceedings of the 13th Petroleum Conference, v. 1: Cairo, Egypt, The Egyptian General Petroleum Corporation, p. 40-59.

Bengtson, C.A., 1981, Statistical curvature analysis techniques for structural interpretation of dipmeter data: AAPG Bulletin, v. 65, p. 312-332.

Bosworth, W.B., R. Guiraud, and L.G. Kessler, II, 1999, Late Cretaceous (ca. 84 Ma) compressive deformation of the stable platform of northeast Africa (Egypt): Far-field stress effects of the "Santonian event" and the origin of the Syrian arc deformation belt: Geology, v. 27, p. 633-636.

Dolson, J., 2016, Understanding Oil and Gas Shows and Seals in the Search for Hydrocarbons: Switzerland, Springer International Publishing Switzerland, 486 p.

Dolson, J., O. El-Gendi, H. Sharmy, M. Fathalla, and I. Gaafar, 1996, Gulf of Suez rift basin sequence models - Part A, Miocene sequence stratigraphy and exploration significance in the greater October Field area, Northern Gulf of Suez, *in* M. Youssef, ed., Proceedings of the 13th Petroleum Conference: Cairo, Egypt, The Egyptian General Petroleum Corporation, v. 2, p. 227-241.

Dolson, J.C., M. Atta, D. Blanchard, A. Sehim, J. Villinski, T. Loutit, and K. Romine, 2014, Egypt's future petroleum resources: A revised look in the 21st Century, *in* L. Marlow, C. Kendall, and L. Yose, eds., Petroleum Systems of the Tethyan Region: AAPG Memoir 106, p. 143-178.

Dolson, J.C., M.V. Shann, S. Matbouly, C. Harwood, R. Rashed, and H. Hammouda, 2001, The petroleum potential of Egypt, *in* M.W. Downey, J.C. Threet, and W.A. Morgan, eds., Petroleum Provinces of the 21st Century: AAPG Memoir 74, p. 453-482.

Dolson, J.C., B. Steer, J. Garing, G. Osborne, A. Gad, and H. Amr, 1997, 3D seismic and workstation technology brings technical revolution to the Gulf of Suez Petroleum Company: The Leading Edge, v. 16, p. 1809-1817.

Editors, 2012, Sea Dragon taps deeper oil pay in Egypt's Kom Ombo: Oil and Gas Journal, June 7 issue.

El-Ghamri, M.A., I.C. Warburton, and S.D. Burley, 2002, Hydrocarbon generation and charging in the October Field, Gulf of Suez, Egypt: Journal of Petroleum Geology, v. 25, p. 433-464.

Gordon, G., 2012, Prospectivity in the north Red Sea, Egypt: new data, new challenges, new opportunities, The challenges of sub-salt exploration and development in deep sea Middle East and North Africa: SPE International Amman, Jordon.

Gordon, G., B. Hansen, J. Scott, C. Hirst, R. Graham, T. Grow, A. Spedding, S. Fairhead, L. Fullarton, and D. Griffin, 2011, The hydrocarbon prospectivity of the Egyptian North Red Sea Basin: Petroleum Geology: From mature basins to new frontiers, p. 783-789.

Gordon, G., B. Hansen, J. Scott, C. Hirst, R. Graham, T. Grow, A. Spedding, S. Fairhead, D. Pocknall, L. Fullarton, and D. Griffin, 2010, Prospectivity in the North Red Sea Egypt: new data, new challenges, new opportunities: AAPG International Convention and Exhibition, Calgary, Alberta, Canada, AAPG Search and Discovery Article #90108 (2010). Website accessed October 29, 2018.

http://www.searchanddiscovery.com/pdfz/abstracts/pdf/2010/intl/abstracts/ndx_gordon.pdf.html

Hughes, S.C., H. Ahmed, and T.A. Raheem, 1997, Exploiting the mature South El Morgan Kareem reservoir for yet more oil: A case study on multi-discipline reservoir management, Middle East Oil Show and Conference, Bahrain, Society of Petroleum Engineers.

Jackson, C.A.L., R.L. Gawthorpe, C.W. Leppard, and I.R. Sharp, 2006, Rift-initiation development of normal fault blocks: insights from the Hammam Faraun fault block, Suez Rift, Egypt: Journal of the Geological Society of London, v. 164, p. 165-183.

Khavari-Khorasani, G., J.K. Michelsen, and J.C. Dolson, 1998a, The factors controlling the abundance and migration of heavy vs. light oils, as constrained by data from the Gulf of Suez, Part I, The effect of expelled petroleum composition, PVT properties and petroleum system geometry: Organic Geochemistry, v. 29, p. 255-282.

Khavari-Khorasani, G., J.K. Michelsen, and J.C. Dolson, 1998b, The factors controlling the abundance and migration of heavy vs. light oils, as constrained by data from the Gulf of Suez, Part II, The significance of reservoir mass transport processes: Organic Geochemistry, v. 29, p. 283-300.

Khavari-Khorasani, G.J., J.C. Dolson, B.L. Steer, J.W. Stewart, J.D. Garing, D.T. Tanasichuk, and J.K. Michelsen, 1998c, The effect of source-carrier-reservoir geometrical inter-relationship, phase fractionation of migrating fluids and in-reservoir processes on the quality and distribution of petroleum types in the Gulf of Suez, Egypt (abs): AAPG 1998 Hedberg Conference, Integrated Structural and Stratigraphic Analysis in Rift Settings.

Matbouly, S., and M.E. Sabbagh, eds., 1996, Gulf of Suez oil fields (a comprehensive overview): The Egyptian General Petroleum Corporation, Cairo, Egypt, v. 1, 735 p.

Moustafa, A.R., 1996, Internal structure and deformation of an accommodation zone in the northern part of the Suez rift: Journal of Structural Geology, v. 18, p. 93-107.

Moustafa, A.R., R.E. Badrawy, and H. Gibali, 1998, Pervasive E-ENE oriented faults in Northern Egypt and their effect on the development and inversion of prolific sedimentary basins., *in* M. Eloui, ed., 14th Petroleum Conference: Cairo, Egypt, The Egyptian General Petroleum Corporation, v. 1, p. 51-67.

Moustafa, A.R., and M.H. Khalil, 1990, Structural characteristics and tectonic evolution of north Sinai fold belts, *in* R. Said, ed., The Geology of Egypt: Rotterdam, Netherlands, A.A. Balkema Publishers, v. 1, p. 381-392.

Moustafa, A.R., and M.H. Khalil, 1995, Superimposed deformation in the Northern Suez Rift, Egypt: relevance to hydrocarbon exploration: Journal of Petroleum Geology, v. 18, p. 245-266.

Patton, T.L., A.R. Moustafa, R.A. Nelson, and S.A. Abdine, 1994, Tectonic evolution and structural setting of the Gulf of Suez rift, *in* S.M. Landon, ed., Interior Rift Basins: AAPG Memoir 59, p. 9-56.

Peijs, J.A.M.M., T.G. Bevan, and J.T. Piombino, 2012, The Gulf of Suez rift basin, *in* D.G. Roberts, and A.W. Bally, eds., Regional Geology and Tectonics: Phanerozoic Rift Systems and Sedimentary Basins: Geological Society of London, v. 1B, p. 165-194.

Ramzy, M., B. Steer, F. Abu-Shadi, M. Schlorholtz, J. Mika, J. Dolson, and M. Zinger, 1996, Gulf of Suez rift basin sequence models - Part B, Miocene sequence stratigraphy and exploration significance in the central and southern Gulf of Suez, *in* M. Youssef, ed., Proceedings of the 13th Petroleum Conference: The Egyptian General Petroleum Corporation, Cairo, Egypt, v. 2, p. 242-256.

Ray, F.M., S.J. Pinnock, H. Katamish, and J.B. Turnbull, 2010, The Buzzard Field: anatomy of the reservoir from appraisal to production: Petroleum Geology conference series 2010, p. 369-386.

Salah, M.G., and A.S. Alsharhan, 1996, Structural influence on hydrocarbon entrapment in the northwestern Red Sea, Egypt: AAPG Bulletin, v. 80, p. 101-118.

Shagar, A., 2006, Source rock evaluation of some intervals in the Gulf of Suez area, Egypt: Egyptian Journal of Aquatic Research, v. 32, p. 70-87.

Wescott, W.A., M. Atta, and J.C. Dolson, 2016, A brief history of the exploration history of the Gulf of Suez, Egypt: AAPG International Conference and Exhibition, Cancun, Mexico, Search and Discovery Article #30473 (2016), Website accessed October 29, 2018.

http://www.searchanddiscovery.com/pdfz/documents/2016/30473westcott/ndx_wescott.pdf.html

Younes, M.A., 2012, Crude oil geochemistry dependent biomarker distributions in the Gulf of Suez, Egypt, *in* M.A.-A. Younez, ed., Crude Oil Exploration in the World, InTech, p. 1-22.

Younes, M.A., and K. McClay, 2002, Development of accommodation zones in the Gulf of Suez-Red Sea rift, Egypt: AAPG Bulletin, v. 86, p. 1003-1026.

Young, M.J., R.L. Gawthorpe, and I.R. Sharp, 2002, Architecture and evolution of the syn-rift clastic depositional systems towards the tip of a major fault segment, Suez Rift, Egypt: Basin Research, v. 14, p. 1-23.

Major tectonic changes due to plate movements: Miocene NW-SE rifts overlying inverted Syrian Arc inversions of NE-SW Jurassic rifts.

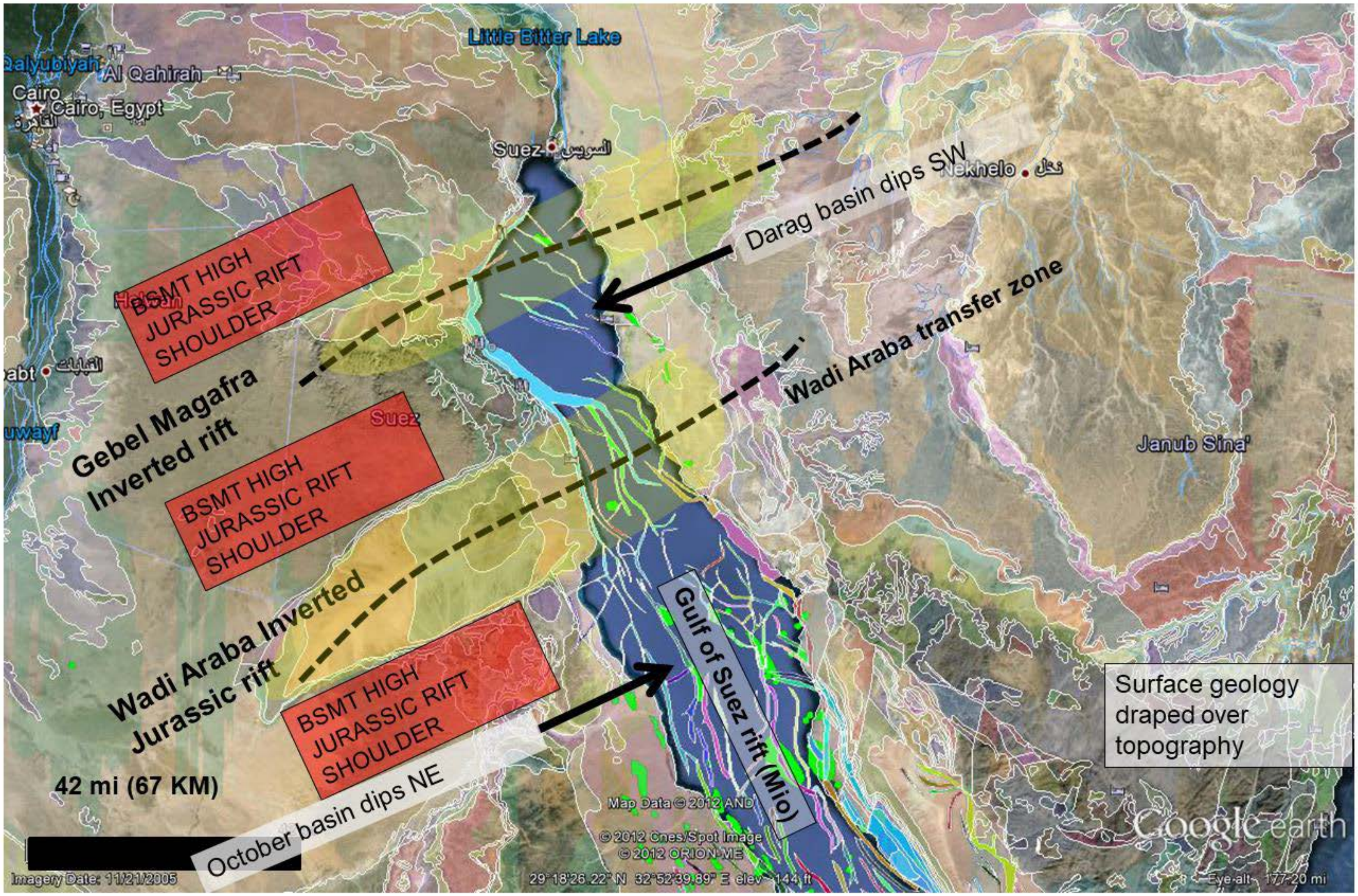


Figure 1. Location of major transfer zones caused by earlier rift inversion during the Syrian Arc event (90 MA). (Ayyad and Darwish, 1996; Bosworth et al., 1999; Moustafa et al., 1998; Moustafa and Khalil, 1990; Moustafa and Khalil, 1995).

Nomenclature and source rocks.

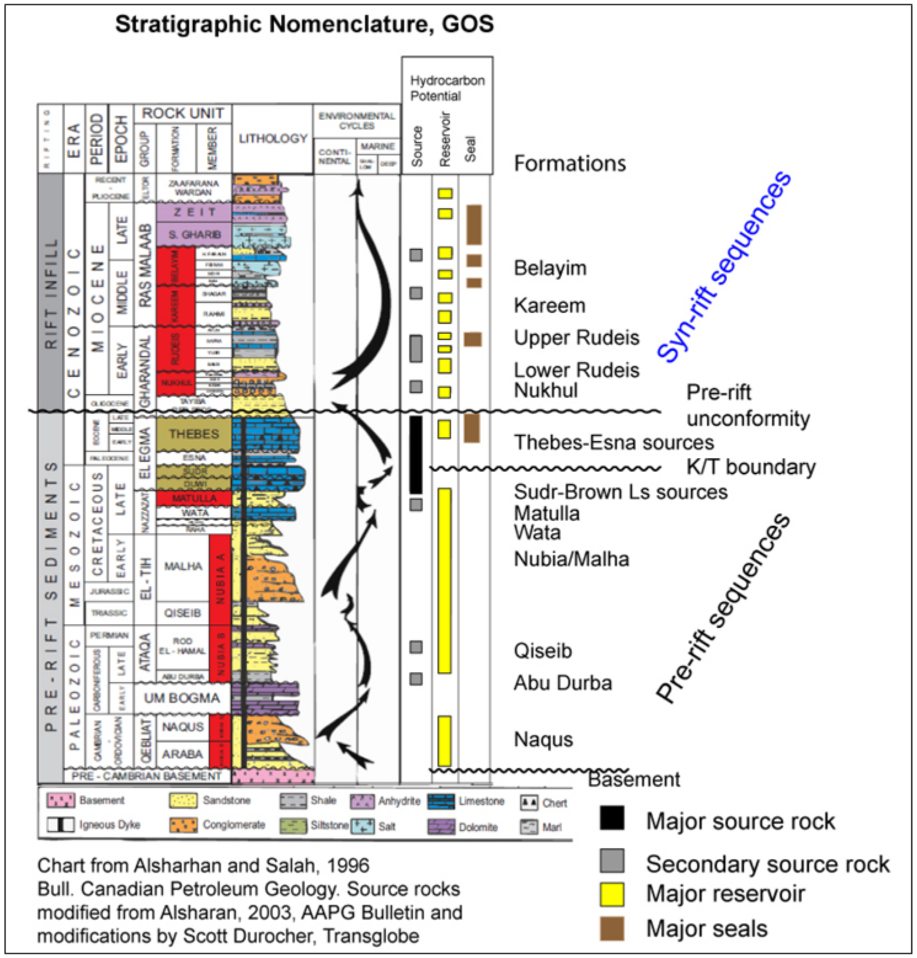
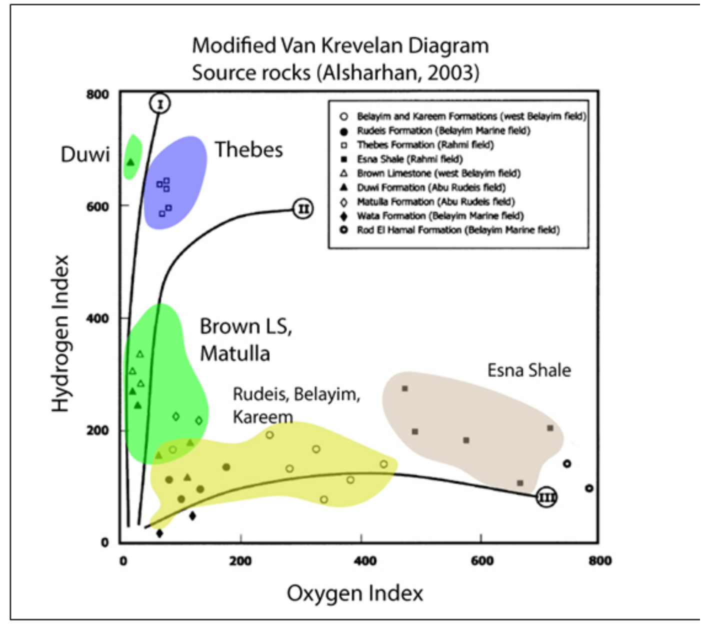


Chart from Alsharhan and Salah, 1996 Bull. Canadian Petroleum Geology. Source rocks modified from Alsharan, 2003, AAPG Bulletin and modifications by Scott Durocher, Transglobe



Note: Belayim Source rocks are generally thermal maturity challenged.

Figure 2. Stratigraphic summary of petroleum systems, seals and reservoirs, Gulf of Suez. Adapted from Alsharhan (2003) with some modifications by Scott Durocher, Transglobe.

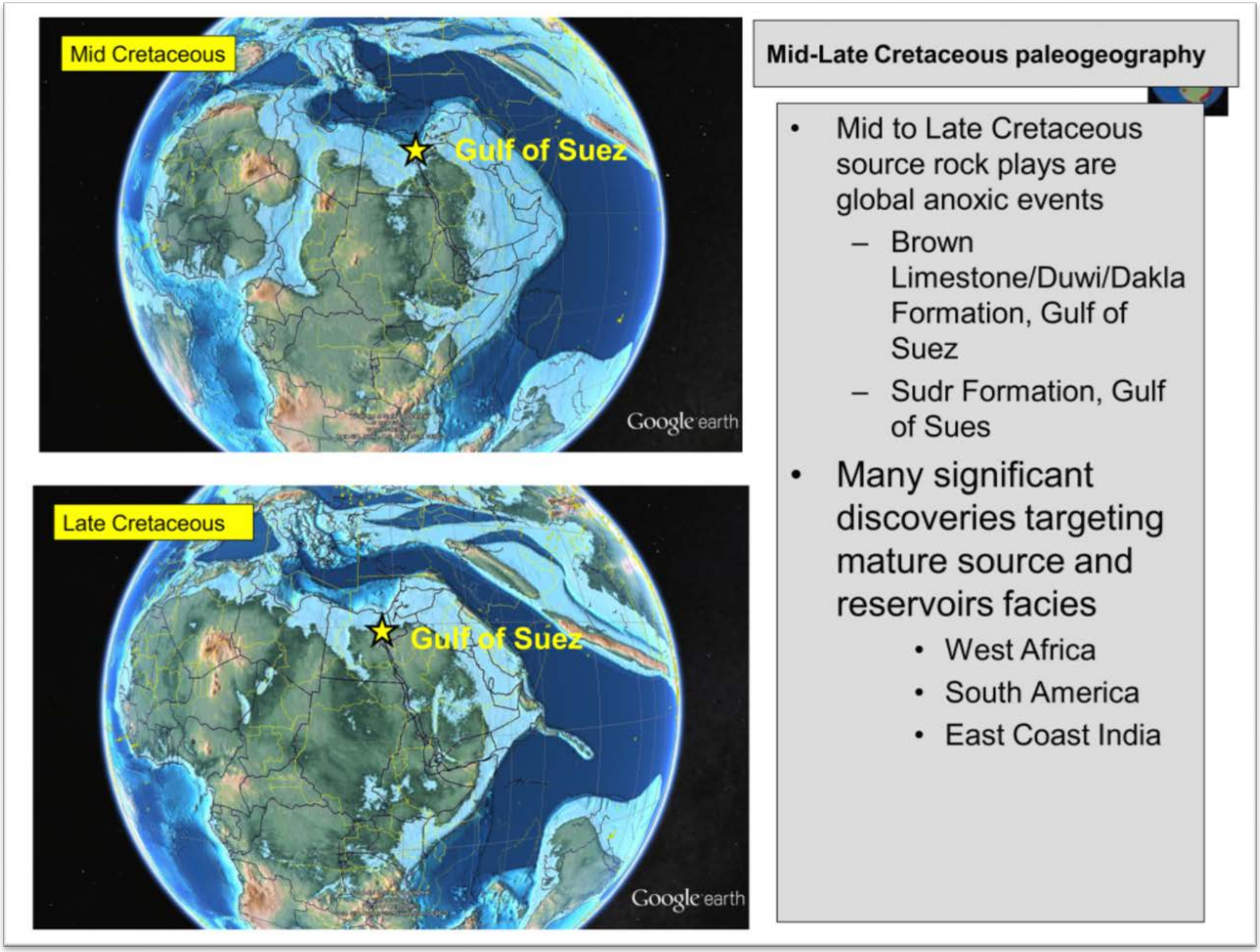


Figure 3. Cretaceous reconstructions of major source rock deposition during 'hot house' periods of global sea level rise.

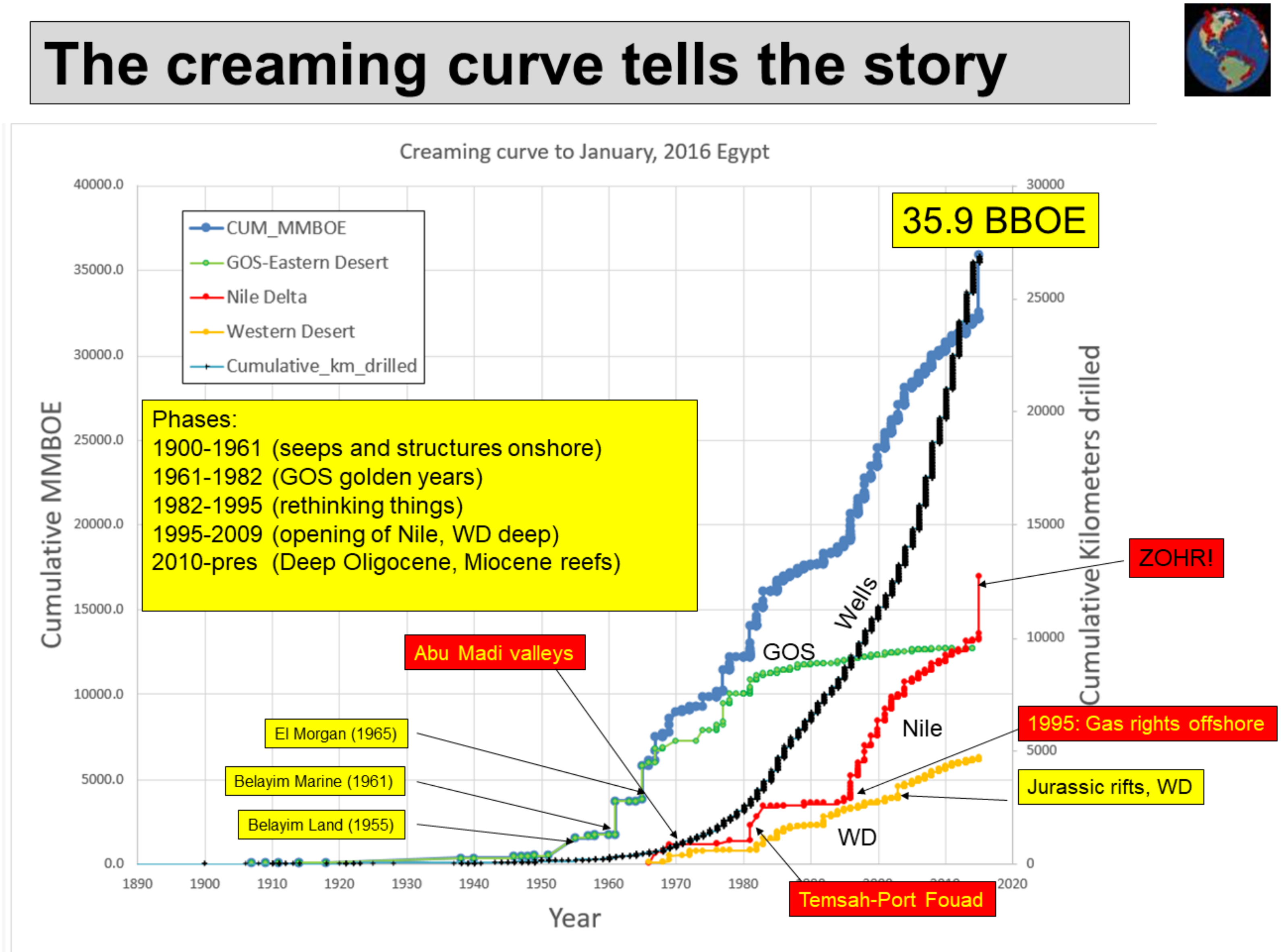
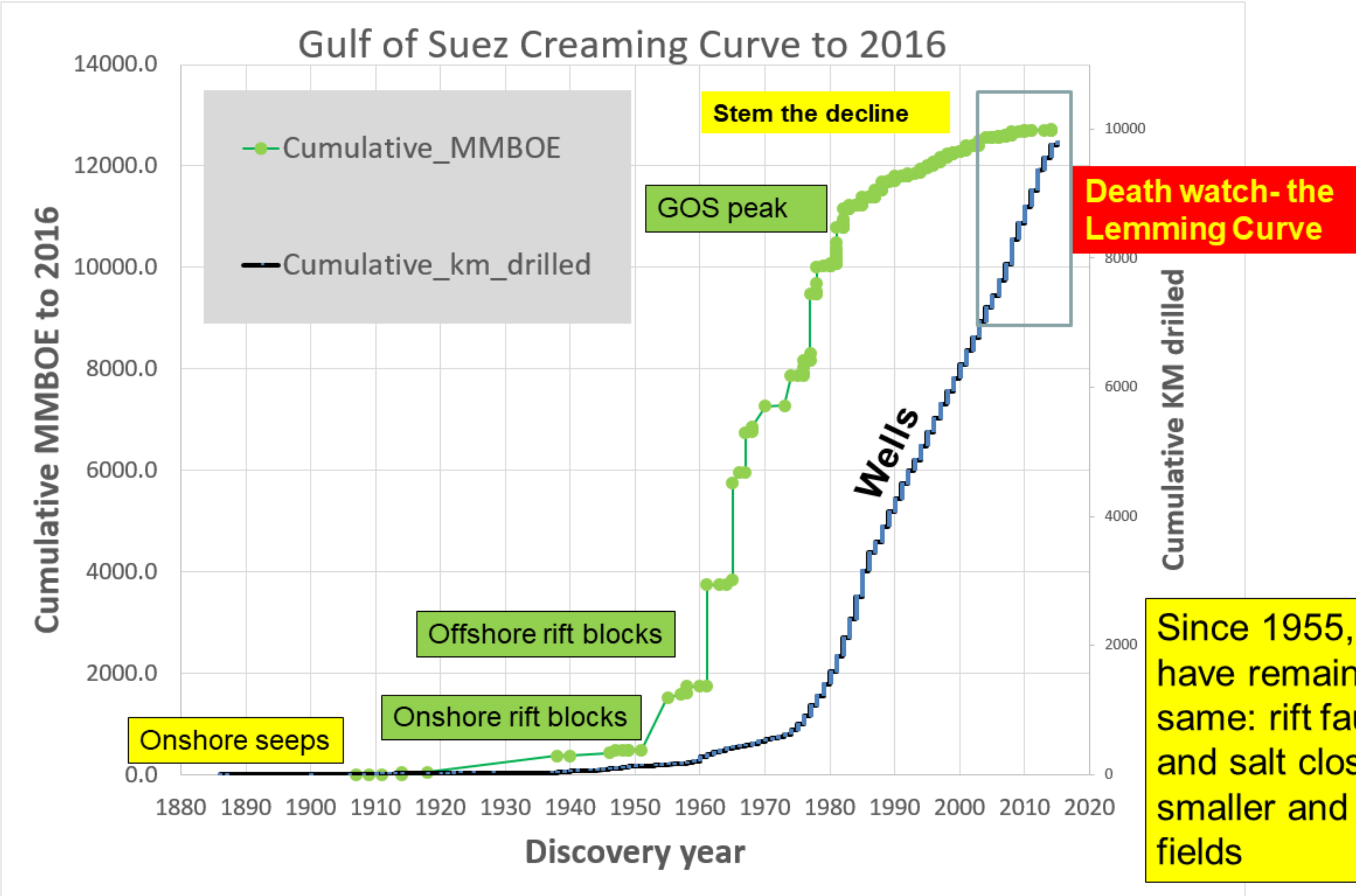


Figure 4. Egypt's creaming curve to 2016. The Gulf of Suez is in a mature phase needing new ideas or technologies to bring forth larger discoveries.

GOS exploration history



Since 1955, the plays have remained the same: rift fault blocks and salt closures, but smaller and smaller fields

AAPG 2016 Egypt GTW, GOS session, J. Dolson

Figure 5. Creaming curve, Gulf of Suez.

Paying tribute: One of the 1st big paradigm busters in Egypt

James Wilson Vanderbeek

1926-1993

- A son of missionaries in Turkey and China
- US Navy, MIT, Dartmouth, B.S. geology, 1947
- “I figured there was big oil in Saudi Arabia and big oil in Libya. There must be big oil somewhere in Egypt, ‘because it was in between’.
  - After 3-4 dry holes, told to leave Egypt (there is no oil!)
  - Staked El Morgan as a water commitment well—announced discovery of ‘5 feet of pay’ (at 1 foot equals 1000’ on an elog)
  - Built a pipeline without permission—”I figured if Egyptians could build the pyramids, they could do a pipeline”
- Worked through the 1967 war
- Awarded Egypt’s Order of the Republic by Gamal Abdel Nasser

AAPG 2016 Egypt GTW, GOS session, J. Dolson

Figure 6. A tribute to Amoco's Jim Vanderbeek, who was a pioneer recognizing the potential for major oil fields in Egypt.

We have been in the Lemming phase in the GOS for about 13 years

AAPG 2016 Egypt GTW, GOS session, J. Dolson

Figure 7. Definition of insanity as applied to the Gulf of Suez. Drilling progressively smaller and more difficult to image fault blocks will not result in a major new trend.

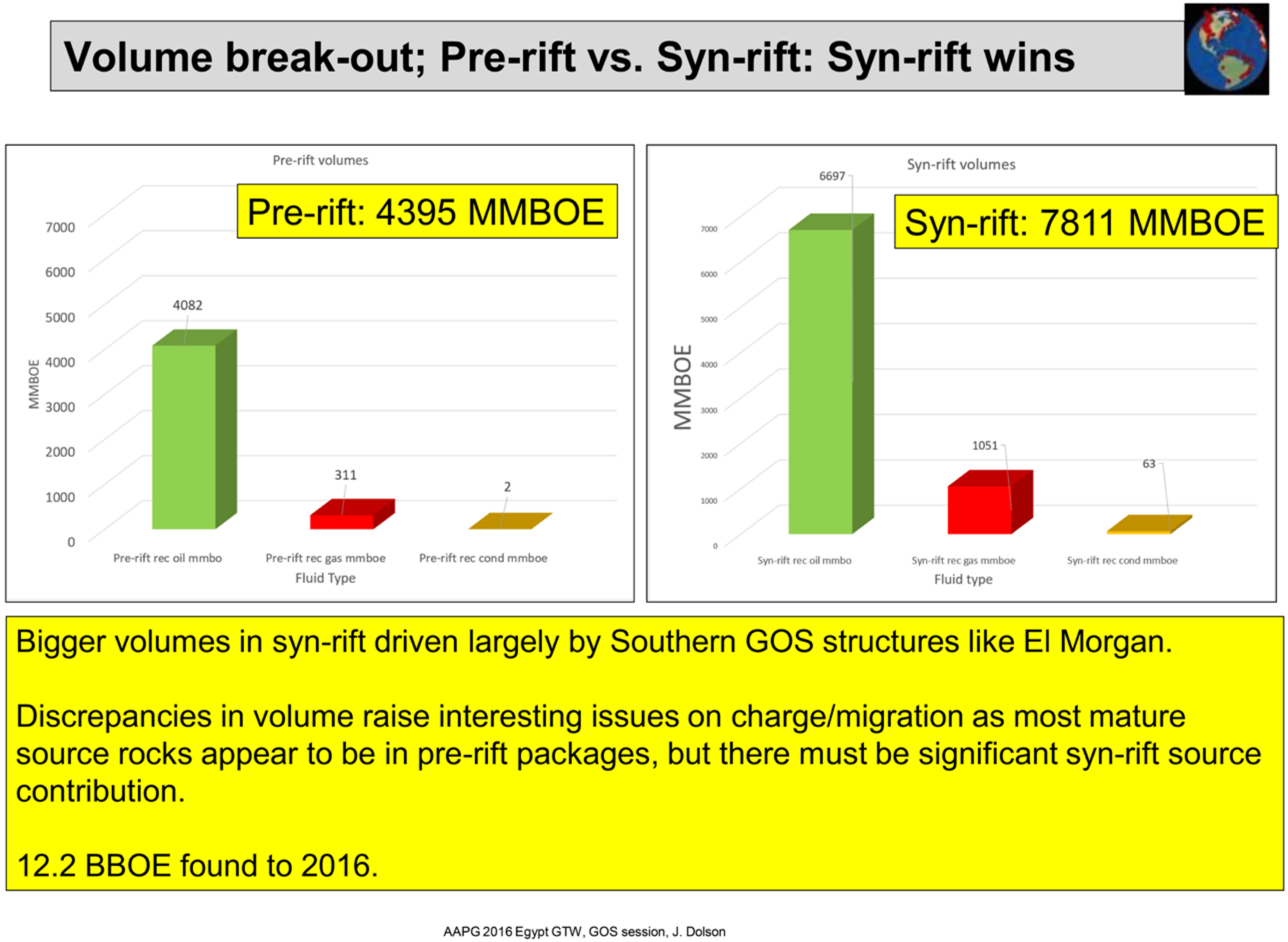


Figure 8. Comparison of pre-rift and syn-rift reserves. Despite most of the source rocks volumetrically in the pre-rift section, more pay has been established in syn-rift reservoirs, partly due to huge accumulations in the Morgan and Belayim offshore fields.

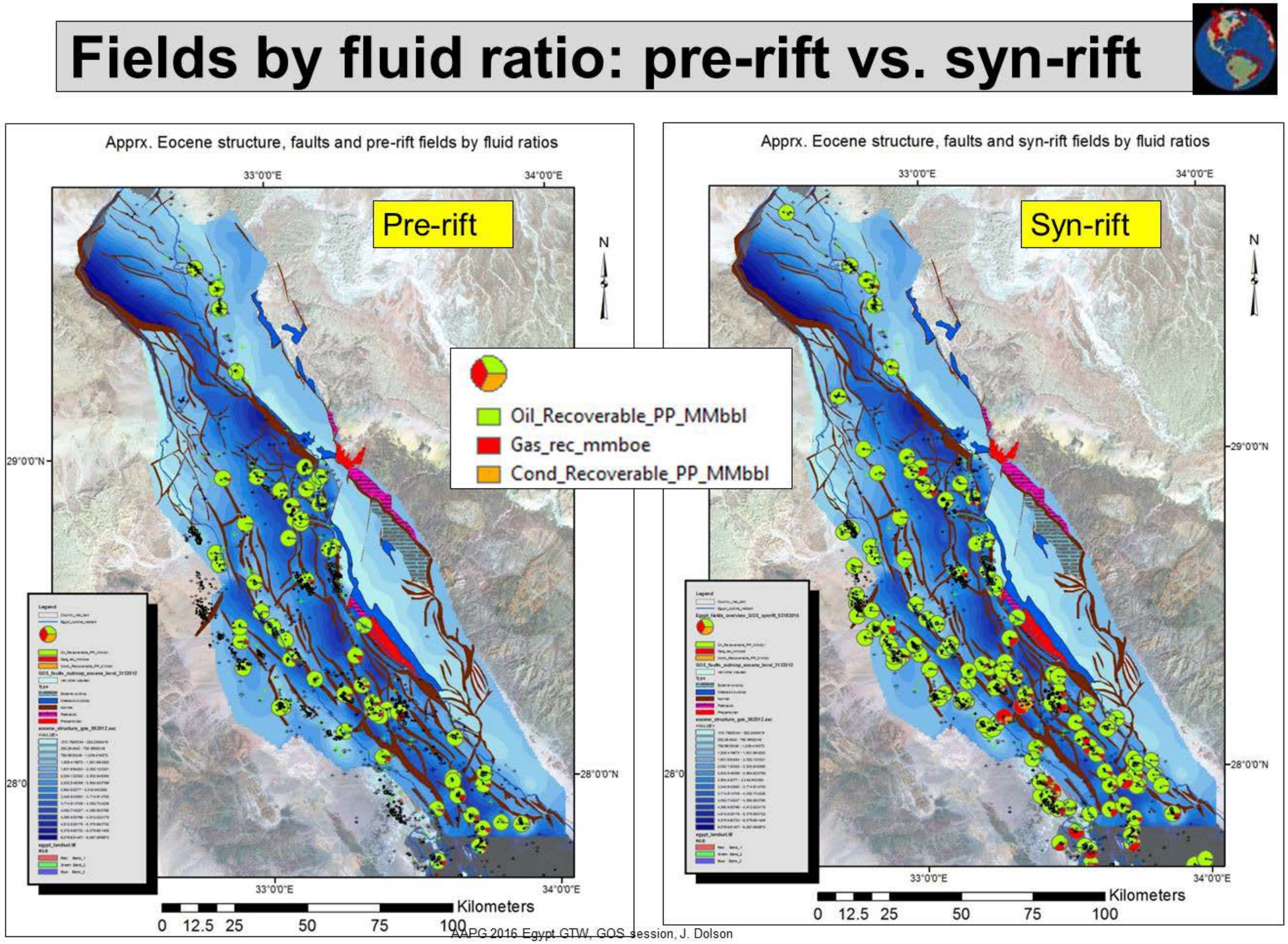


Figure 9. Eocene structural contours (dark blue is deeper than light blue) and the distribution of field fluid ratios. Gas fields are largely localized only it the southern part of the basin.

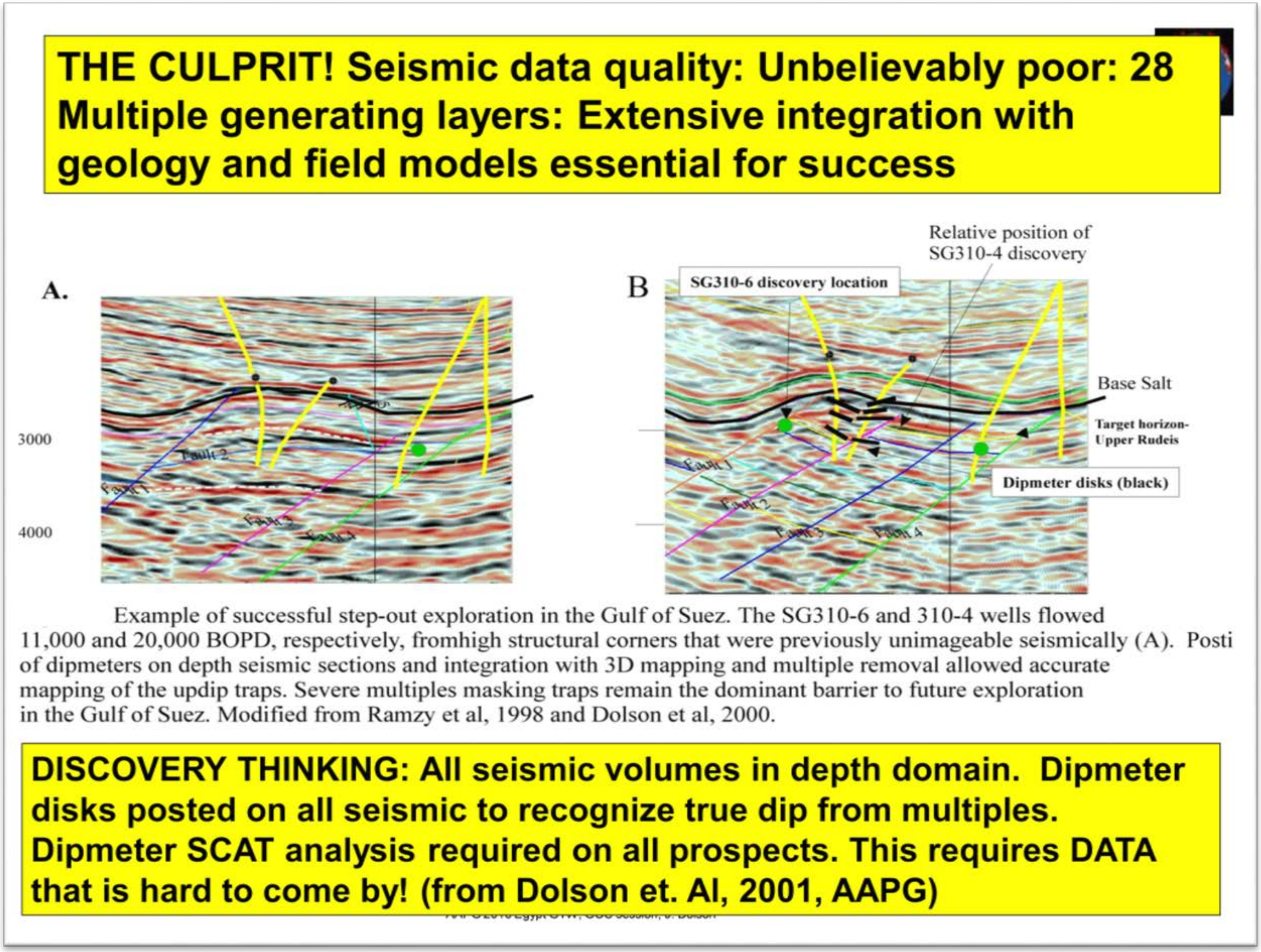


Figure 10. Seismic data quality hampers stratigraphic and smaller structural exploration. See Dolson et al. (2001) for original figure. SCAT analysis techniques are discussed in Bengtson (1981).

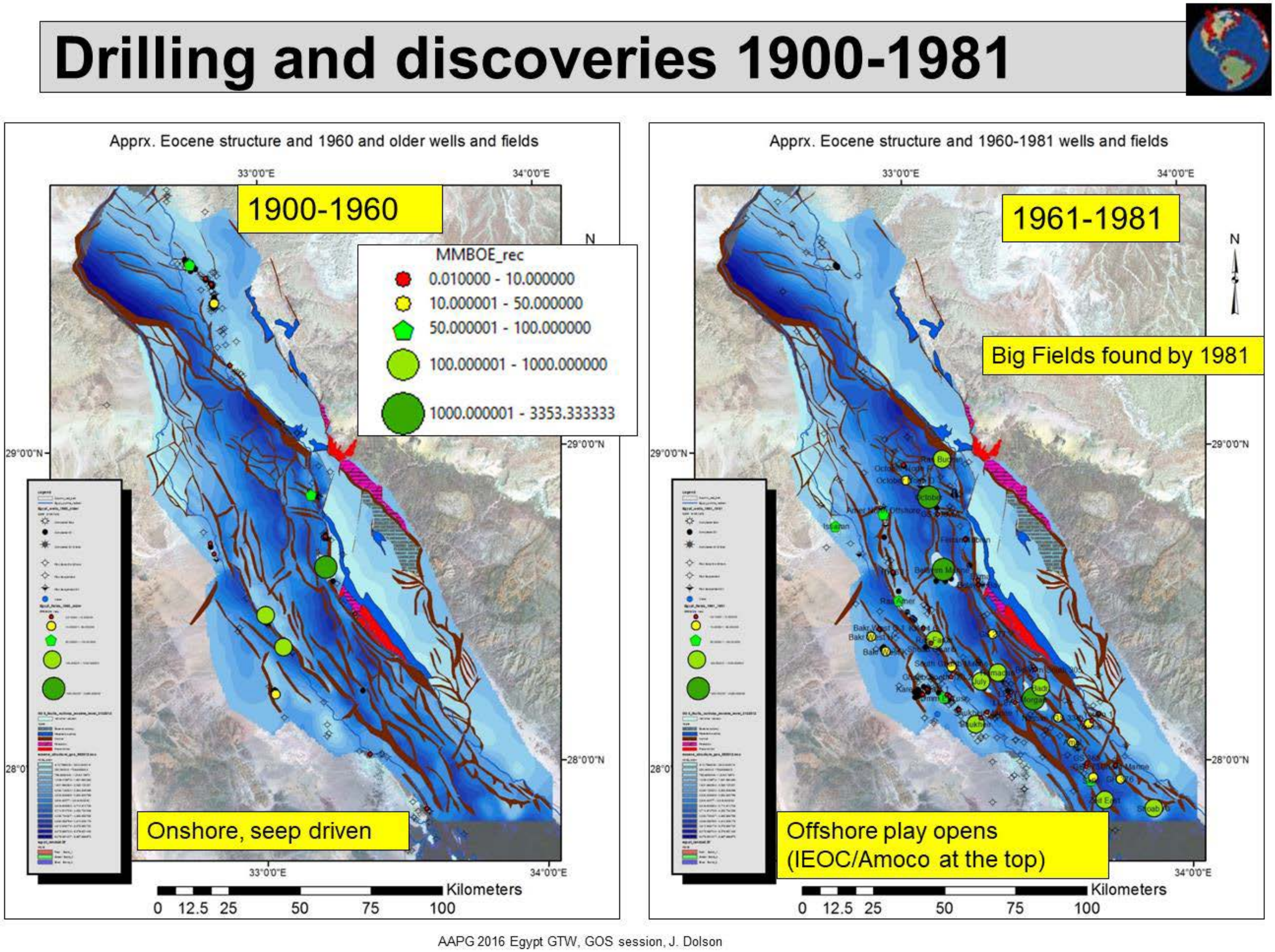


Figure 11. Discoveries and wells from 1900 through 1981. Most tests were on gravity, seismically defined structures and/or sea floor topography.

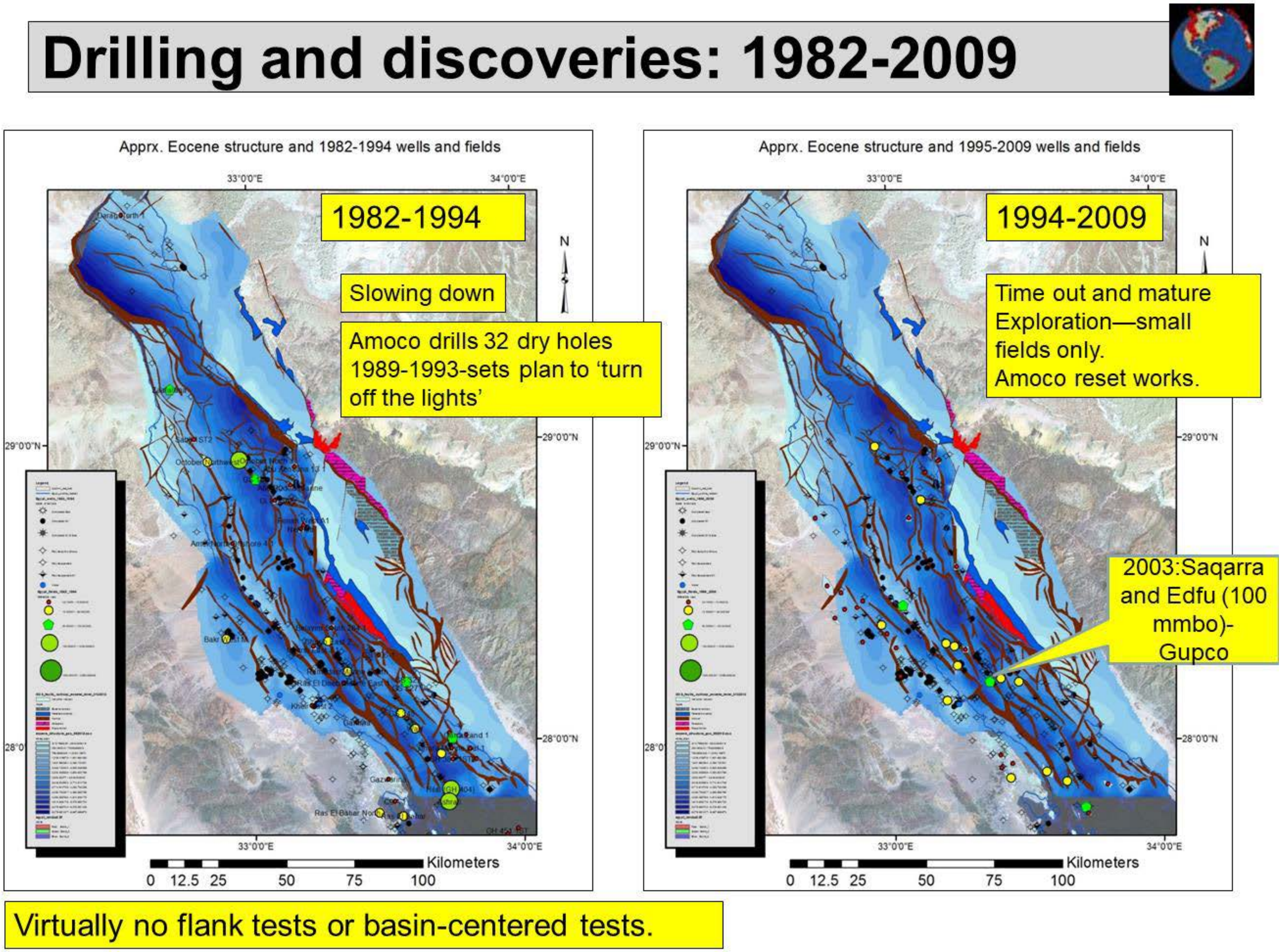
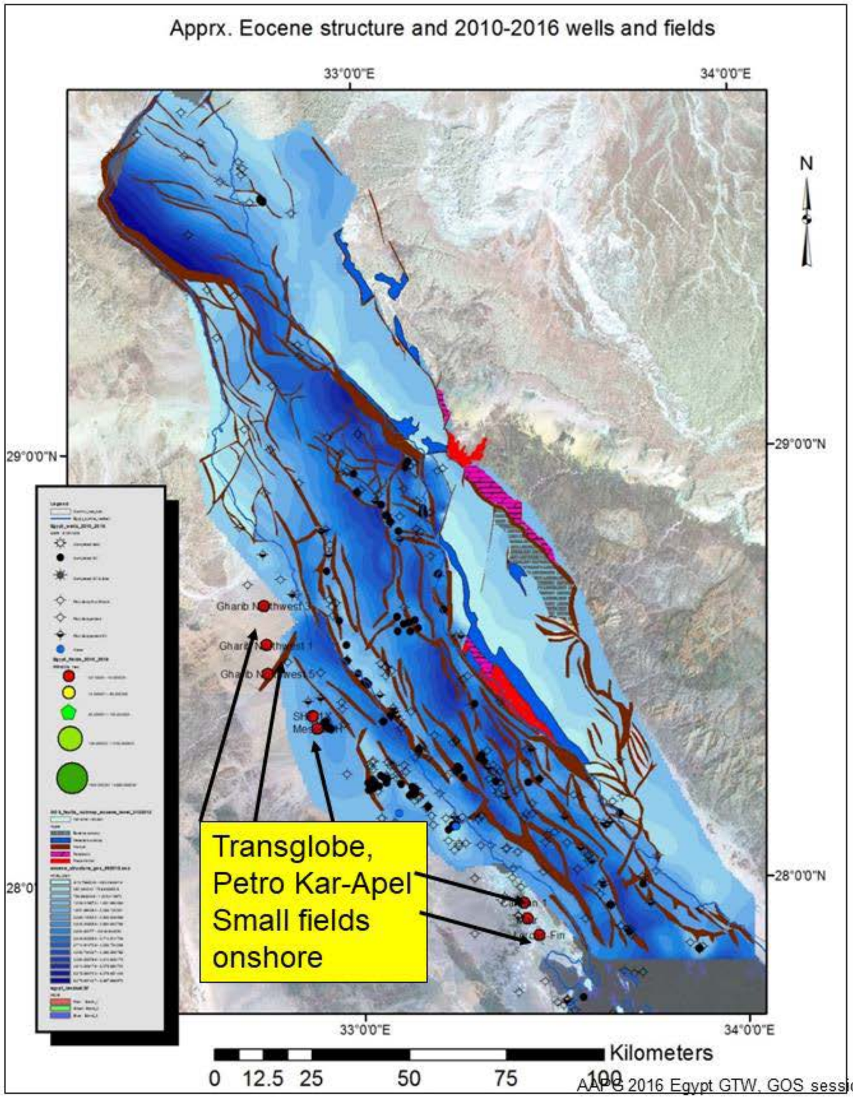


Figure 12. Drilling phases, 1982-2009. The plays remained the same, but the reserves discovered smaller with high failure rates.

2010-2016

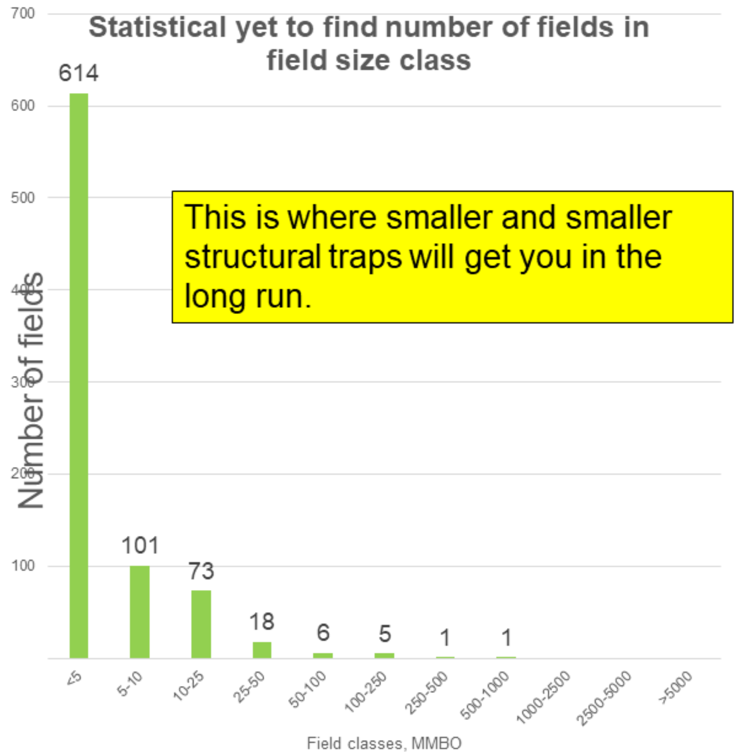


- This basin has been 'dead' for the last 6 years and dying for the last 13
- Seismic quality remains the culprit
- Only minor stratigraphic discoveries
- Very little well control in flank positions or in basins

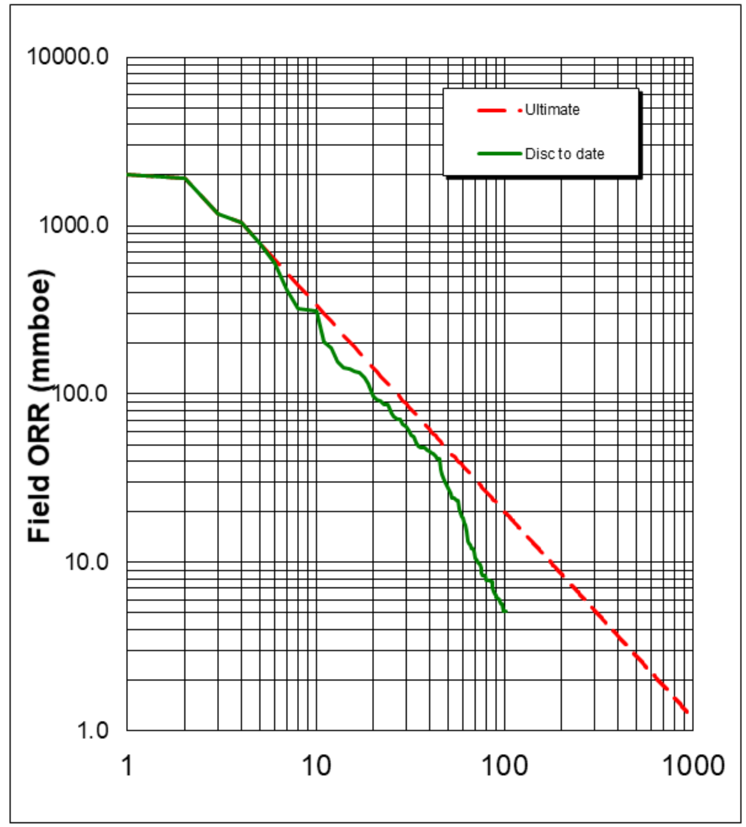
AAPG 2016 Egypt GTW, GOS session, J. Dolson

Figure 13. Drilling and discoveries 2010-2016.

A statistical yet to find of 6 BBOE if doing the same thing over and over



Size Class (mmboe)	Ultimate Disc.	Ultimate Vols.	Disc to date Disc.	Disc to date Vols.	Yet-to-find Disc.	Yet-to-find Vols.
<5	690	1598	76	130	614	1468
5-10	134	936	33	226	101	710
10-25	93	1440	20	331	73	1109
25-50	36	1258	18	709	18	549
50-100	21	1481	15	1103	6	378
100-250	14	2218	9	1344	5	874
250-500	5	1736	4	1366	1	370
500-1000	3	1944	2	1385	1	558
1000-2500	4	6120	4	6120		0
2500-5000						
>5000						
	1000	18729	181	12714	819	6016



Most future fields in the 5-55 MMBO range

session, J. Dolson

Figure 14. Lognormal plot of field sizes by class and potential yet-to-find (gaps between the red and green lines). The vast majority of pools are below 10-25 MMBOE in size. These data suggest the largest fields for the play type made have already been found.

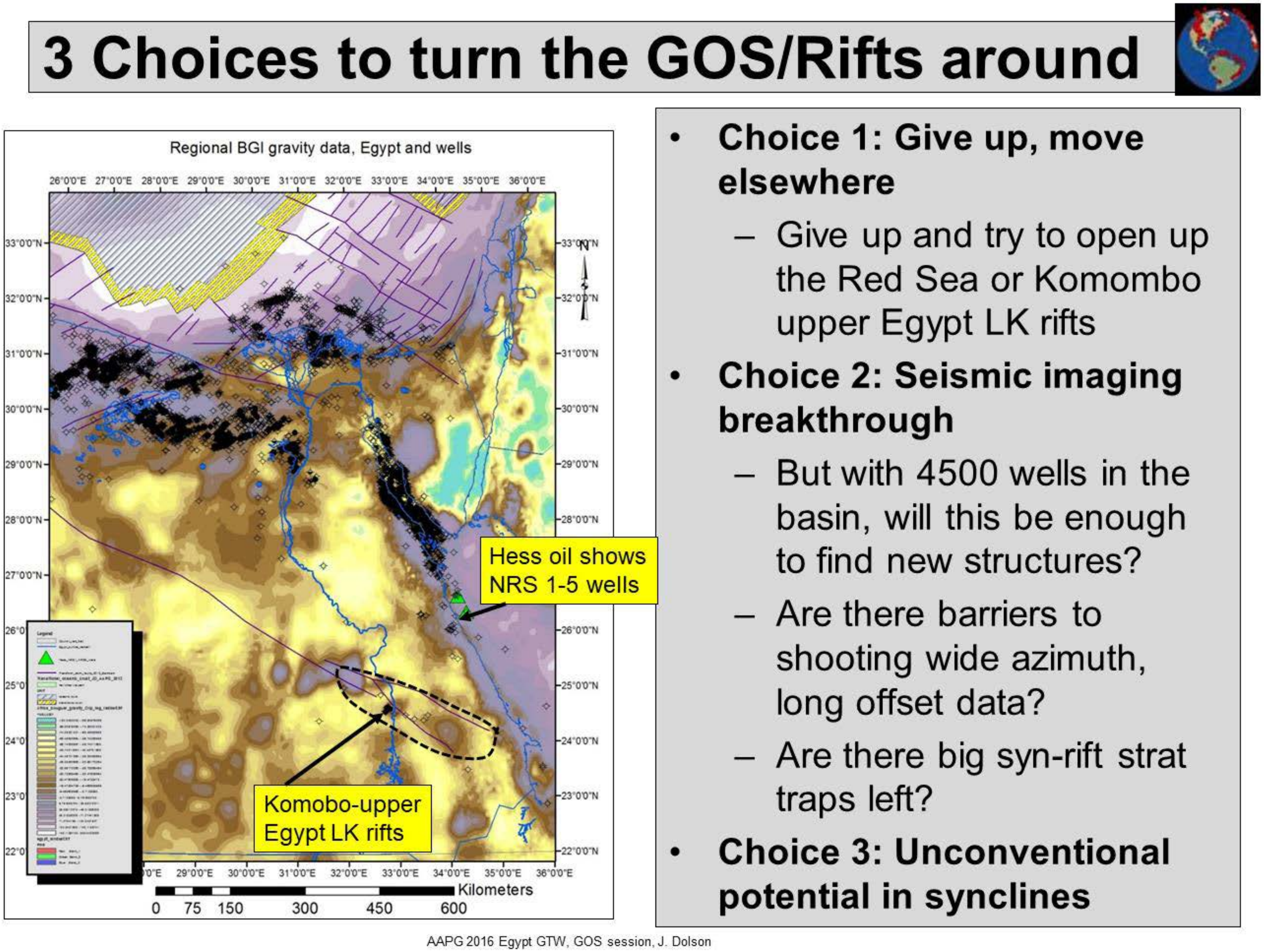
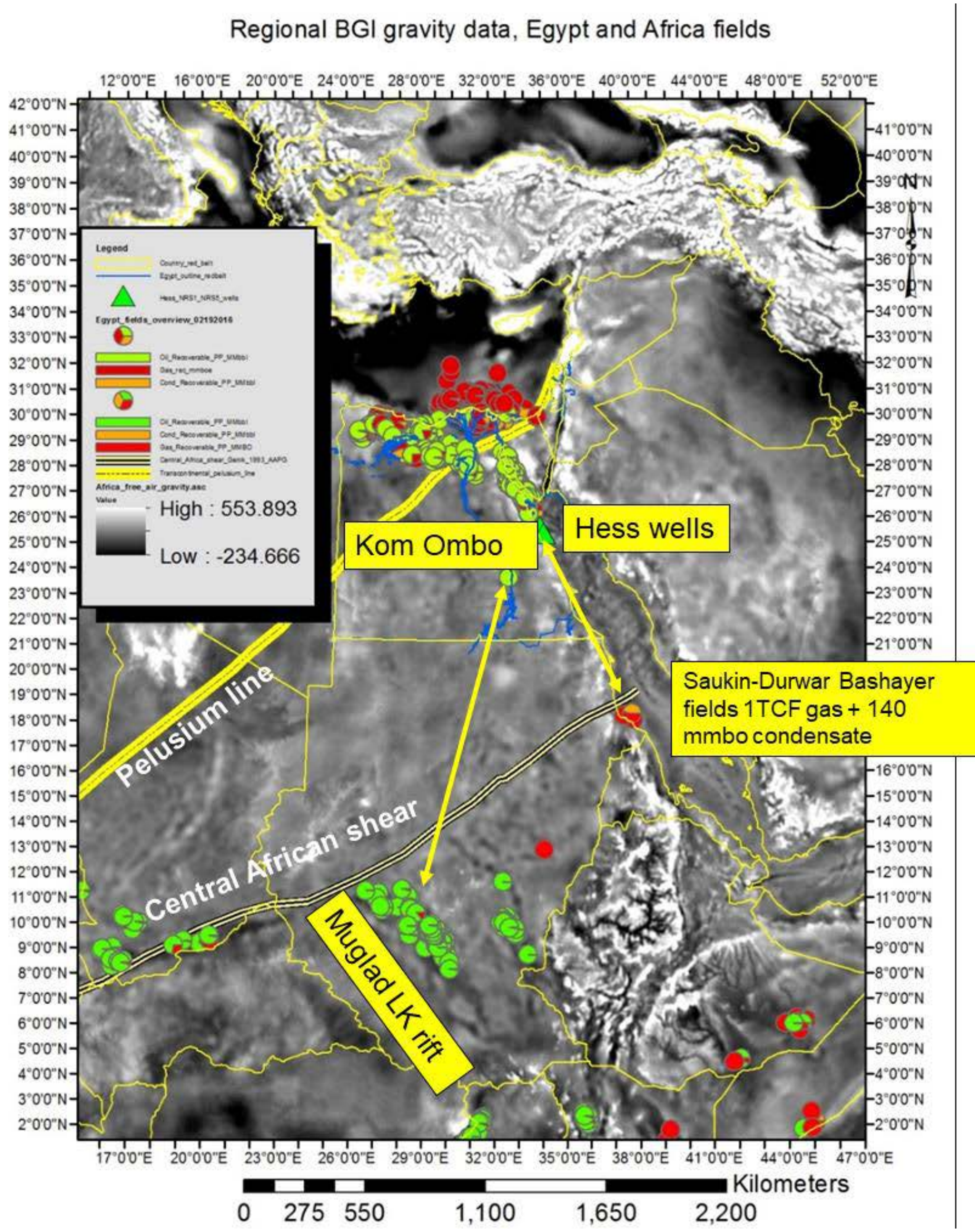


Figure 15. Rift trends left in Egypt (exclusive of the Western Desert). Extensions of Gulf of Suez to the Red Sea have proven uneconomic. The Kom Ombo Basin in Upper Egypt is a fairly unexplored Lower Cretaceous rift that has proven difficult to monetize.



Choice 1: new basins in Upper Egypt or Red Sea

- Upper Egypt-Red Sea poorly understood
- Nearest analog production-Red Sea
  - 900 KM SE of Hess wells
  - This ought to work somewhere!
- Nearest analog production to Kom Ombo
  - Central Africa Lower Cretaceous rifts
    - 1400 KM SW at Muglad Basin, Sudan

Figure 16. The Red Sea offers a huge area of sub-salt Miocene fault block exploration with oil shows in the north (Hess wells) to the Sauk-Dunaw Bashayer fields in the extreme south. Kom Ombo Basin may have its analog in the Muglad Rift of Sudan.

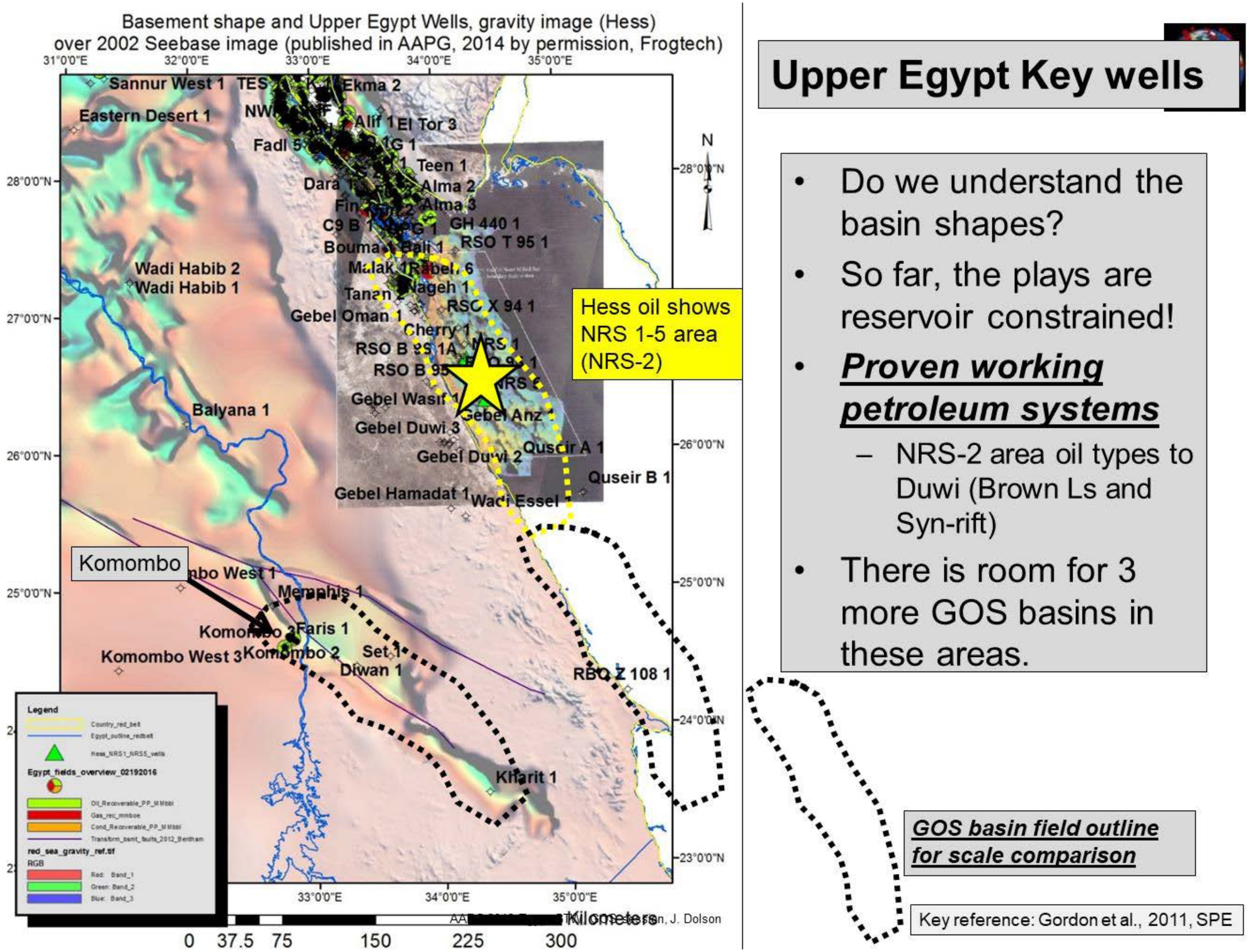


Figure 17. Red Sea and Kom Ombo basin sizes compared to the Gulf of Suez.

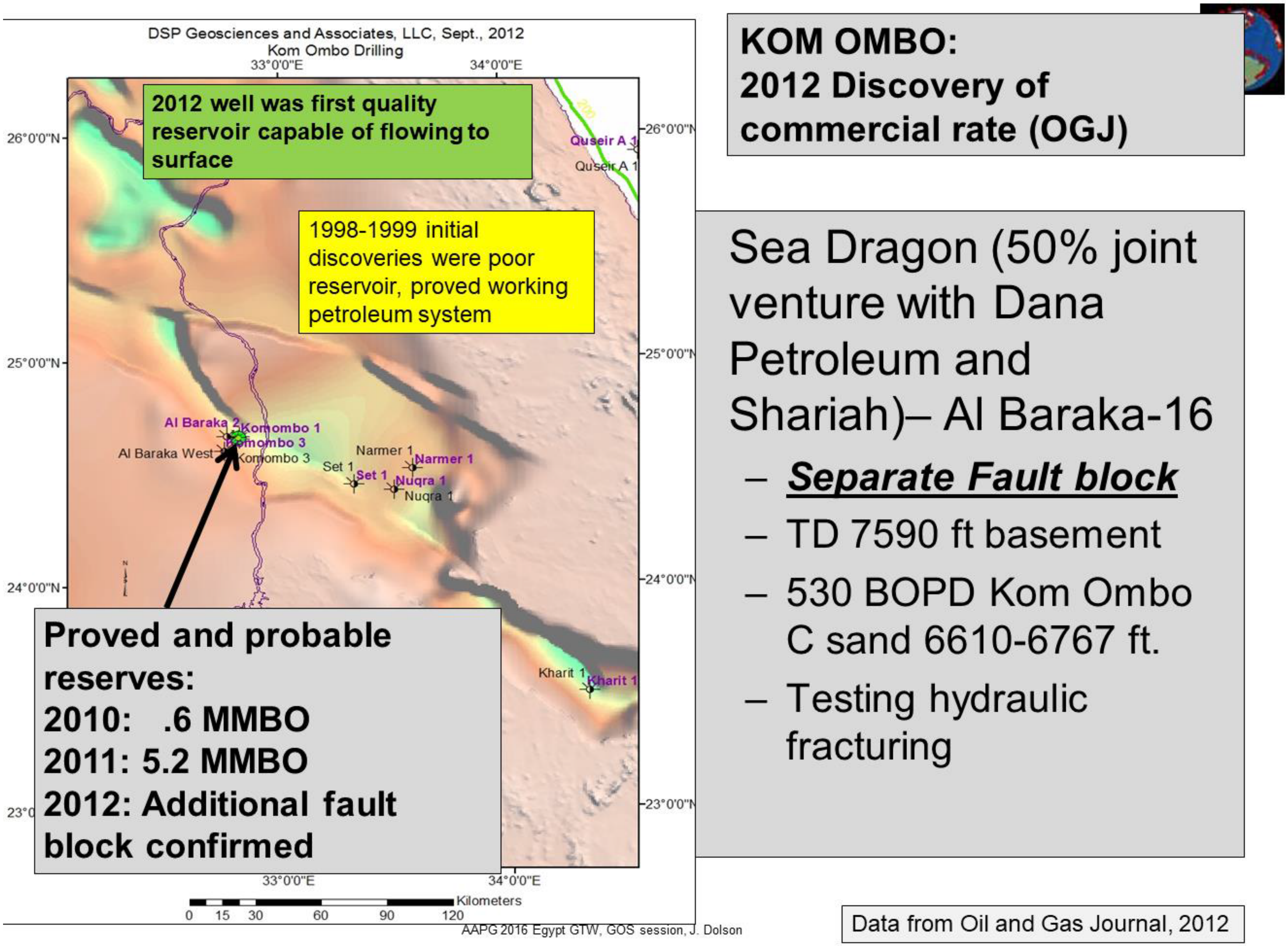


Figure 18. Kom Ombo Basin rough shape. Basin shape and reserves quoted from Editors (2012). Reservoir quality has been low in most wells.

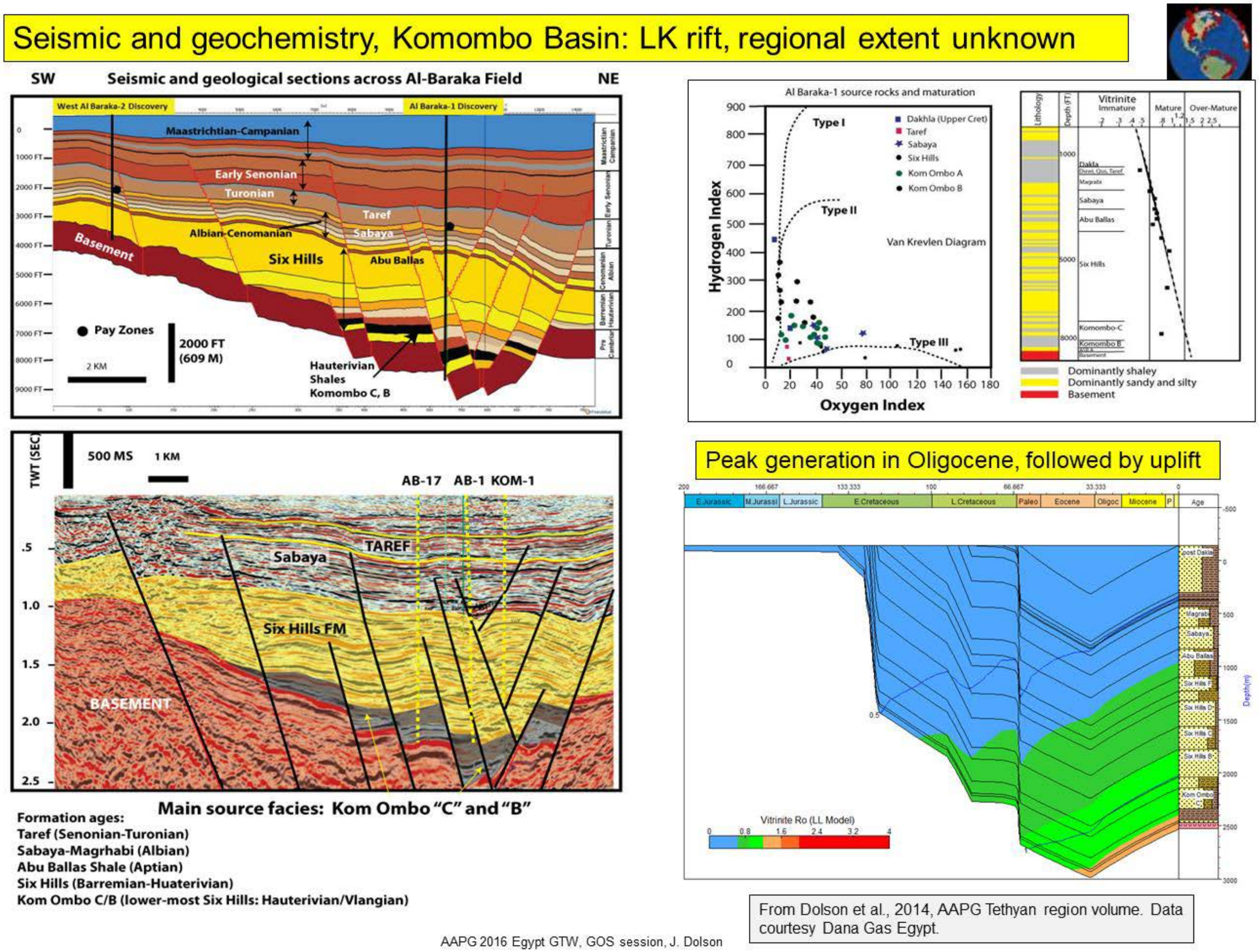


Figure 19. Summary of Kom Ombo structure, stratigraphy and burial history (Dolson et al., 2014).

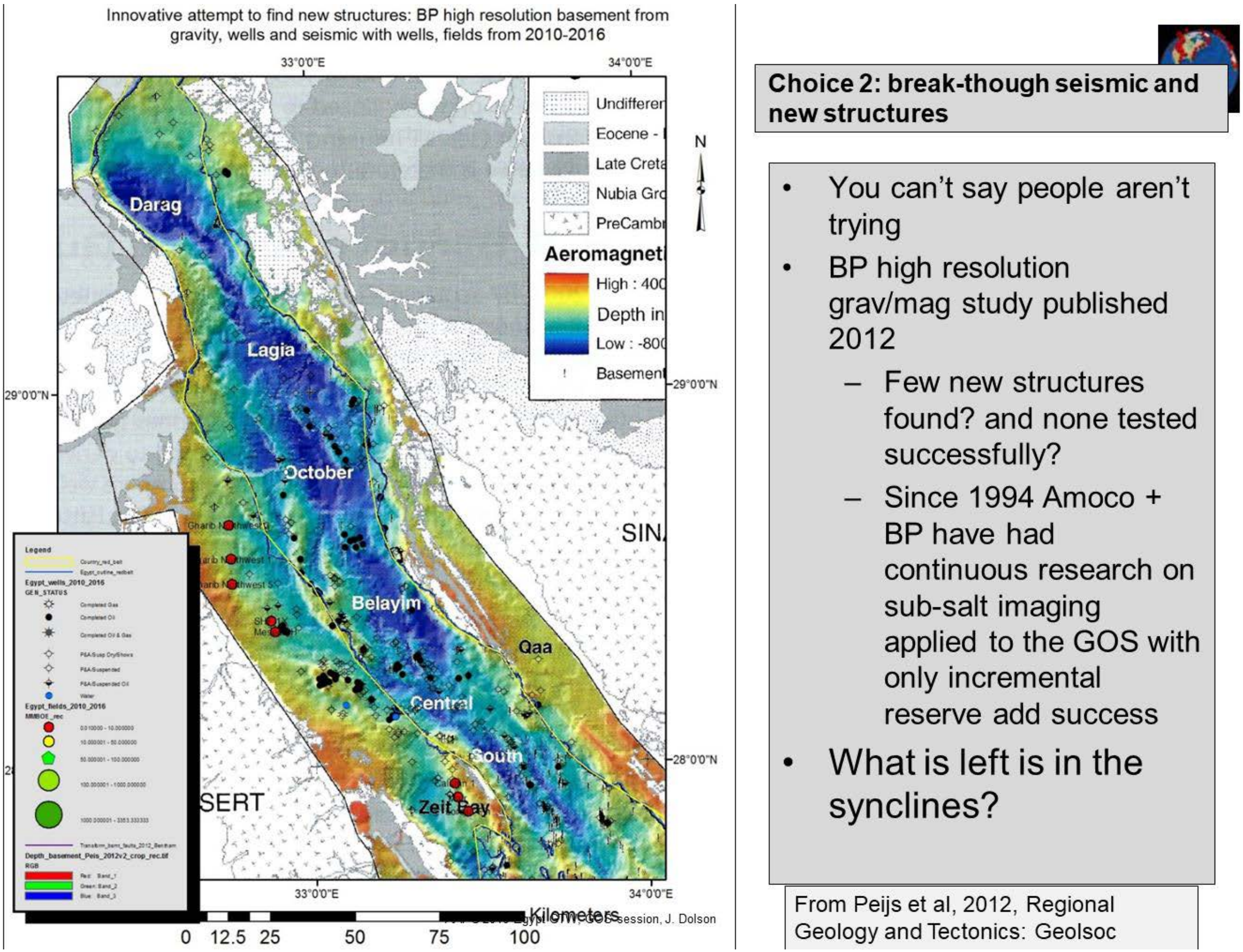
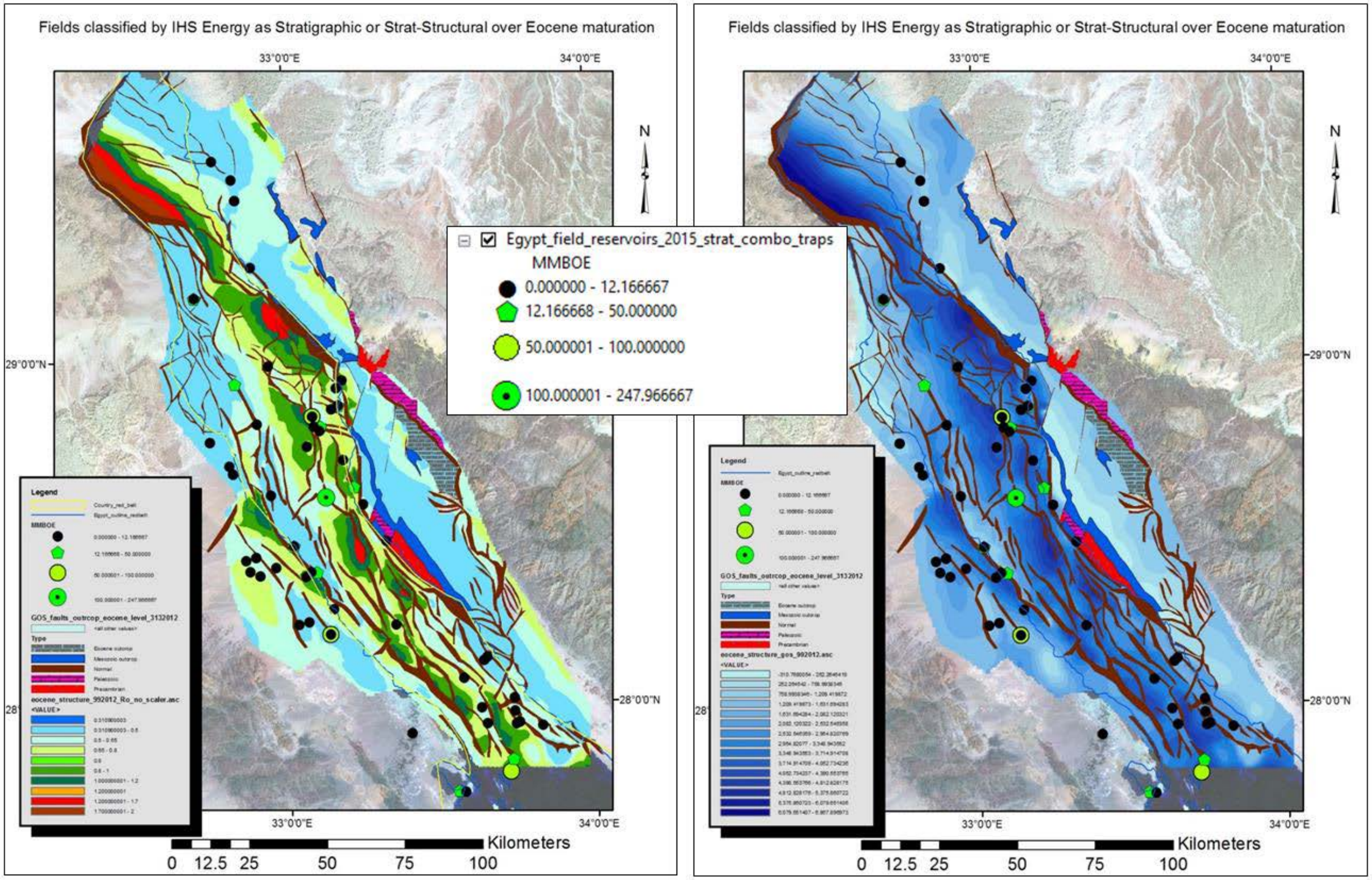


Figure 20. Basement structure in the Gulf of Suez from integrated seismic, wells and gravity (Peijs et al., 2012).

Where are the strat traps? Very small volume relative to structural traps. Most traps simply modification across paleo-highs. Almost no basinal, true flank position successes.



AAPG 2016 Egypt GTW, GOS session, J. Dolson

Figure 21. Top of Eocene maturation (left) and Eocene structural shape, with locations of fields classified as stratigraphic or combination traps (IHS Energy Data, 2016). Red colors on the left are in the gas window; dark green, mature oil window; light blue, immature at the Eocene structural level. Field sizes are consistently shown as small.

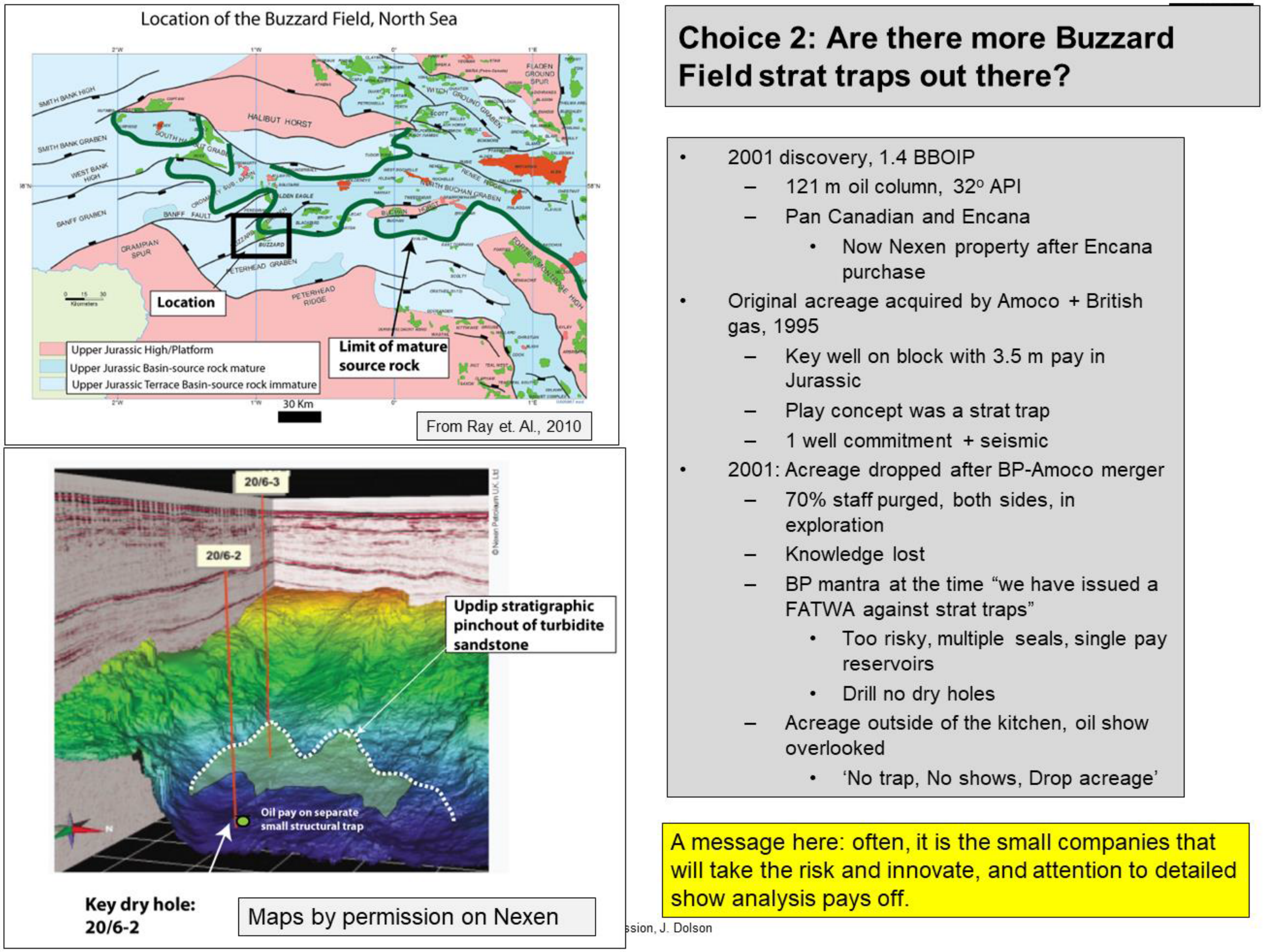


Figure 22. Buzzard Field syn-rift turbidite stratigraphic trap analog, North Sea. Figure from Ray et al. (2010) and summarized as a case history in Dolson (2016). 3D seismic clearly defined the trap pre-drill, a luxury as yet not applied successfully in the Gulf of Suez.

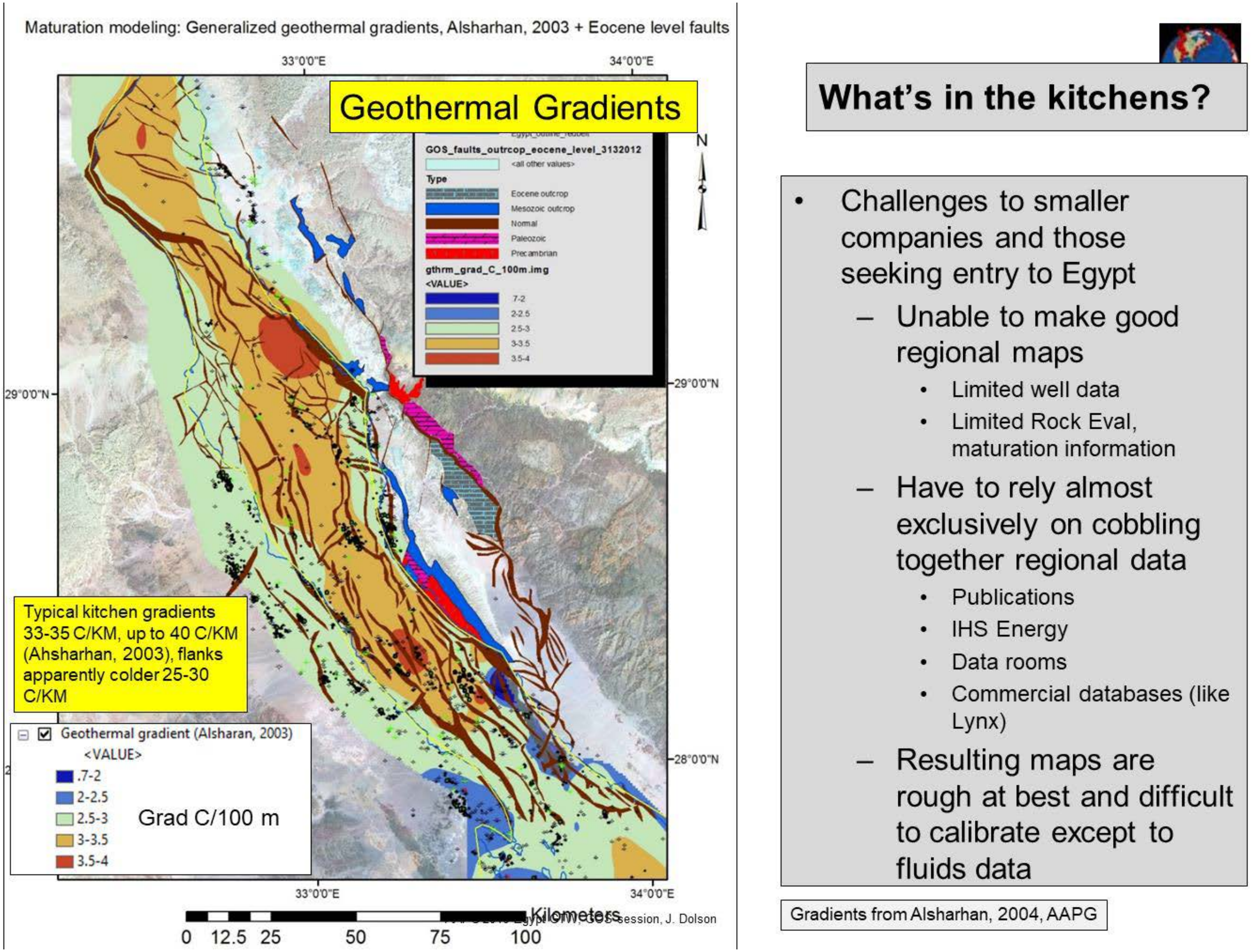
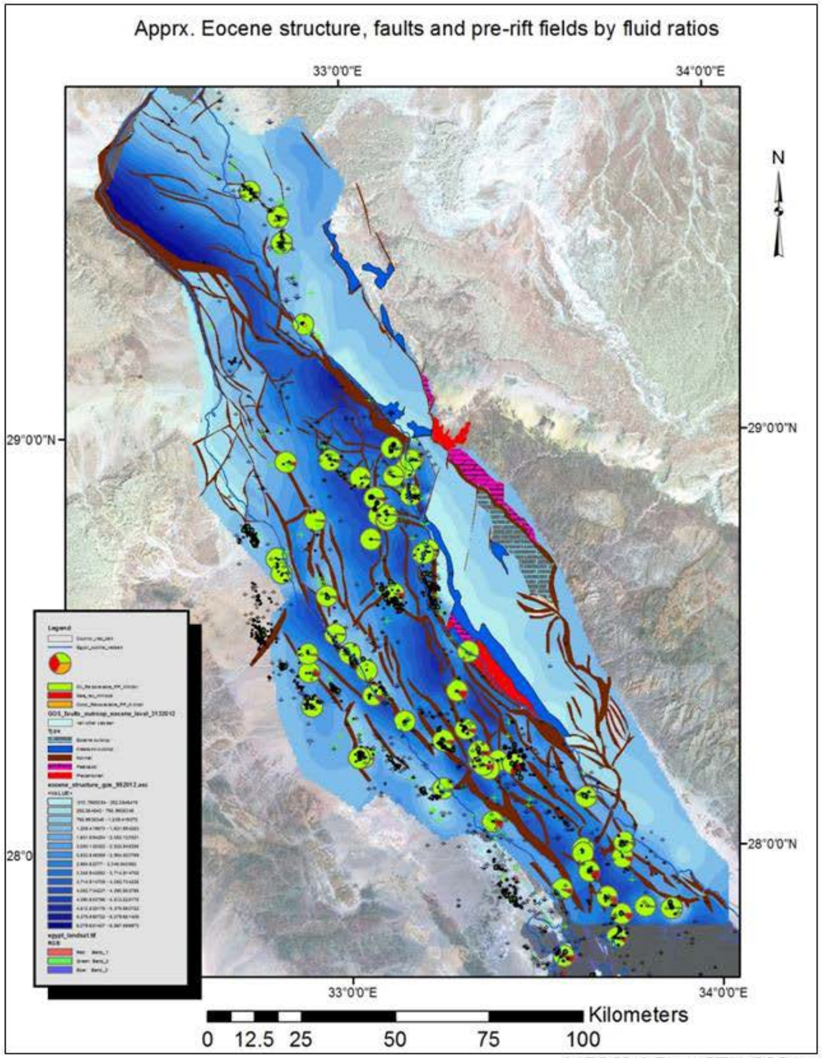


Figure 23. Regional geothermal gradient (Alsharhan, 2003).

It starts by understanding gaps in knowledge



- Eocene structure map source
  - Dolson, 2001, AAPG georeferenced and re-gridded image
  - Not the best or most current view, but ‘it is what it is’.
- Other structural levels build up from published isopachs
- Geothermal gradients from Alsharhan, 2003
- Published literature on source rocks (limited and not underpinned with 1D models)
- Various maturation models tested against field fluid distributions and shows databases

The GUPCO mantra:
“The map is wrong, it is always wrong, the question is, ‘how wrong is it?”

AAPG 2016 Egypt GTW, GOS session, J. Dolson

Figure 24. Pre-rift fields by fluid type and Eocene structural shape.

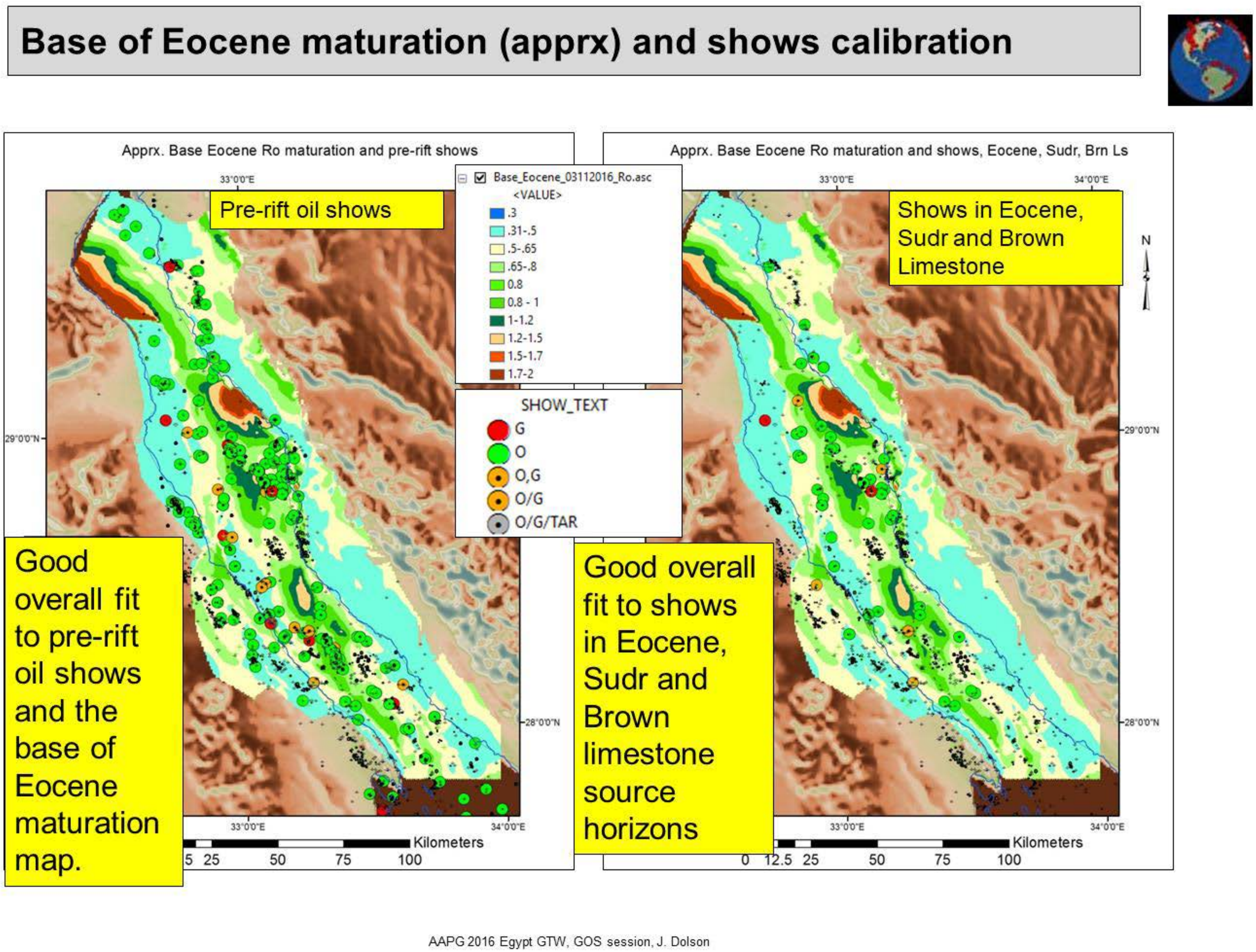


Figure 25. Approximate maturation, top Eocene and oil and gas shows.

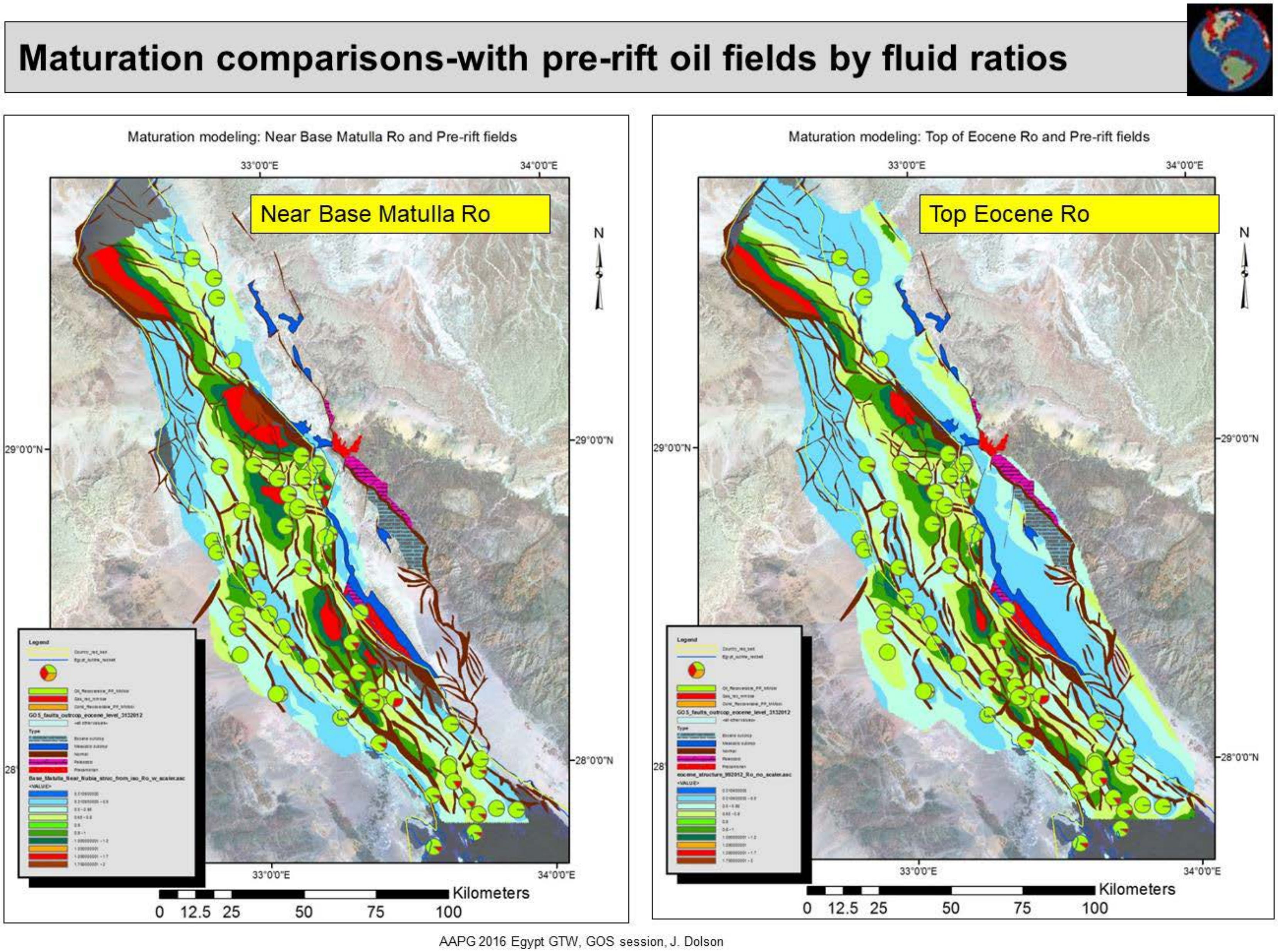
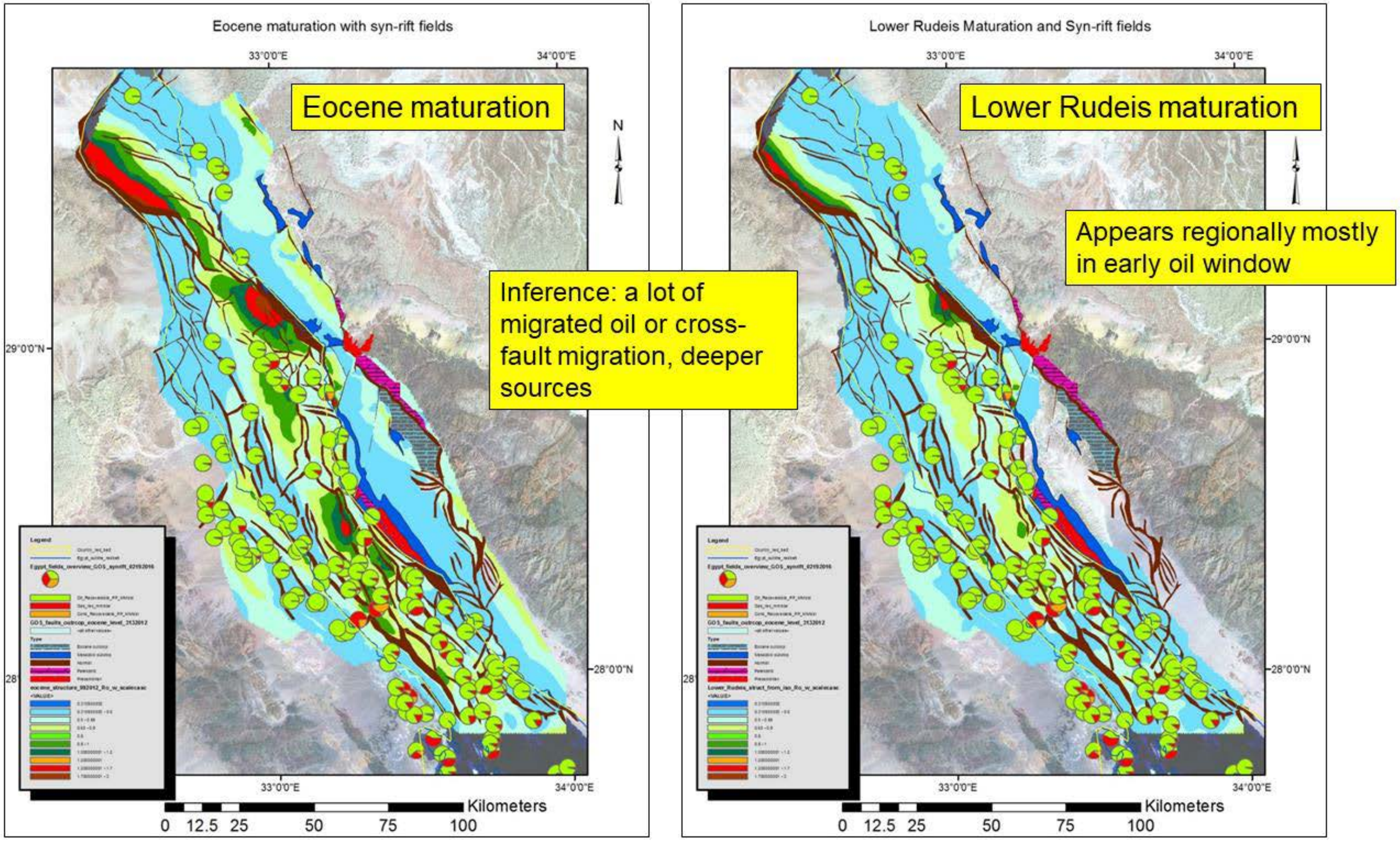


Figure 26. Approximate maturation, near Base of the Matulla, with pre-rift oil fields by fluid ratios.

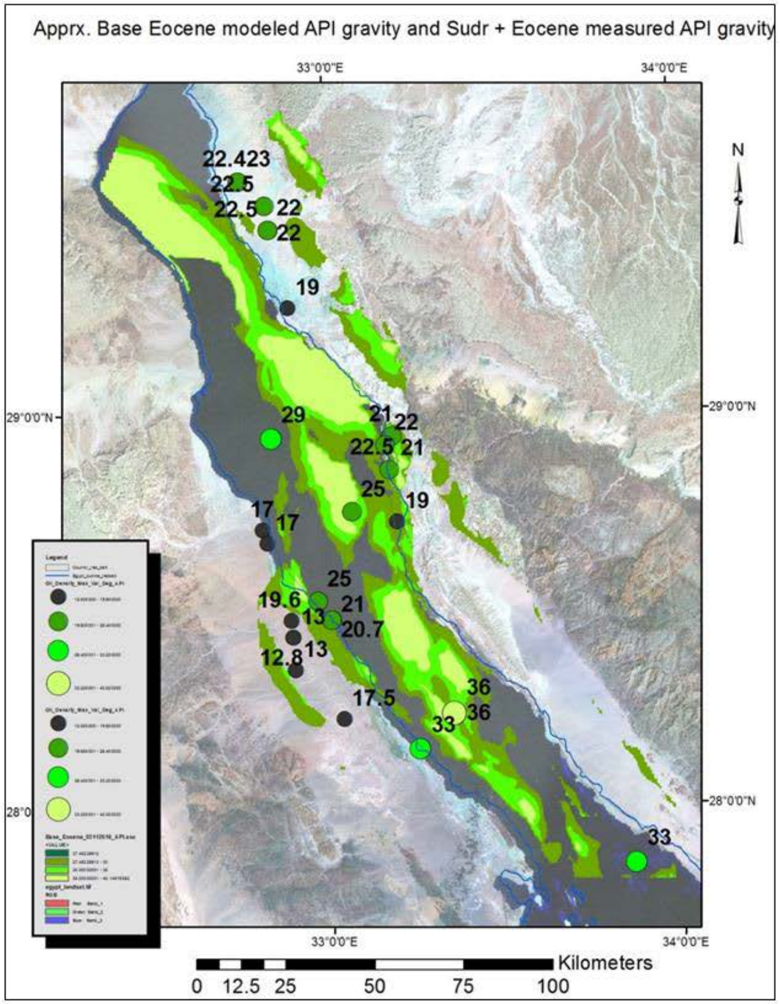
Maturation comparisons with syn-rift fields



AAPG 2016 Egypt GTW, GOS session, J. Dolson

Figure 27. Syn-rift fields overlying Eocene and Lower Rudeis maturation.

API gravity model: base Eocene predicted and measured API gravities, Sudr and Eocene



- Sudr and Eocene API gravities
  - Generally low (12-29) and outside the kitchens
  - Implies fields are laterally migrated, early product or biodegraded
    - Don't provide an analog to 'unconventional' traps
  - Best APIs in southern kitchens

AAPG 2016 Egypt GTW, GOS session, J. Dolson

Figure 28. Base Eocene predicted API gravity and measured API gravity, Sudr and Eocene fields. Dark greens are predicted heavy oil and light greens, lighter oil gravities.

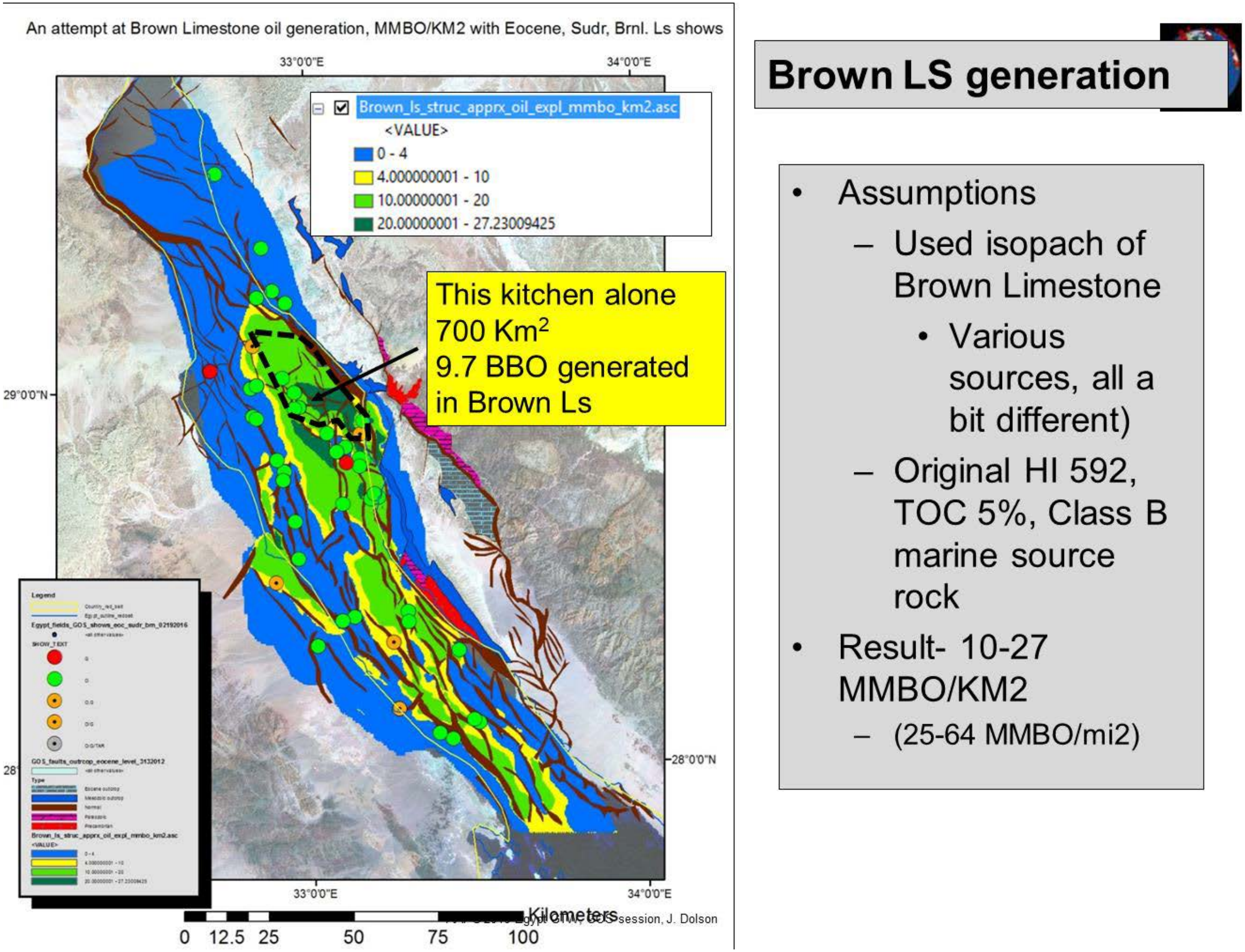


Figure 29. Estimate of Brown Limestone generation Eocene, Sudr and Brown Limestone hydrocarbon shows.

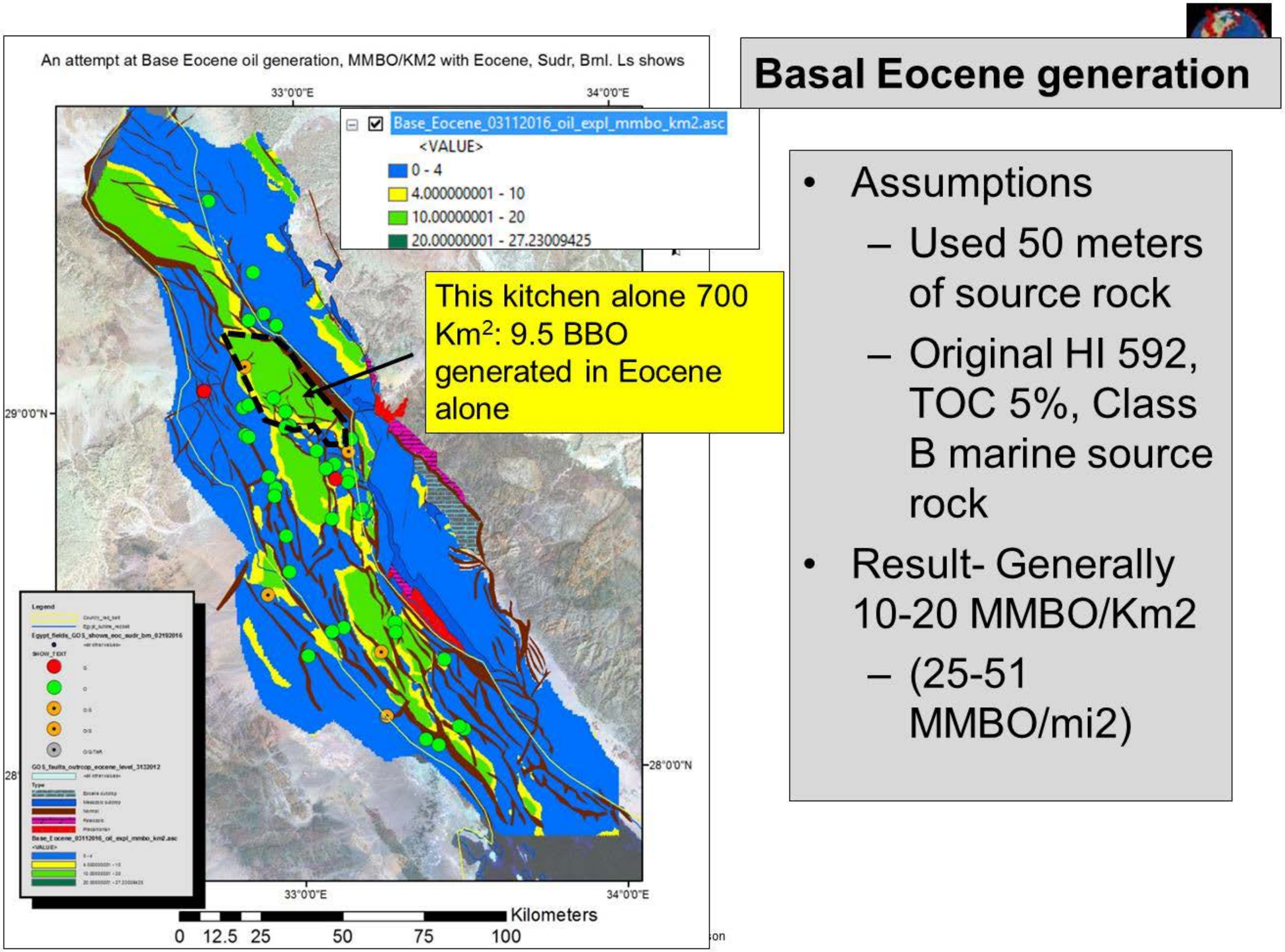
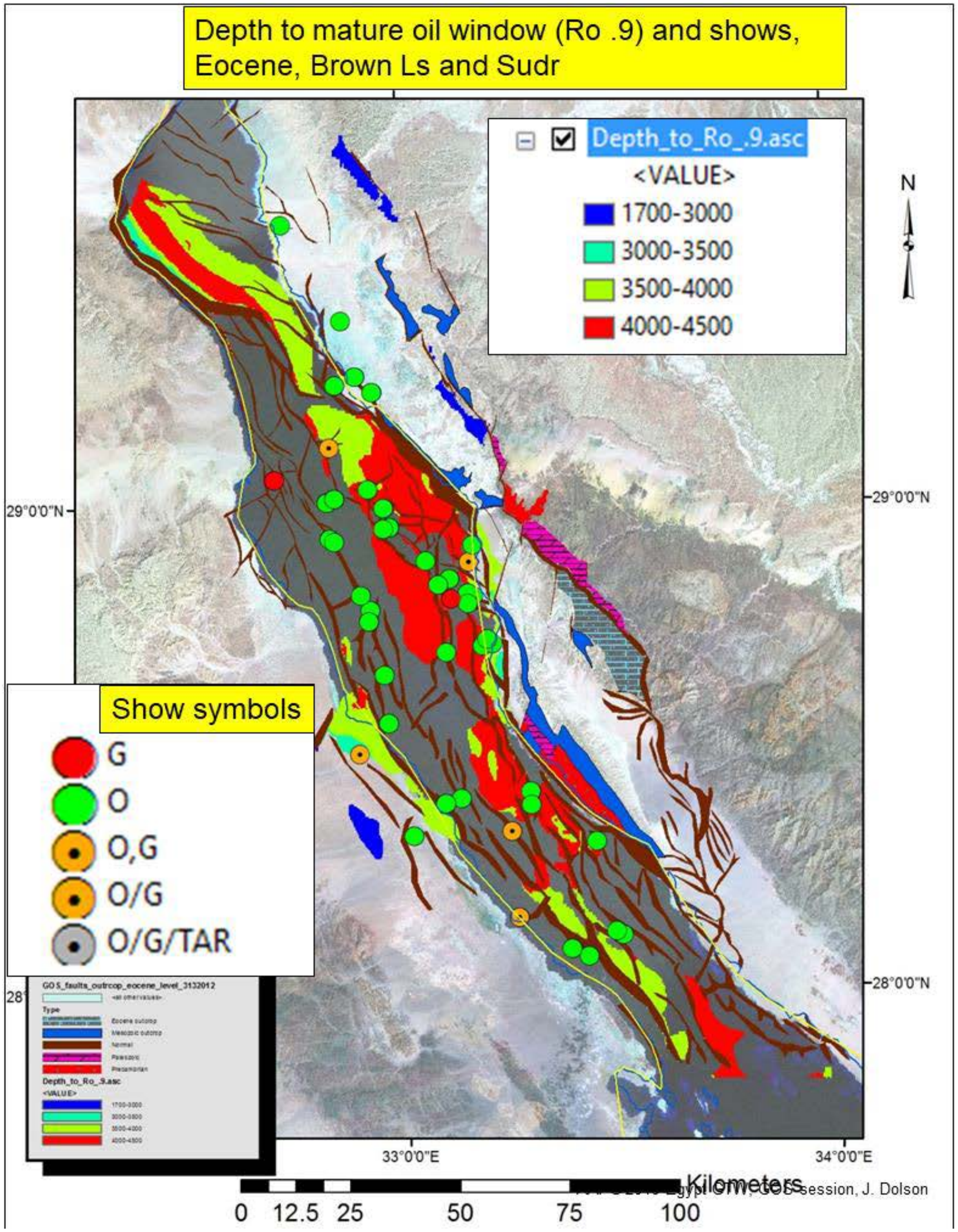


Figure 30. Potential Eocene maturation volumes.



OK-the numbers are big, the areas are big- so what?

- Huge challenges
  - Mature oil window at 3500-4500 meters
  - Changing stress regimes block by block will require different completion techniques
  - Less 'layer cake' stratigraphy than in USA plays
  - Unconventional plays are largely untested in rift settings
  - Economically doesn't make sense at these prices and concession terms
  - Nearly impossible to make good screening maps for companies lacking data
    - (THESE MAPS, HENCE, are ALSO CRUDE)
- Upside
  - Fracture production in Eocene, Sudr proven in conventional traps already
  - Plenty of interbedded brittle zones and source facies
  - World-class source rocks

Figure 31. Depth to mature oil window and oil and gas shows, Eocene, Brown Limestone and Sudr wells and fields.

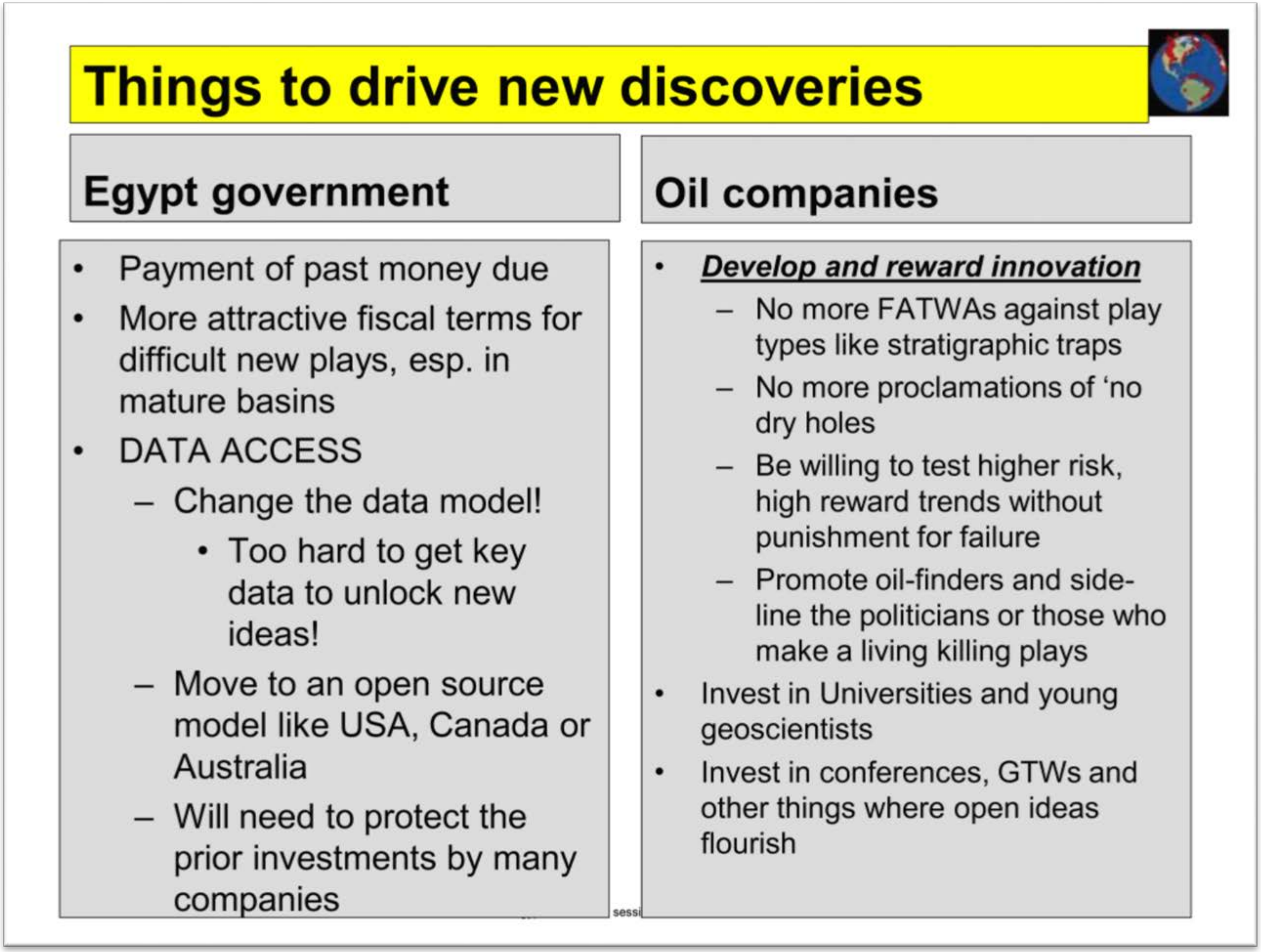


Figure 32. Drivers to new discoveries.