Why Not Both Conventional and Unconventional Exploration in Sub-Saharan Africa?*

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Abstract

Conventional exploration typically progresses through the classic sequence of petroleum system identification, definition of trap, reservoir, seal and timing, and finally drilling and production operations. North American unconventional exploration has followed conventional in established basins, building on petrophysical data in the target source/reservoir interval and ambient pressure/ stress information from a myriad of conventional wells, to produce remnant hydrocarbons using directional drilling and hydrofracking techniques. Data from the conventional provides first-order controls on orientation and stimulation design of unconventional projects. Despite conventional production from several onshore basins, there has been little unconventional activity across Africa. The density of unconventional-supporting data is thin. Yet Africa has numerous prospective basins with Paleozoic through Cenozoic (potential and realized) plays. Like eastern North America, the geology consists essentially of a vast expanse of Phanerozoic epi-cratonic basins that overlie Precambrian crystalline basement. In both cases there are fringing late Paleozoic fold belts, broad foreland basins, and interior block-faulted terranes. Differences include the extent of crystalline basement exposure, some young and active intracratonic volcanic provinces, and the East African Rift System in Africa; North America carries a lower to mid- Paleozoic sedimentary section that reflects more extensive marine flooding. From late Carboniferous onward, however, the evolution of the continental interiors is similar. The similarities suggest that Africa could ultimately develop an indigenous unconventional industry, but conventional plays must mature before the future is clearer. Knowing the criteria for successful unconventional development, African conventional and unconventional (shale and CBM) plays may progress simultaneously, feeding each other's progress. Downhole data may be supplemented by innovative use of geodynamic inferences from tectono-structural and regional sedimentological data. We present results of a detailed, kinematically realistic overlay for the Purdy Memorial Project 'Exploration Fabric of Africa', highlighting previously hidden potentially conventional-unconventional coupled onshore plays. One example lies in northeast Namibia where new interpretations suggest hidden basins under Etendeka basalts and Kalahari sands.

Introduction

The revolution known as unconventional exploration and production began in North America with the application of two innovations, hydraulic fracturing and horizontal drilling, to mature if not post-mature basins where conventional production of hydrocarbons had been going on for decades if not a century (Figure 1). Data and experience developed during the conventional development of interior basins had provided the feedstock for the initiation of unconventional approaches. As of 2017, virtually all of the intra-cratonic and foreland basins in North America have at least been evaluated for such enhanced production, and many are advanced in their development as unconventional plays. Africa, on the other hand, suffers from severe immaturity in most onshore exploration plays. Of late, important offshore discoveries in East Africa and northwest Atlantic Africa have augmented the traditional West African provinces and changed the trajectory of African production. Onshore a beginning of conventional exploration has been made in the East African Rift basins, and continued production in the traditional plays along the Central African Rift and Shear system has matured, but nowhere near to the point of North American basins. Otherwise, onshore sub-Saharan Africa remains simply not evaluated for either conventional or unconventional potential. Only a rudimentary database of unconventional-relevant production data (e.g. hydrocarbon type, kerogen maturity, shale brittleness, pressure, etc.) has accumulated for African basins. Clearly, both conventional and unconventional technology is available for the future development of Africa, and both approaches can be synergistic to each other and simultaneously advantageous to explorers.

North American and Africa Geological Parallels

In many ways, the geology of sub-Saharan Africa resembles that of cratonic interior North America, which leads us to the thesis that exploration for and the development of hydrocarbon resources onshore in Africa may likely follow a two-track path forward, what we are calling a dual- focus. That bimodal focus may ultimately fuel indigenous energy development, specifically electricity generation, which is beginning in some countries. Figure 2 outlines the concept and defines some terms we will use subsequently here, and Figure 3 outlines the risks to exploration as we see them that are involved in this approach. The advantage is that the best of modern technology on both conventional and unconventional fronts can be applied, thus maximizing the probability of success in inherently risky ventures. The biggest risks as we see them are not technological but rather derive from economic and political uncertainties.

Figure 4 shows a comparison of some Paleozoic gas-productive shale basins in interior North America that have developed unconventional plays in comparison to a similarly-scaled portrayal of Karoo (Permo-Carboniferous) basins in sub-Saharan Africa. Their intra-cratonic character can be seen by the scatter across the continents, but also a similar foreland basin relationship to the Appalachians and to the Cape fold belt is evident. Even taking into consideration only the Karoo, which is the most likely unconventional play in Africa, it is evident that the area of potentially prospective basins is large and maybe even exceeds North American basins, depending on how one counts the acreage. The stratigraphy of the North American examples spans a larger sweep of geological time, and are covered by post-Paleozoic sediments to a greater extent, so the comparison is only an order of magnitude one. The point here is that both NA and Africa are intra-cratonic realms overlying Precambrian crystalline basement with shale-bearing sections of broadly comparable ages.

The degree to which the stratigraphy sub-Saharan Africa bears not only Permo-Carboniferous but also older Paleozoic prospective sections is shown in Figure 5. The classic Paleozoic section of South Africa has been depicted by the University of Manchester (http://www.sees.manchester.ac.uk/our-research/research-areas/pes/basin-studies-), on the left, is compared with the Namibian section from Hoak et al. (2014) on the right. A lower Paleozoic section is present in South Africa that is not present in Namibia, nor is commonly recognized elsewhere in southern Africa. Ordovician, Silurian, and Devonian sections parallel the typical situation in North America, and recall that the Devonian is a major source/reservoir component of unconventional play area in North America, such as the Barnett or Bakken. The efficacy of the source rock intervals in all these units in Africa is poorly constrained and the maturity levels, as is the case in North America, vary widely. Some of that information has been summarized in USGS assessment reports (Brownfield, 2016; USGS, 2012, 2016a, 2016b, 2017) (Figure 6), but note their focus on offshore reserves with regard to conventional plays.

The USGS treatment of southern African petroleum potential is incomplete in that it does not reflect the complete distribution of Paleozoic sedimentary rocks or even Karoo sediments. A quick comparison of the distribution of Karoo in Figure 4 and Figure 6 illustrate the incompleteness of the assessment, but that is entirely a result of the fact that the rocks are poorly known, not an intentional neglect. The Karoo in eastern Africa is fairly well known, if unexplored for hydrocarbons, where it outcrops extensively in extensional basins. West of southern Zambia, however, the Karoo distribution is sketchy and confined to subsurface encounters in a few wells and outcrop along inliers of Precambrian exposure. In connection with a project we call the 'Tectonic Fabric of Africa' (TFA) we have begun to detail a wider distribution of tectonic elements of Paleozoic age in southern Africa that imply a much wider possibility of prospective basins. This project is a compilation of tectonic elements in southern Africa, as an overlay to the Purdy Memorial Project 'Exploration Fabric of Africa' (EFA; http://www.efafrica.com/). The purpose of that project is to compile a kinematically sound interpretation of fault systems in relation to the Phanerozoic basins and their distributions of sedimentary sections, on an African-wide basis.

Figure 7 is an example of the TFA products. Shown in red are elements of the Central African Shear Zone (CARZ), and other strike-slip elements of the mega-system, such as strike-slip elements of the Benue Trough. Shown in blue are the faults of the extensional elements of the Central African Rift System, such as the rift basins in Sudan and Niger, as well as the Doseo Basin, a pull-apart basin along the CASZ. Basement outcrop is shown in pink and the thickness of the sedimentary section is shown in the background colors, reds being thickest and the blues thinnest. These data are from the DIGS Marimba project (http://www.digsgeo.com/MARIMBA.html). The Central African systems are dominantly Cretaceous in age, so not strictly parallel to the Paleozoic North American analogy here, but each of these basins may also be subject to unconventional approaches, as have been several basins in North America of similar ages, e.g. the Denver/Julesburg basin in NE Colorado where the Niobrara play is an active and prolific unconventional play that is successor to a conventional one.

Sub-Saharan Exploration Basins

Returning to sub-Saharan Africa, Figure 8 shows the results of two exploration efforts by Instinct Energy and Reconnaissance Energy International that have added to the TFA. Specifically, they have added two tectonic elements or basins along what we call the Southern Trans-African Rift and Shear System ('STARSS'). Instinct Energy mapped a set of NE-trending faults in the Caprivi panhandle of Namibia, part of which is a contemporary fault with a surface scarp that is an element in the actively extending, largely subsurface Okavango Rift system (Bufford et al., 2012). The other faults suggest a strike-slip related basin (the 'Caprivi Basin') that lies along the same trend as the Zambezi Belt, Chimaliro Fault, and Mwembeshi shear zone in Zambia (Daly, 1988; Daly et al., 1989; Versfelt and Rosendahl, 1989) (Figure 9). Those features connect eastward into the Karoo Basins of eastern Zambia, Malawi, Mozambique, and Tanzania. The inference here is that the Neogene Okavango Rift is a reactivation of pre-Tertiary structures that trend in a westerly orientation.

The second feature is a deep basin in north-easternmost Namibia, where Reconnaissance Energy Int'l has several blocks, that was detected in an inversion of high-resolution aeromagnetic data. This previously unknown basin, hidden under Etendeka (Cretaceous) basalts and Kalahari surficial, mostly sandy, deposits is called the Kavango Basin. To the west, the Kavango feature lies along the extension of the tectonic elements of the Damara (Neoproterozoic) fold belt and lineaments related to it. Figure 9 illustrates how these two basins fit into the big picture, essentially 'transforming' the Owambo basin in northern Namibia to the elements of the Karoo system in the east.

The Kavango Basin was discovered during a Werner inversion of the regional high-resolution aeromagnetic survey obtained by Reconnaissance as a legacy data set when the contract was signed. Bill Cathey of Earthfield Technology (Houston) performed the inversion and produced the depth to basement map shown in the upper right of Figure 10. A number of profiles were produced, such as that in the upper left of Figure 10 that shows the frequency spectra for the shallow Etendeka basalts (the red curve) and for the basement (black). Cathey resolved these into a prediction of the depth to basement (red) and the base of the cover rocks (green). The senior author then constructed 'theoretical' structure sections parallel to those basement curves, using the top-of-basement as hard data (error on the depth is +/- 10%) and average regional thicknesses for a generalized stratigraphy to create cross sections, an example of which is shown in the lower section in Figure 10. Attempts were made to tie these sections and determine a notional direction of extension by applying restoration techniques in LithoTect™ structure modeling software from Landmark. The most successful attempts at that effort used a domino-structural style oriented in the NE-SW direction, as shown in Figure 10. Note the depth to basement in this basin exceeds 7 km in places, and that the basin is elongate in the direction of extension parallel to the regional lineament/shear zone systems. Connecting the elements from the Karoo overlying the Damara Precambrian rocks in Namibia across Africa to Zambia and Malawi suggests a set or shear systems dating originally from the Precambrian but importantly reactivated by Permo-Triassic and likely Cretaceous tectonic activity. Evidently, there is a set of basins similar to the Doseo Basin in Chad along STARSS, as well as strictly rift basins, such as the Karoo Basins and other potential but poorly understood basins. Examples of less well-understood basins are inferred in Figure 9 as especially thick sedimentary sections shown in reds and yellows of the Marimba project (e.g. westernmost Zambia, neighboring Angola, or Botswana-Zimbabwe). None of these has been explored to any degree, even with regional reconnaissance seismic data.

The point here is that there is unrealized exploration potential throughout southern Africa that could be exploited using traditional conventional techniques, but also may be as or more amenable and productive if approached from an unconventional point of view. Or both. Very little has been done to evaluate these possible resources, but given the impending economic growth in southern Africa, both points of view may well be of value to the host governments.

Economies of Southern Africa

What about the age-old problem of markets for hydrocarbon production? If the geology is broadly similar, the economies of Africa and North America could not be more different. In North America, the rise of unconventional resources has reversed the decline of oil and gas development and is poised to reverse the dependence on imported hydrocarbons, even to promote exports from North America. This has happened in the context of a well-developed world-class economy, and hence fed into a fully functional infrastructure. Africa on the other hand is quintessentially a part of the developing world, but by many estimates poised to show explosive growth (on a percentage basis) in economic development and particularly of electricity demand. Figure 11 shows a graphic to impress the point of the difference in electrical usage between the 'northern countries' and Africa: on the left is an orbital shot of Africa, Europe, and western Asia at night. Note only a few of the capital cities in Africa show up in the image, and the only bright spot is around Johannesburg in South Africa, testifying to the low usage of electricity.

On the right in Figure 11 is a plot of the growth of the Human Development Index for a number of regions through 2004 (https://en.wikipedia.org/wiki/Human_Development_Index). Note that sub-Saharan Africa has perennially lagged behind even other parts of the developing world not only in absolute HDI but also in its growth. Seko (2016), among others, however, has pointed out that African economic growth has been greater than the world average since 2000, but that it faces many challenges to sustainability. One of the major ones is to make the nations both producers of resources as well as consumers, and to build infrastructure. Implicit behind the needs for growth is the need to cultivate and grow indigenous sources and uses of electricity, which arguably is one of the most important measures and means out of poverty and into economic viability (Figure 12). Insofar as one of the major products of unconventional exploration has been gas, the economic outlook of southern Africa would suggest a nascent demand for natural gas as a feedstock for electrical generation, and oil for the development of indigenous industry. Historically, oil and gas development, particularly offshore, has been regarded as an export industry and a source of foreign exchange.

Kenya is a good example of what the future may hold. One of the largest countries population-wise in sub-Saharan Africa, Kenya has started to address its power needs with modern high-efficiency installations, notably the Olkaria Geothermal Plant in Hell's Gate National Park (Figure 13). Kenya ranks 10th worldwide in geothermal energy production and is on its way to realize the goal of 70% satisfaction of power demand from geothermal resources. This plant takes advantage of the natural blessing of a relatively unusual resource, but it illustrates how an indigenous resource can be translated into the basis of modernization through development of a state of the art power generation facility. This sort of project could just as easily be a high-efficiency gas powered plant utilizing local fossil fuel resources, especially if it is coupled with carbon capture technology. These plants can and are being distributed in a decentralized grid.

Barriers and Risks

Despite the obvious and long-standing barriers of strongman politics, corruption, and tribalism that have held back African economic development since independence, globalism brought on by population growth and modern social media exerts pressure for upward mobility of African populations and thus a demand for the foundation of continuous and affordable electricity. Both conventional and unconventional development can result in oil discoveries and reserves growth, which can obviously contribute to industrial development, but three major barriers to dual-focus exploration programs exist (Figure 14):

1. Operational infrastructure: pursuing both sides of a dual-focus plays is expensive, as they require somewhat separate operational equipment. Given that mobilization and de-mobilization costs can be expensive in southern Africa, it can be a prohibitive expensive to pursue both.
2. Market considerations: dual-focus exploration can equally result in gas and/or oil/condensate discoveries. Oil and condensate can be fed into the export minded game plan for the countries involved, but gas resources are often considered to be stranded. Gas is the cleanest fossil fuel to drive electrical development. Operators, however, face the timing conundrum of gas discovery versus infrastructure installation to use the gas. Substituting gas for other feedstock of mini-grids or the installation of brand new regional grids is a real market consideration.

3. Operators interested in unconventional programs also face a more mundane risk that the legal infrastructure may not exist, or is covered by a separate hydrocarbon law (a mining law, for example, rather than a hydrocarbon exploration law), which may lead to complications in terms of contract satisfaction.

Cooperative energy generation and hydrocarbon exploration programs are not normally in the business plan for foreign contract operators, so that the most fundamental problem may lie in altering both governmental and contractor perspectives from an export attitude to a partnership for in-country development to capitalize on resources.

Conclusions

The geology of Sub-Saharan Africa in many ways is similar to interior North America in that a number of Paleozoic basins lie atop Precambrian basement. The extent that this is so is yet to be fully realized. At this moment in time both undeveloped conventional plays are likely to lie undiscovered which might also be approached from an unconventional point of view. In North America, the two have had a sequential history, the unconventional being made possible by the application of conventionally acquired know-how and data to hydraulic fracturing and horizontal drilling feeding into a mature economy. In Africa, it would seem prudent to consider both possible at the outset. Insofar as Africa stands prone to capitalize on potential onshore oil and gas reserves in accelerating modernization, such a dual-focus exploration program should be considered a partnership between operators (perhaps indigenous) and governments within the scope of comprehensive economic development programs.

Acknowledgments

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References Cited

Brownfield, M.E., 2016, Geologic Assessment of Undiscovered Hydrocarbon Resources of Sub-Saharan Africa: Digital Data Series 69-GG, U.S. Dept. Interior, U.S. Geological Series, and papers therein.

Bufford, K.M., E.A. Atekwana, M.G. Abdelsalam, E. Shemang, E.A. Atekwana, K. Mickus, M. Moidaki, M.P. Modisi, and L. Molwalefhe, 2012, Geometry and faults tectonic activity of the Okavango Rift Zone, Botswana: evidence from magnetotelluric and electrical resistivity tomography imaging: Jour. African Earth Sci., v. 65, p. 61-71.

Daly, M.C., 1988, Crustal shear zones in central Africa: a kinematic approach to Proterozoic tectonics: Episodes, v. 11, p. 5-11.

Daly, M.C., J. Chorowicz, and J.D. Fairhead, 1989, Rift basin evolution in Africa: the influence of reactivated steep basement shear zones: in M.A. Cooper and G.D. Williams, (eds), Inversion Tectonics, Geol. Soc. Spec. Pubs 44, p. 309-344.

Hoak, T.E., A.L. Klawitter, C.F. Dommer, and P.V. Scaturro, 2014, Integrated Exploration of the Owambo Basin, Onshore Namibia: Hydrocarbon Exploration and Implications for a Modern Frontier Basin, Search and Discovery Article #10609, Web Accessed February 3, 2018, http://www.searchanddiscovery.com/documents/2014/10609hoak/ndx_hoak.pdf

Seko, M., 2016, Development in Africa is on a firm footing-here's how to take it to the next level: The Conversation, 21 December 2016.

United States Geological Survey, 2012, Assessment of Undiscovered Oil and Gas Resources of Four East Africa Geologic Provinces, Fact Sheet 2012-3039.

United States Geological Survey, 2016a, Assessment of Shale-Gas Resources of the Karoo Province, South Africa and Lesotho, Africa, Fact Sheet 2016-3038.

United States Geological Survey, 2016b, Assessment of Permian Coalbed Gas Resources of the Karoo Basin Province, South Africa and Lesotho, Fact Sheet 2016-3103.

United States Geological Survey, 2017, Assessment of Coalbed Gas Resources of the Kalahari Basin Province of Botswana, Zimbabwe, and Zambia, Africa, Fact Sheet 2017-3003.

Versfelt, J., and B.R. Rosendahl, 1989, Relationships between pre-rift structure and rift architecture in Lakes Tanganyika and Malawi, East Africa: Nature v. 337, p. 354-357.

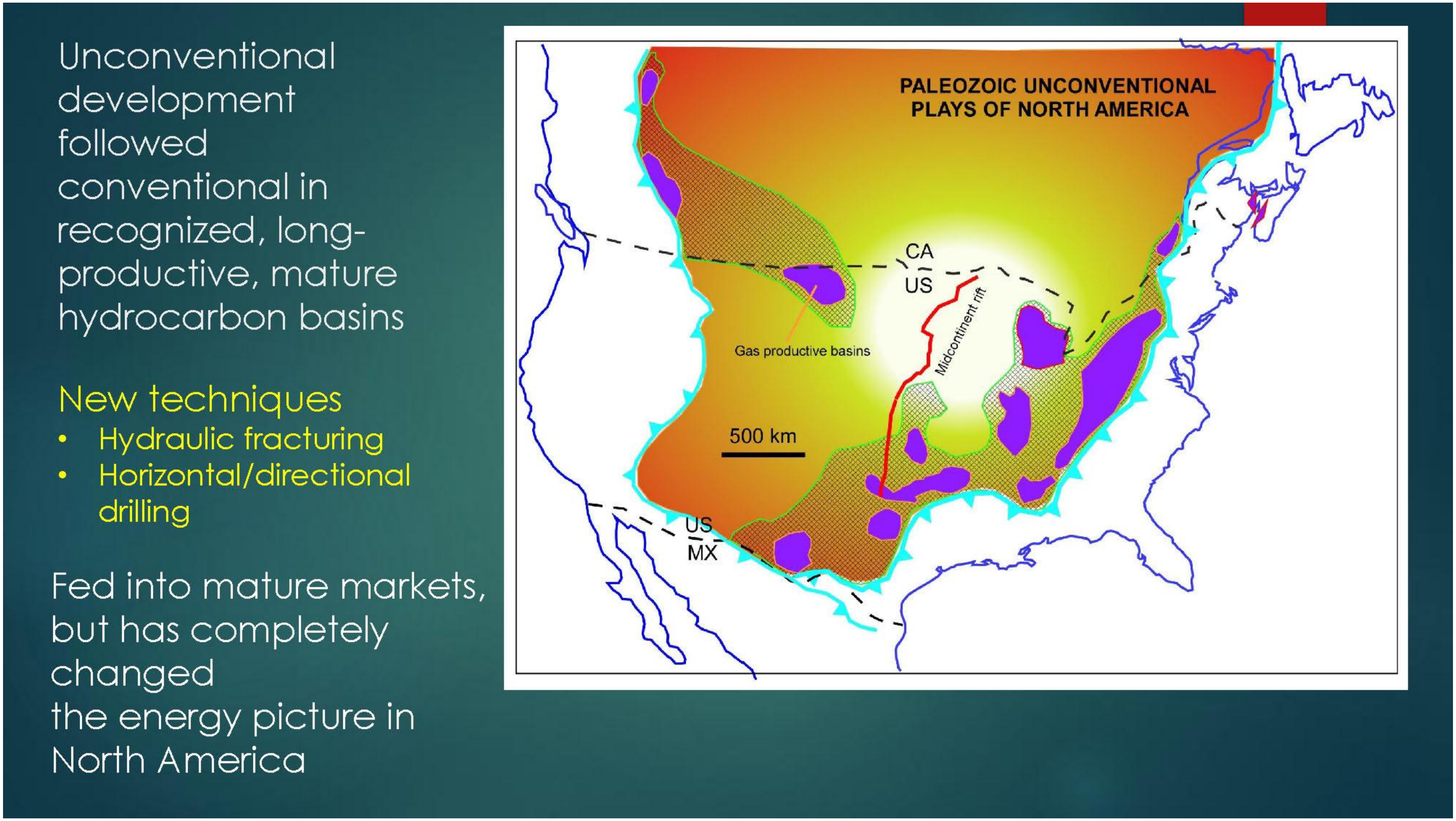

Figure 1. North American unconventional basins.

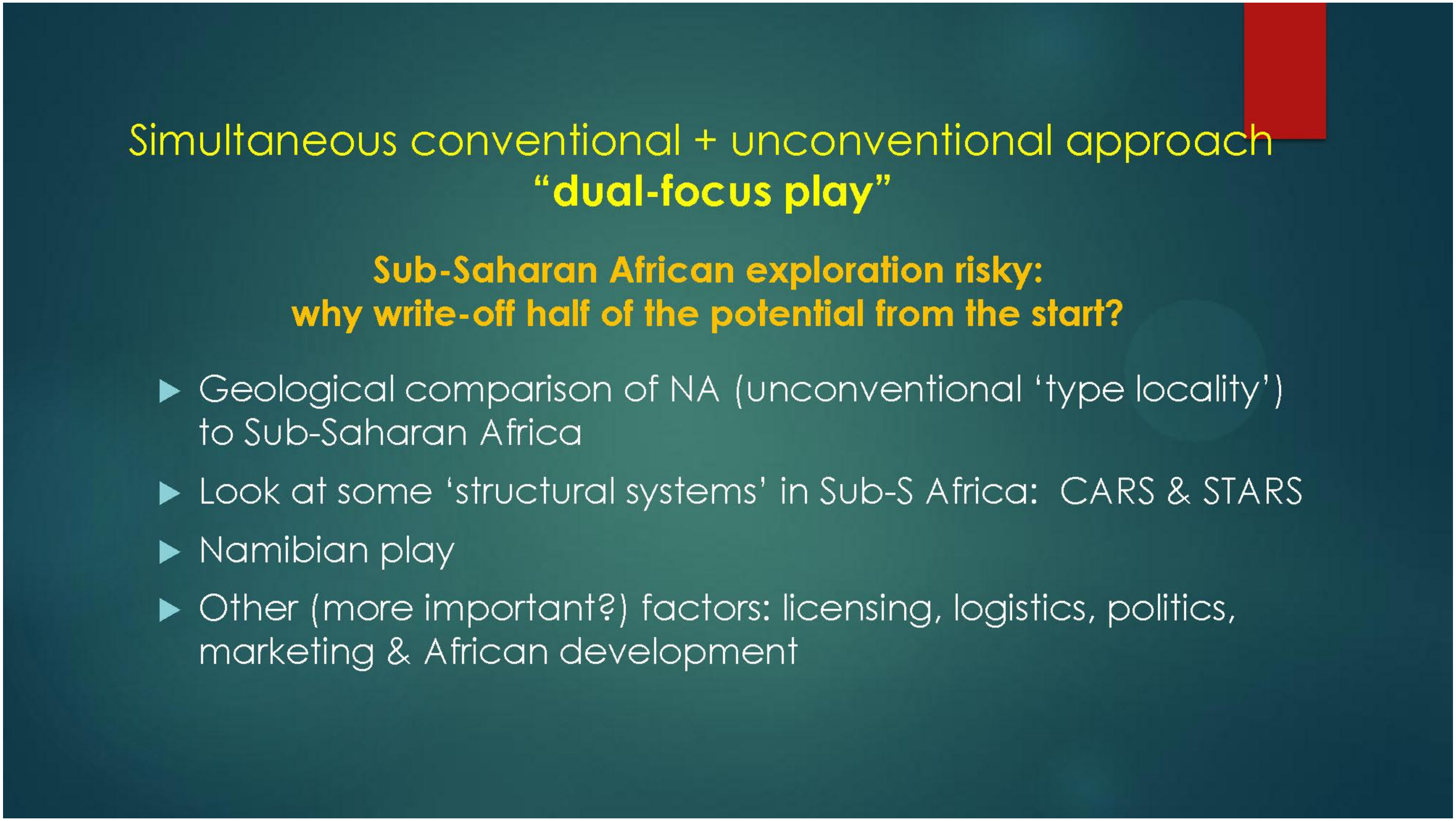

Figure 2. A dual focus play for Sub-Saharan Africa.

Figure 3. Risk factors in a dual approach.

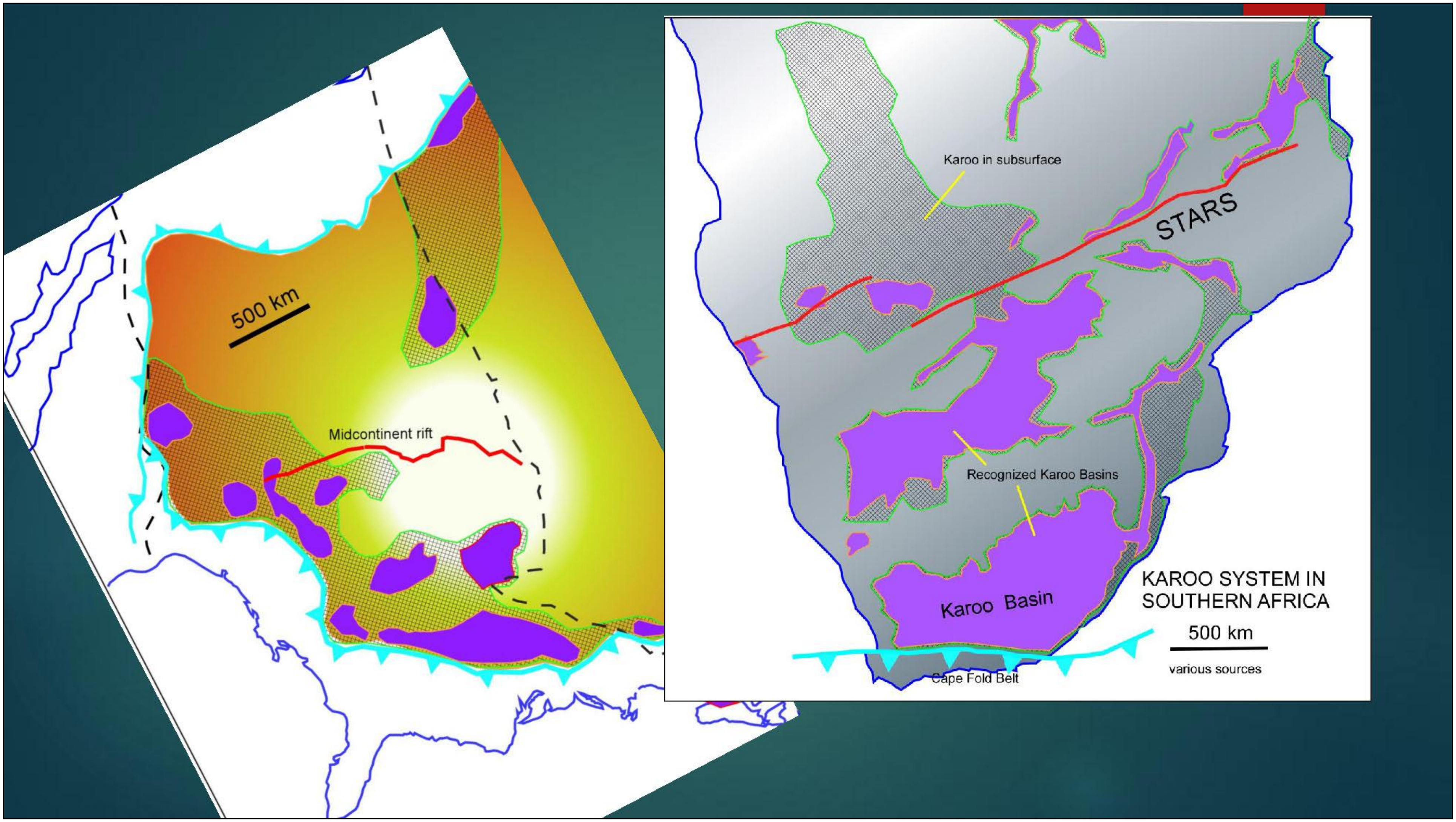

Figure 4. Comparison of North America and Africa.

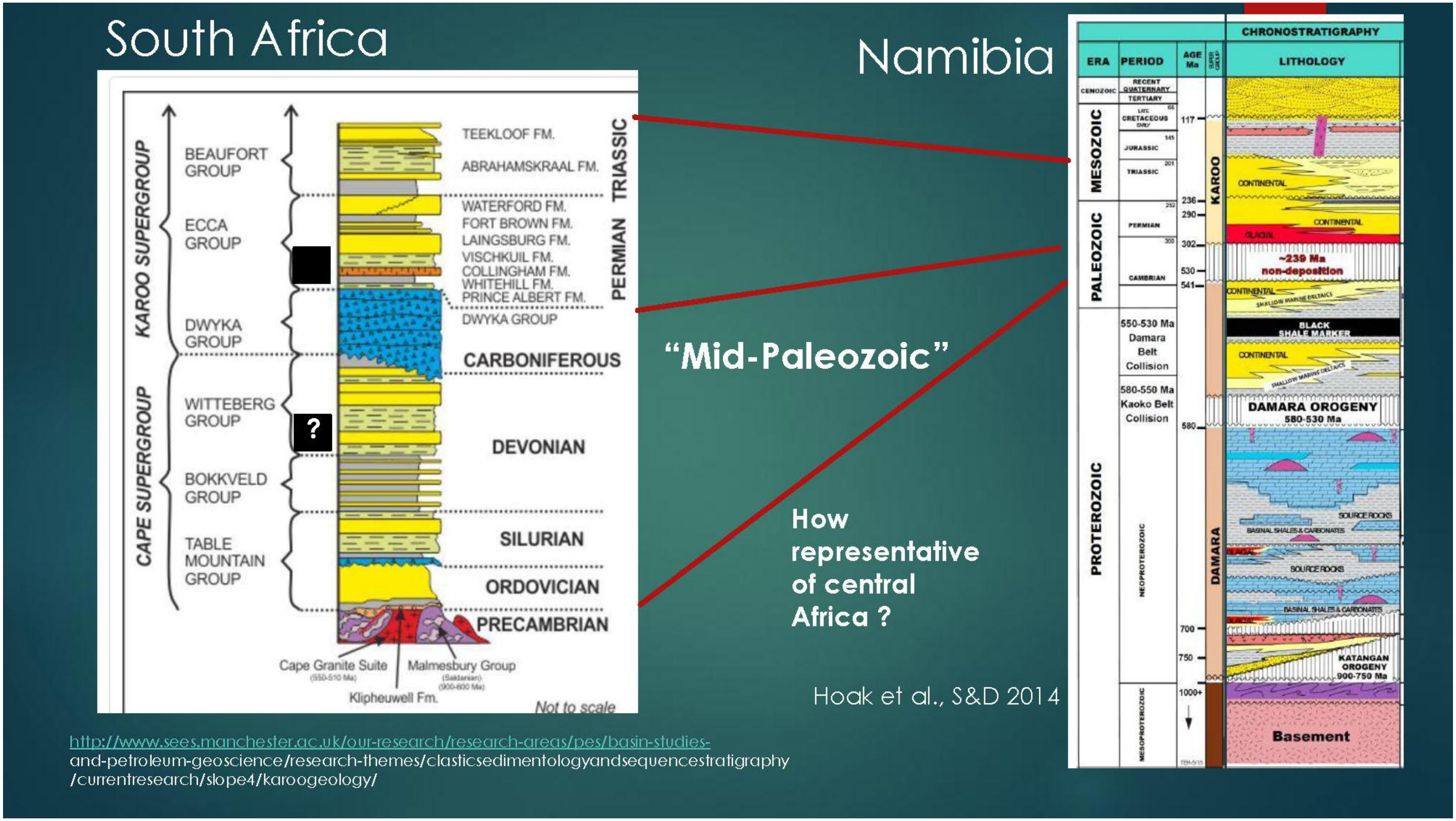

Figure 5. Southern African Paleozoic stratigraphy.

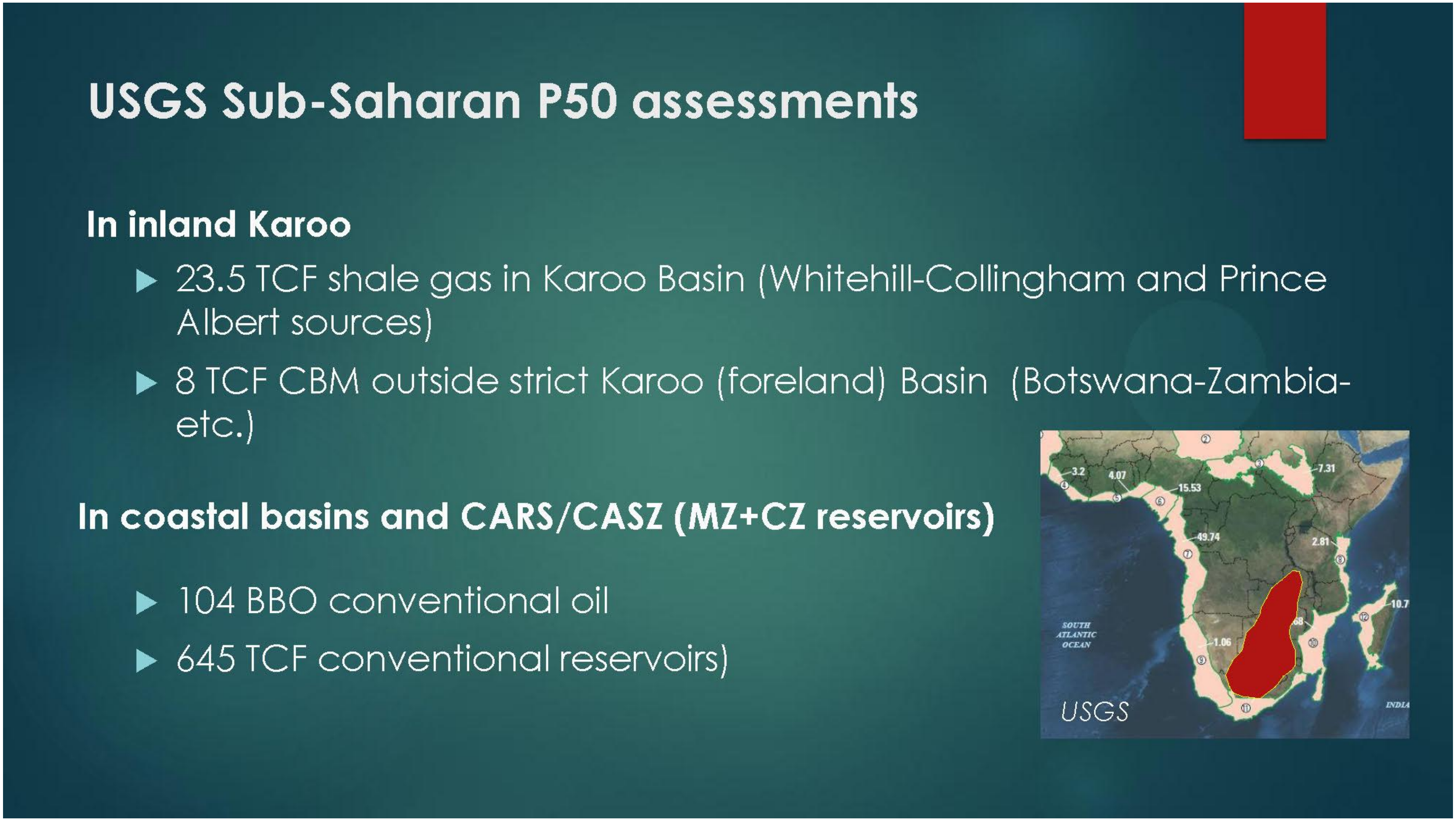

Figure 6. USGS reserves assessments.

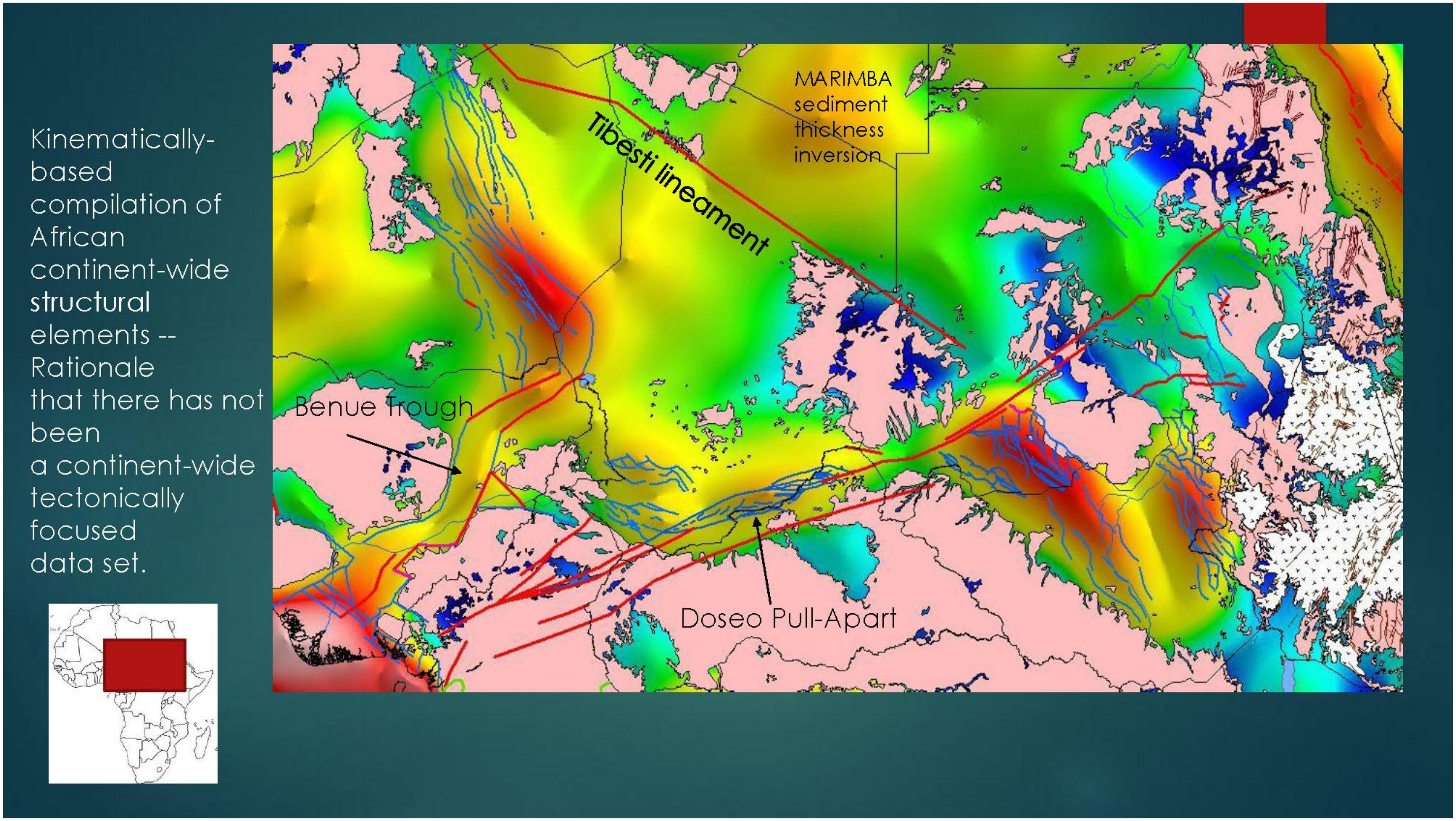

Figure 7. Central African Rift/Shear System.

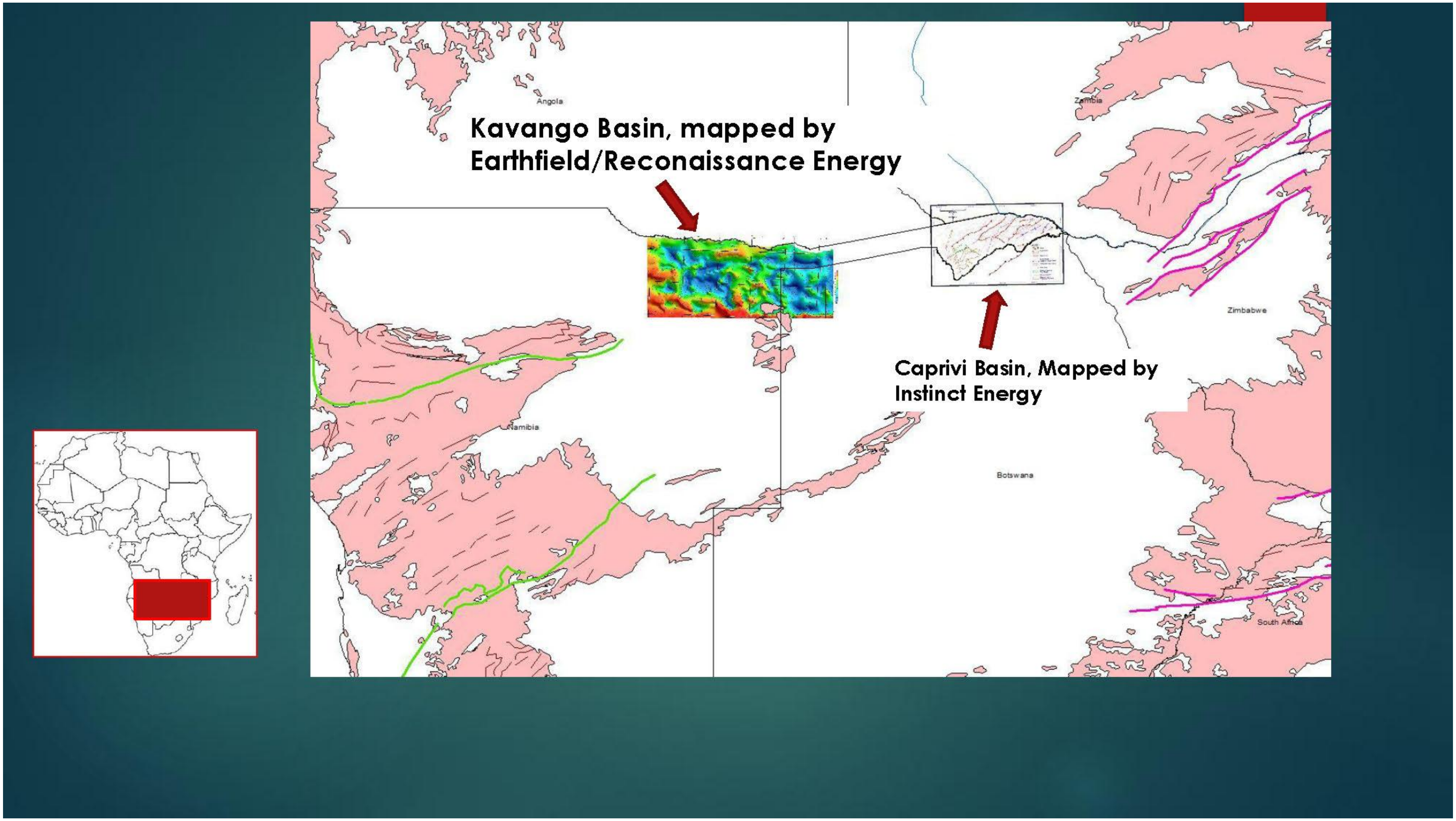

Figure 8. New elements of the "Southern Trans-African Rift and Shear System" (STARSS).

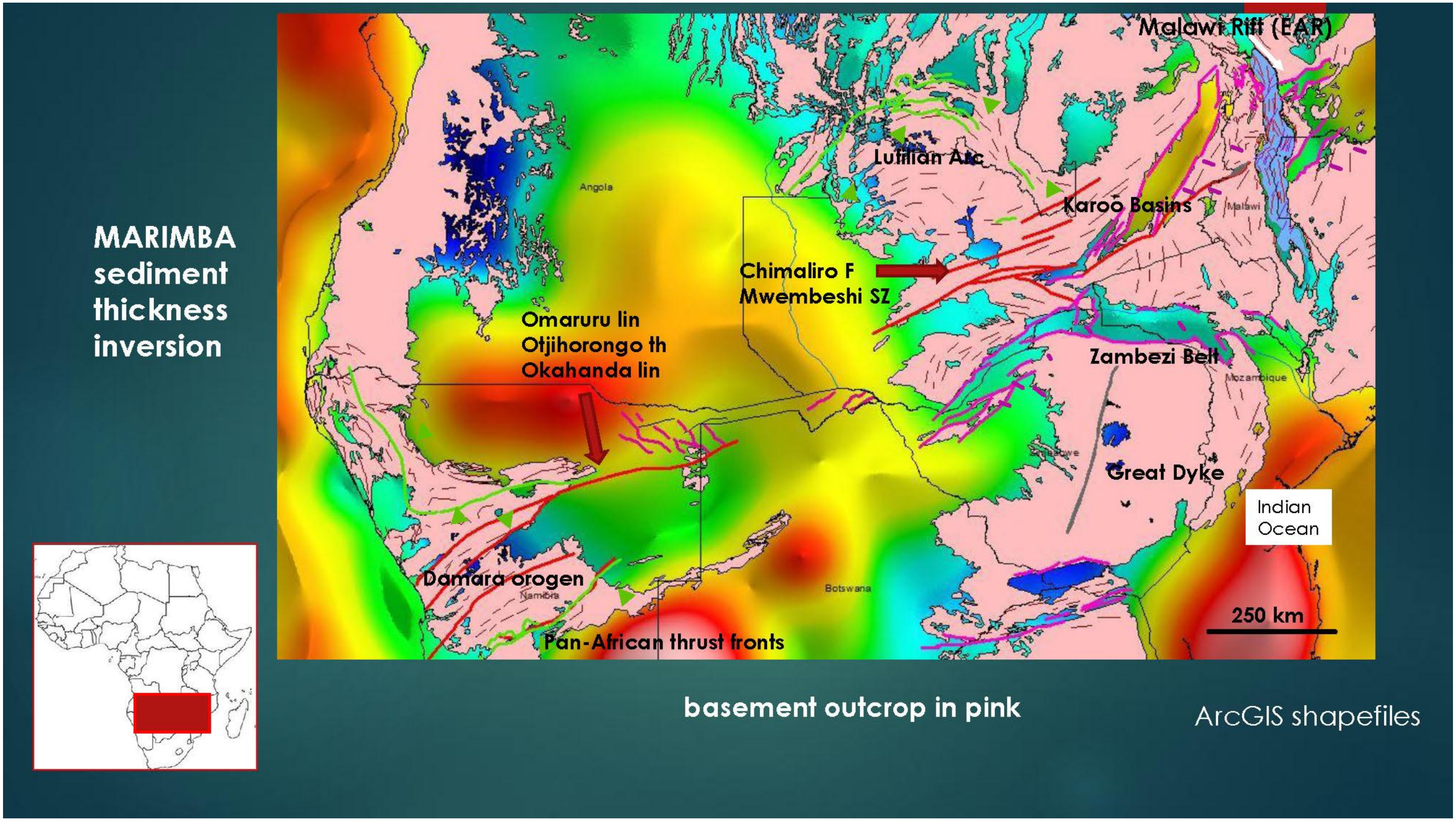

Figure 9. Southern Trans-Africa Rift System 'STARSS'.

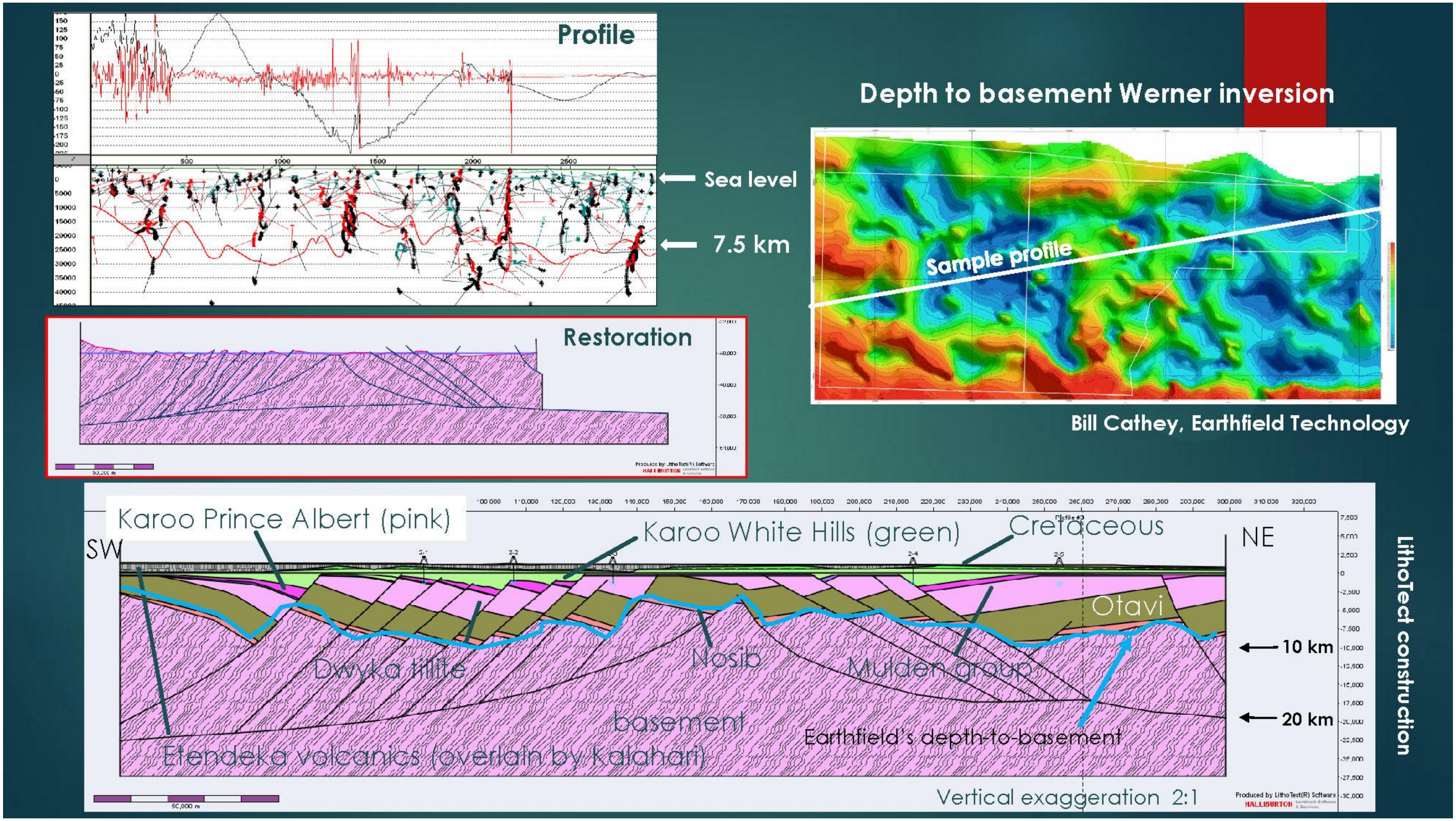

Figure 10. Structural modeling in Kavango Basin.

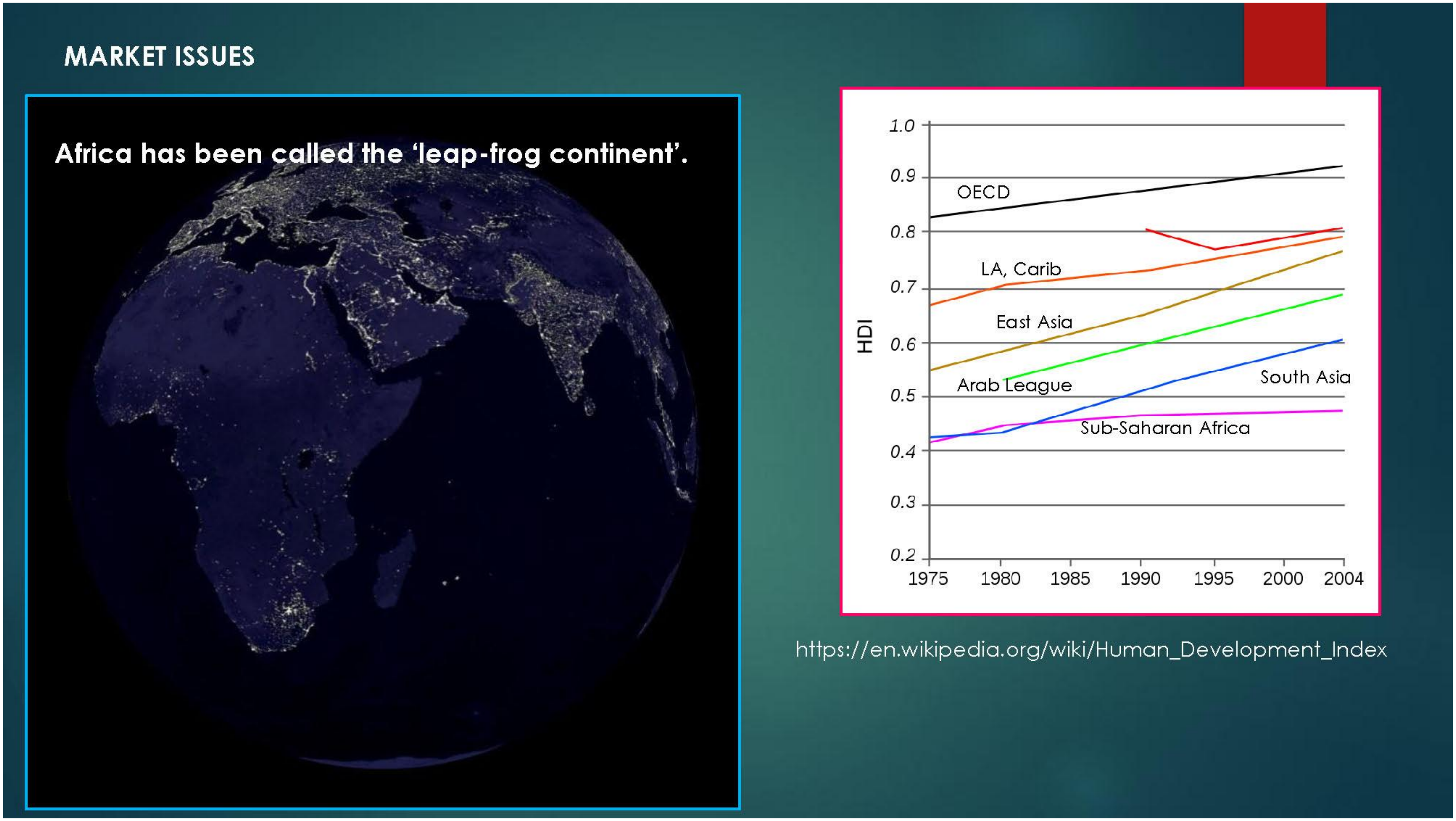

Figure 11. Economic situation is the diametrical opposite of the North American experience with unconventionals: economic growth poised to parallel hydrocarbon development.

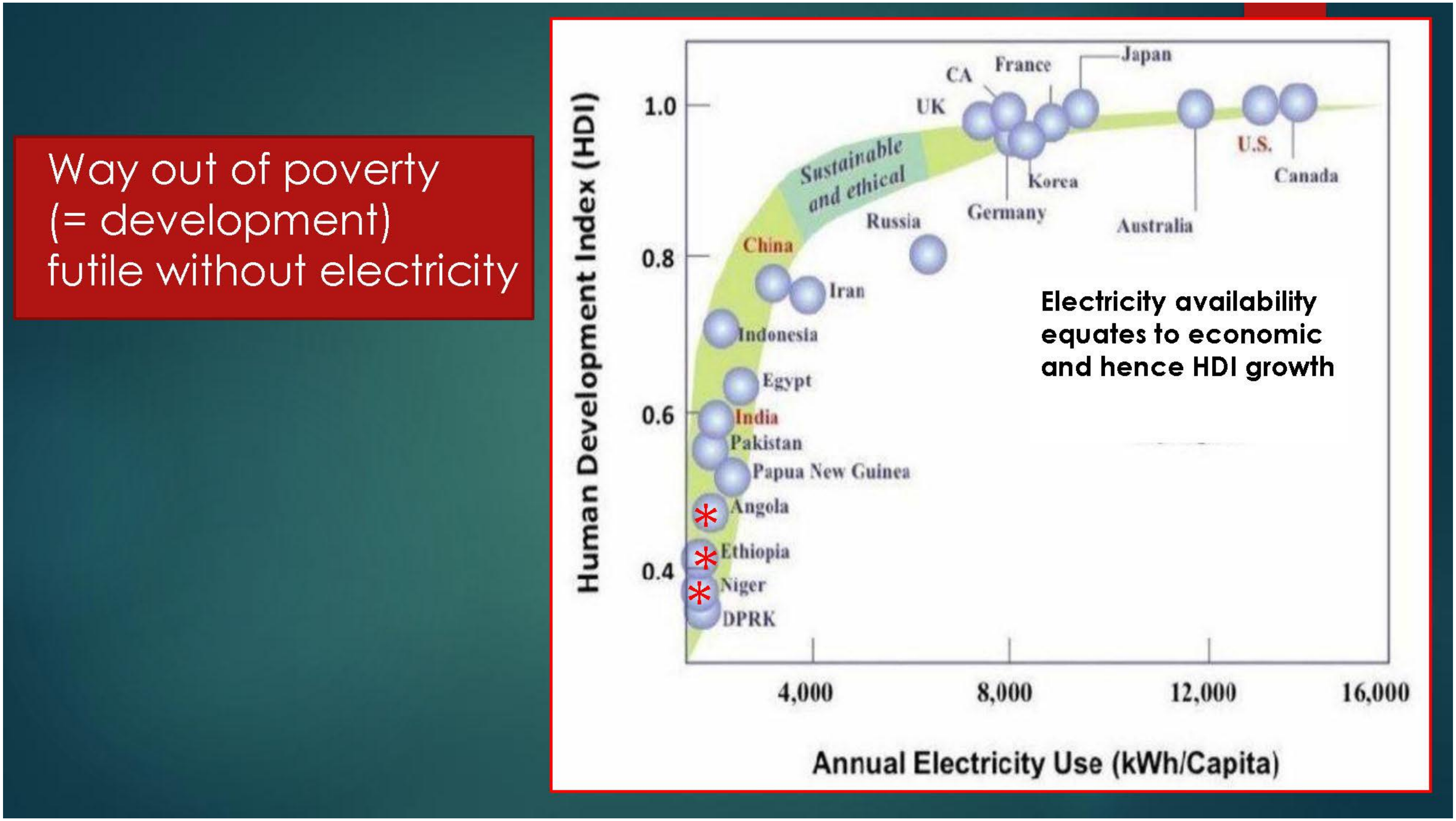

Figure 12. Population growth Urbanization Rural electrification.

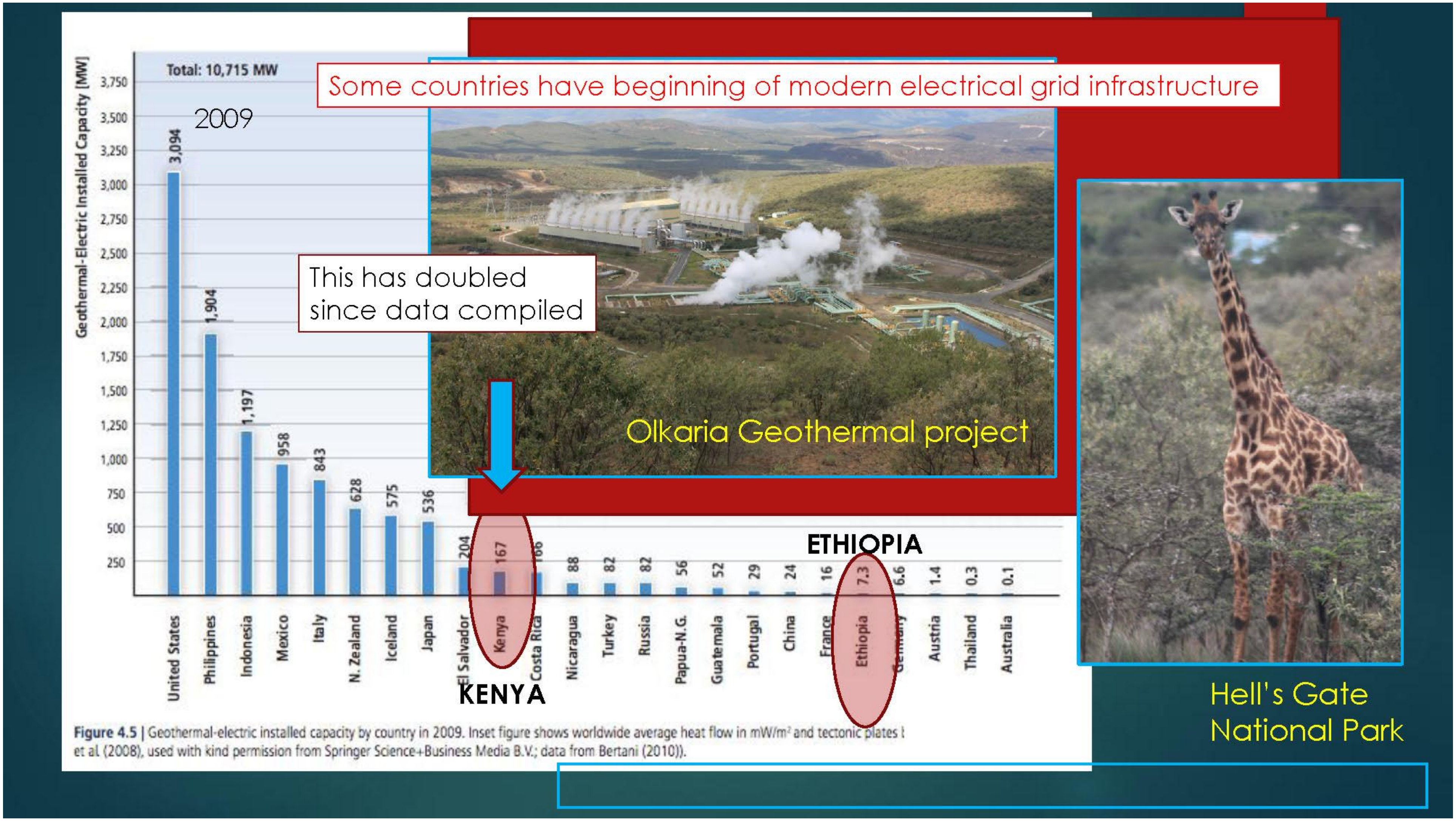

Figure 13. Top 24 in Geothermal Electrical Generation.

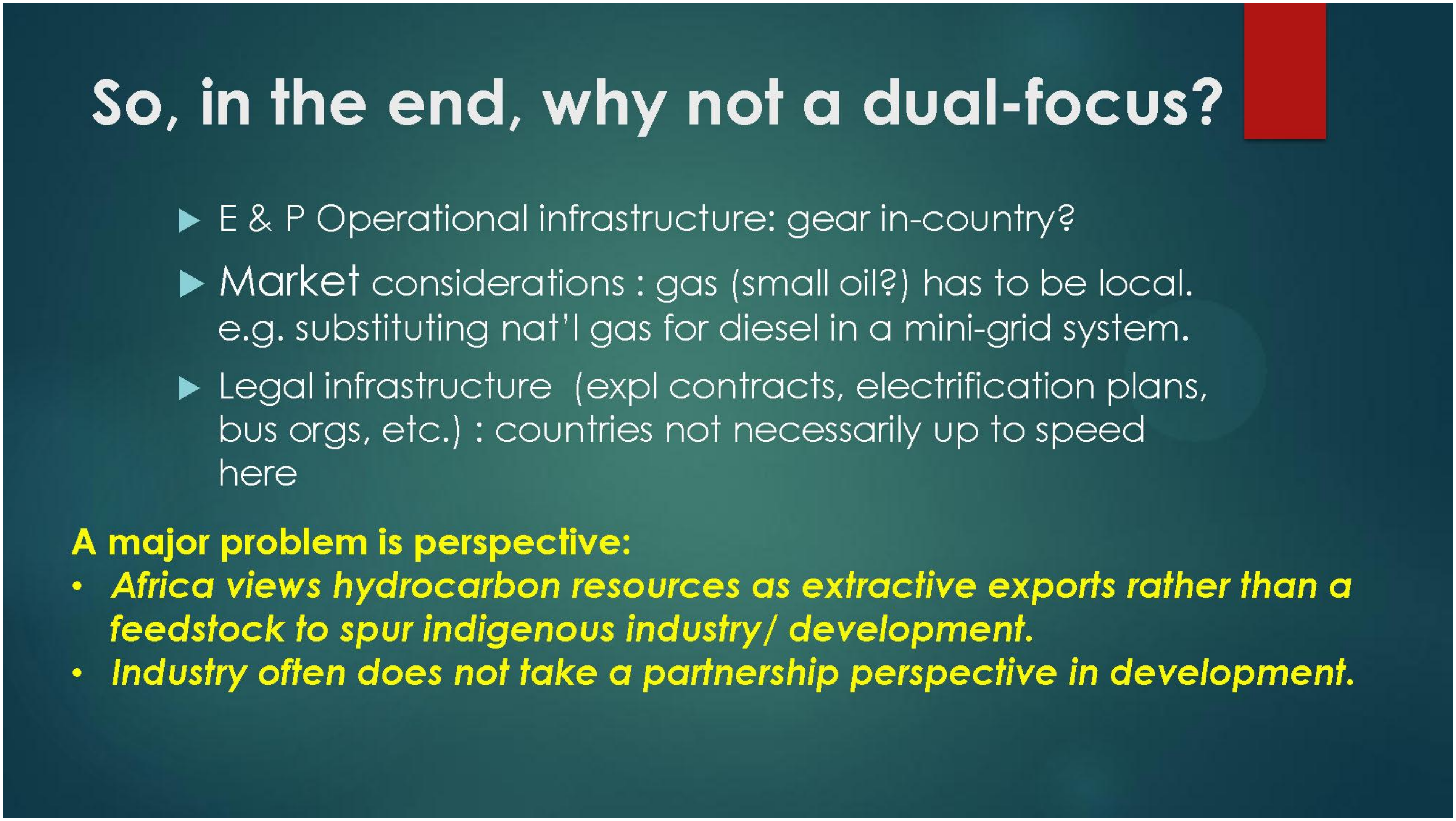

Figure 14. Risks and requirements.