Lithologic Controls of Pressure Distribution in Sedimentary Basins*

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Abstract

The pressure architecture of seventy five sedimentary basins was examined to determine spatial distribution of normal and abnormal pressure. Basins with like depositional histories have similar distribution patterns that are generally classified as either linear or tiered. Linear systems are common in dynamic basins and represent a systematic increase in pressure with increasing depth. Tiered systems occur in both dynamic and senile basins and contain distinct pressure domains or compartments whose distribution patterns are categorized as stepped, recessed, and ledged. Pressures in stepped basins increase with depth and form a staircase pattern of distinct pressure compartments. Recessed patterns are formed by a subnormally pressured interval, which is bounded both above and below by normal pressures. Ledged patterns consist of an overpressured section with subjacent and superjacent normally pressured intervals.

Stepped pressures are representative of basins containing thick sections of shale with intervening hydrocarbon-bearing sandstone reservoirs. Recessed patterns result when underpressured hydrocarbon-bearing carbonate or sandstone reservoirs are sealed from normally pressured reservoirs above and below. Ledged patterns have three distinct pressure domains: (1) a shallow, normal pressured sandstone-rich interval, (2) a shale-dominated interval that consists of overpressured mudrocks and sandstones, and (3) a deeper, normally pressured interval. This deeper normally pressured domain is dominated by carbonates or sandstones that are hydraulically connected to the surface, have active water drives, and contains gas that is buoyancy trapped above the water leg. Gas and oil accumulations in abnormally overpressured and underpressured intervals within tiered basins are dominantly stratigraphically trapped. In contrast, trapping of deep gas in sub-ledge, normally pressured intervals is facilitated by anticlinal folding or faulting.

In the Anadarko Basin, the overpressured Woodford shale can be superjacent to normally pressured Hunton Group carbonates. This juxtaposition creates the potential for fracturing fluid diversion during completion. Similar conditions exist in other basins where "frac barriers" needed to contain hydraulic stimulations are thin or absent and resource play intervals overlie lower pressured, water-charged permeable strata.

Selected References

Alberta Study Group, 1954, Lower Cretaceous of the Peace River region, *in* Western Canada Sedimentary Basin: AAPG Special Publication 15, p. 268-278.

Al-Shaieb, Z., J.O. Puckette, A.A. Abdalla, and P.B. Ely, 1994, Megacompartment complex in the Anadarko basin: A completely sealed overpressure phenomenon, *in* P.J. Ortoleva,(ed.), Basin Compartments and Seals: AAPG Memoir 61, p. 55-66.

Al-Shaieb, Z., J.O. Puckette, and P. Deyhim, 1999, Compartmentalization of the overpressured interval in the Anadarko basins, *in* D.F. Merriam, (ed.), Geoscience for the 21st Century, AAPG Transactions of the AAPG Midcontinent Section Meeting, Kansas Geological Survey Open-File Report 99-28, p. 63-70.

Bachu, S., 1999, Flow systems in the Alberta basin: Patterns, types, and driving mechanisms: Canadian Petroleum Geology Bulletin, v. 47/4, p. 455-574.

Barker, C., 1972, Aquathermal pressuring - role of temperature in development of abnormal pressure zones: AAPG Bulletin, v. 56/10, p. 2068-2071.

California Division of Oil, Gas, and Geothermal Resources, 1982, California oil and gas fields, northern California: California Department of Conservation, Division of Oil, Gas, and Geothermal Resources, Sacramento, Publication TR10-12, CD-1.

Chapman, C.M., 1989, Hamilton Dome: WGAWyoming Oil and Gas Fields Symposium: Big Horn and Wind River Basins, p. 219-224.

Chiarelli, A., and F. Duffaud, 1980, Pressure origin and distribution in Jurassic of Viking basin (U.K. and Norway): AAPG Bulletin, v. 64/8, p. 1245-1251.

Clark, L.M., C.E. Cleveland, R.S. Johnson, and R.C.M. Budd, 1968, Geology of natural gas, Peace River area, Canada, in Natural Gases of North America: AAPG Memoir 9, p. 683-697.

Erlich, R.N., and S.F. Barrett, 1992, Petroleum geology of the eastern Venezuela foreland basin: AAPG Memoir 55, p. 341-362.

Funkhouser, H.J., L.C. Sass, and H.D. Hedberg, 1948, Santa Ana, San Joaquin, Guario, and Santa Rosa oil fields (Anaco fields), Central Anzoátegui, Venezuela: AAPG Bulletin, v. 32/10, p. 1851-1908.

Gleddie, J., 1954, Upper Cretaceous in Western Peace River Plains, Alberta, *in* Western Canada Sedimentary Basin: AAPG Special Publication 15, p. 486-509.

Heritier, F.E., P. Lossel, and E. Wathne, 1979, Frigg Field - large submarine-fan trap in lower Eocene rocks of the North Sea Viking Graben: AAPG Bulletin, v. 63/11, p. 1999-2020.

Hunt, A.D., and J.D. Radcliffe, 1959, Triassic stratigraphy, Peace River area, Alberta and British Columbia, Canada: AAPG Bulletin, v. 43/3, p. 563-589.

Johnson, K.S., 1989, Geological evolution of the Anadarko basin, *in* K.S. Johnson, (ed.), Anadarko Basin Symposium, 1988: Oklahoma Geological Survey Circular 90, p. 3-12.

Keefer, W.R., and R.C. Johnson, 1993, Stratigraphy and oil and gas resources in uppermost Cretaceous and Paleocene rocks, Wind River Reservation, Wyoming: WGA Special Symposium, Oil and Gas and Other Resources of the Wind River Basin, Wyoming, p. 71-85.

Kent, P.E., 1967, Progress of exploration in North Sea: AAPG Bulletin, v. 51/5, p. 731-741.

Krampert, E.W., 1947, Hamilton Dome, Hot Springs County, Wyoming: WGA Bighorn Basin Field Conference Guidebook, p. 229-233.

Lackie, J.H., 1958, Subsurface Jurassic of the Peace River area, *in* Jurassic and Carboniferous of Western Canada: AAPG Special Publication 17, p. 85-97.

Macauley, G., 1958, Late Paleozoic of Peace River area, Alberta, *in* Jurassic and Carboniferous of Western Canada: AAPG Special Publication 17, p. 289-308.

Murany, E.E., 1972, Tectonic basis for Anaco fault, eastern Venezuela: AAPG Bulletin, v. 56/5, p. 860-870.

Paape, D.W., 1968, Geology of Wind River basin of Wyoming and its relationship to natural gas accumulation, *in* Natural Gases of North America: AAPG Memoir 9, v. 1, p. 760-779.

Puckette, J.O., 1996, Evaluation of under pressured reservoirs as potential repositories for liquid wastes: unpublished Ph.D. thesis, Oklahoma State University, 273 p.

Swarbrick, R.E., and M.J. Osborne, 1998, Mechanisms that generate abnormal pressures: An overview, in B.E. Law, G.F. Ulmishek, and V.I. Slavin, (eds.), Abnormal pressures in hydrocarbon environments: AAPG Memoir 70, p. 13-34.

Villaroel, V., 1993, Santa Rosa Field - Venezuela, Eastern Venezuela Basin: AAPG Treatise of Petroleum Geology, Atlas of Oil and Gas Fields, Structural Traps VIII, p. 193-215.

WGA, 1952, Hamilton Dome field, Hot Springs County, Wyoming: WGA 7th Annual Field Conference Guidebook, p. 104-107.

LITHOLOGIC CONTROLS of PRESSURE DISTRIBUTION in SEDIMENTARY BASINS

By

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Problem: Sedimentary Basins Exhibit a Variety of Pressure Distribution Patterns

Question: What Geologic Processes Influence Present Pressure Distribution

Procedure and Summary of Results

Examined Pressure Architecture of 75 Sedimentary Basins

Established Distribution of Normal and Abnormal Pressure (low and high)

Compared Pressure Architecture with Stratigraphy

Basins with Similar Depositional Histories can develop Pressure Architecture/Pressure Distribution Patterns that are Similar

Acknowledgements

AAPG-Datapages
John Shelton
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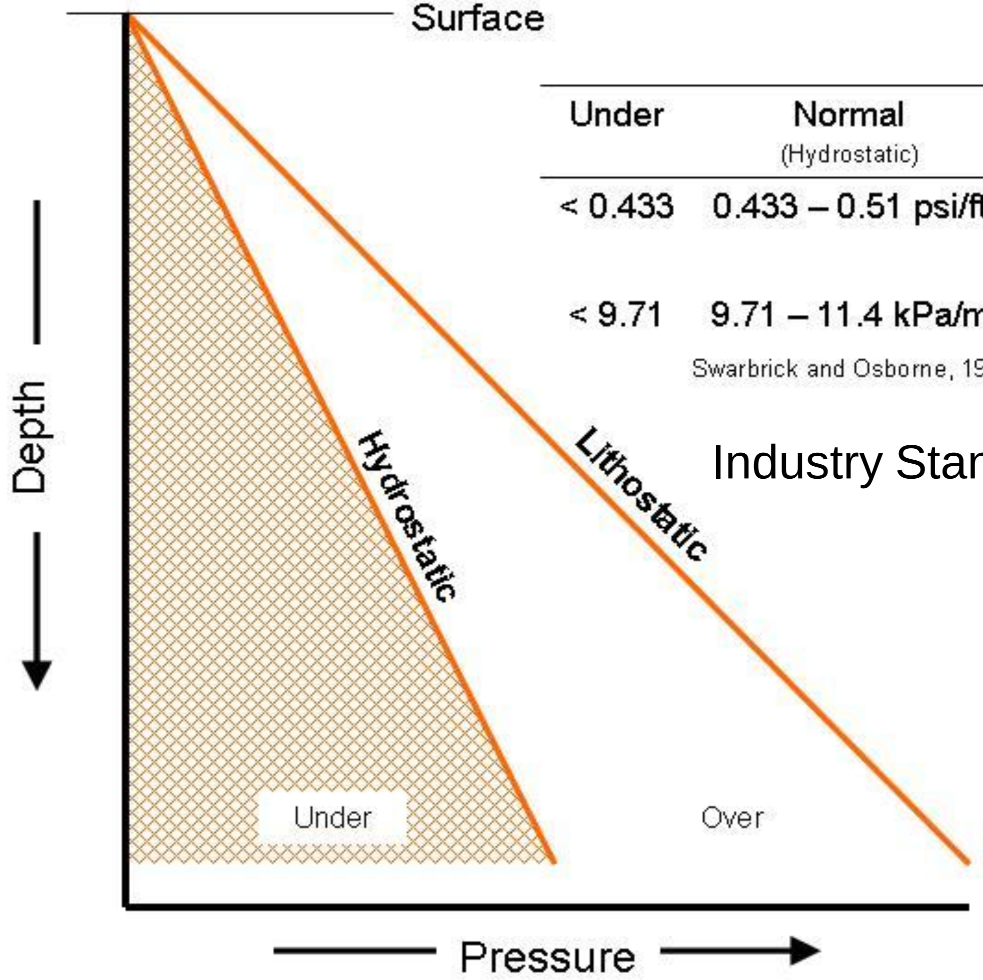
Dedication

David Powley
Amoco Production Company

For Recognizing and Systematically
Documenting Reservoir Pressures in Sedimentary Basins

What are Normal and Abnormal Pressures?

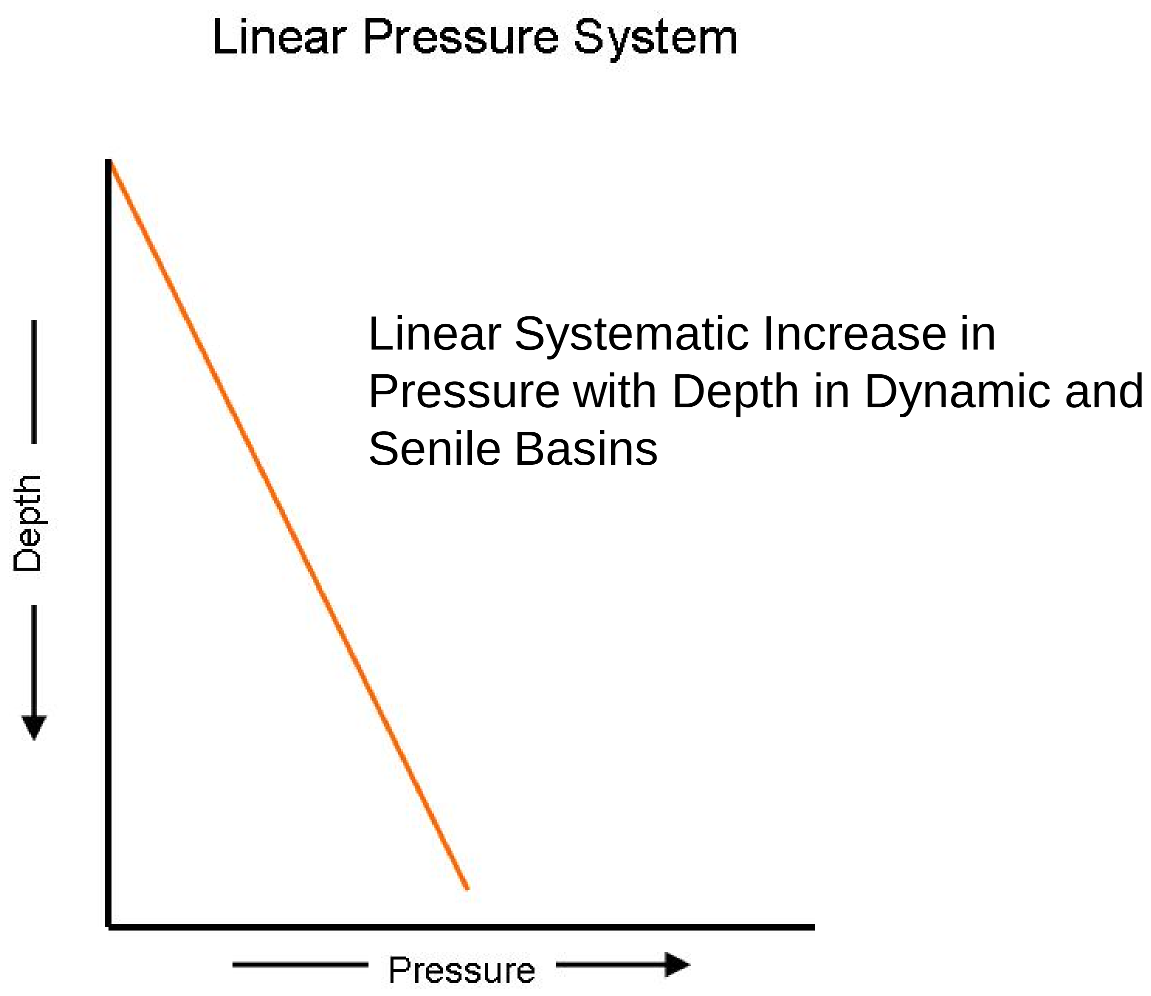


Under	Normal (Hydrostatic)	Over
< 0.433	0.433 – 0.51 psi/ft	> 0.51
< 9.71	9.71 – 11.4 kPa/m	> 11.4

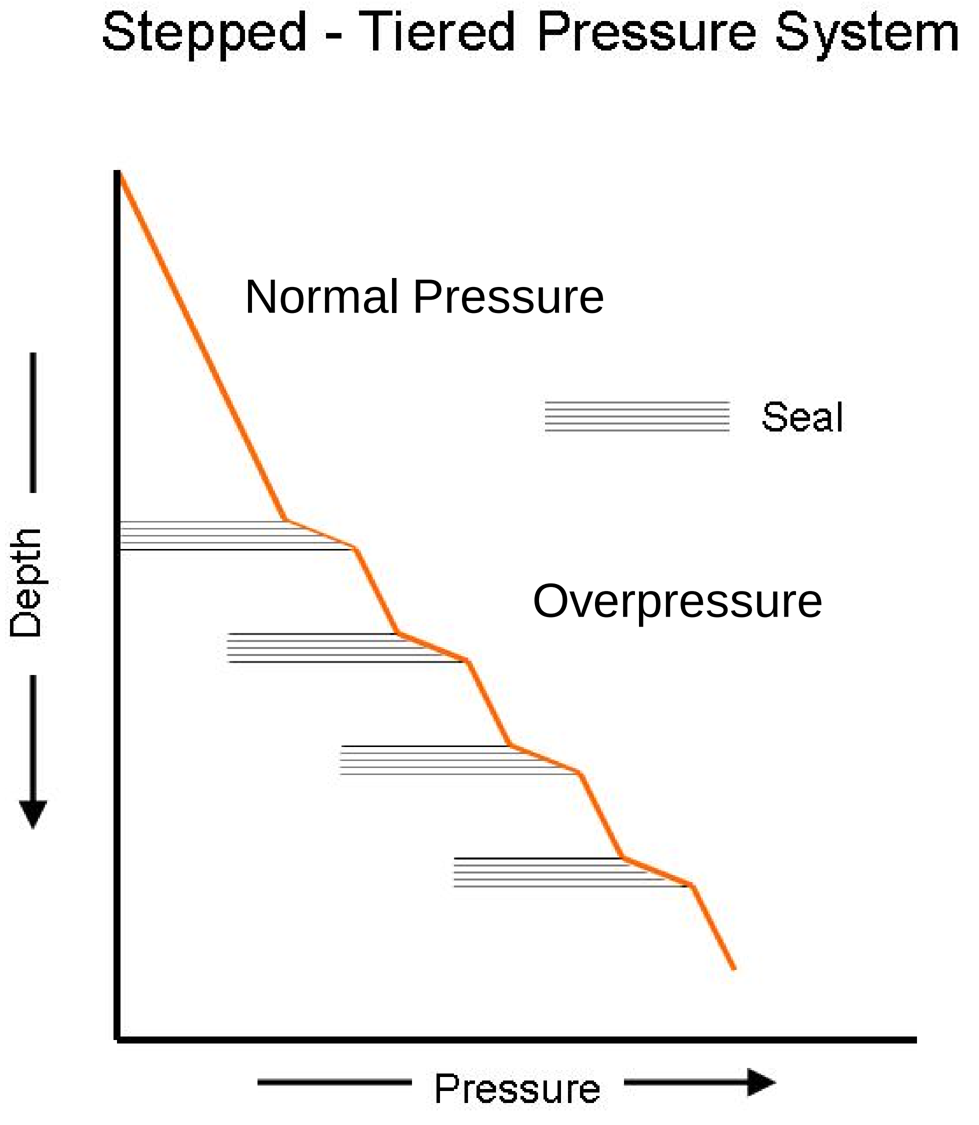
Swarbrick and Osborne, 1998

Industry Standard = 0.465 psi/ft.

Pressure Distribution in Sedimentary Basins

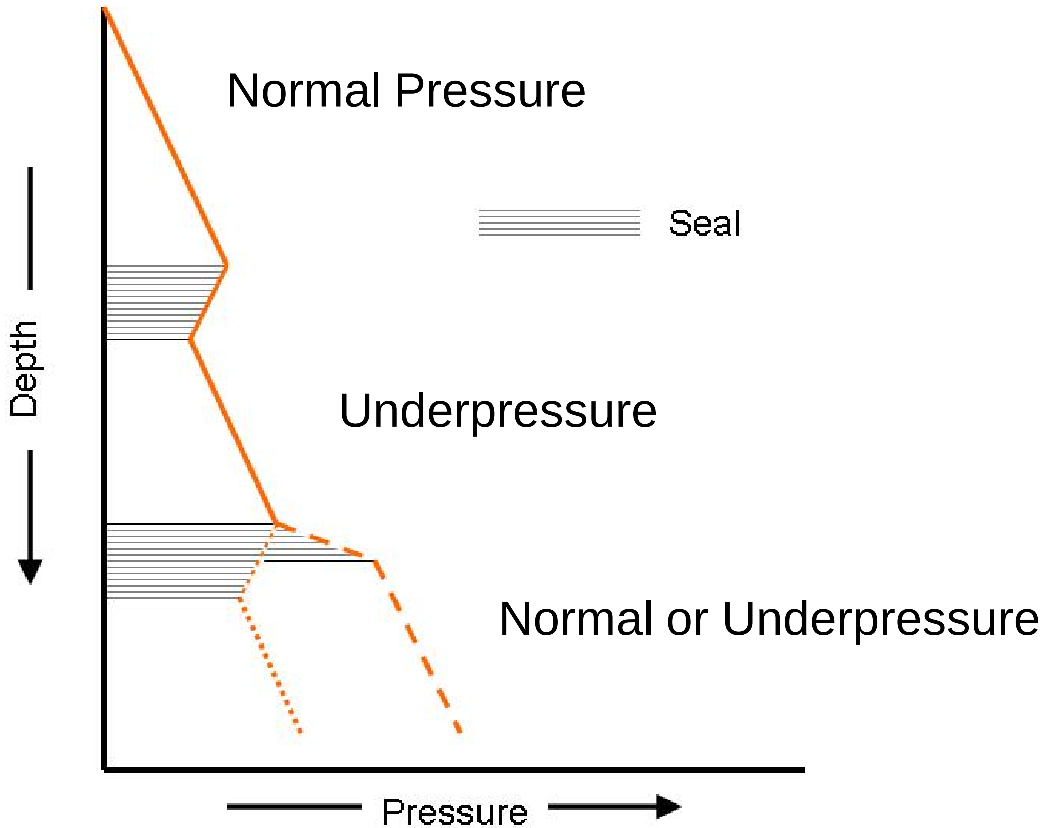


Pressure Distribution in Sedimentary Basins

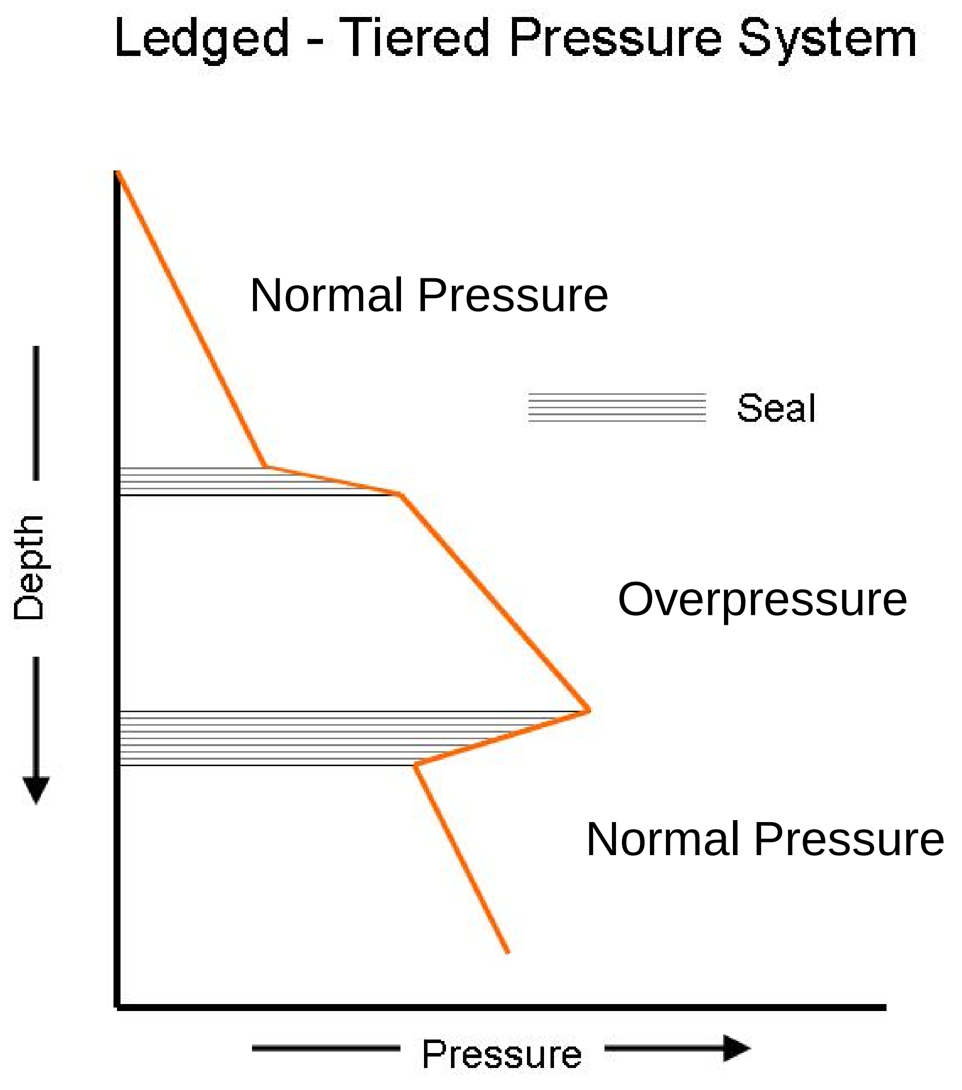


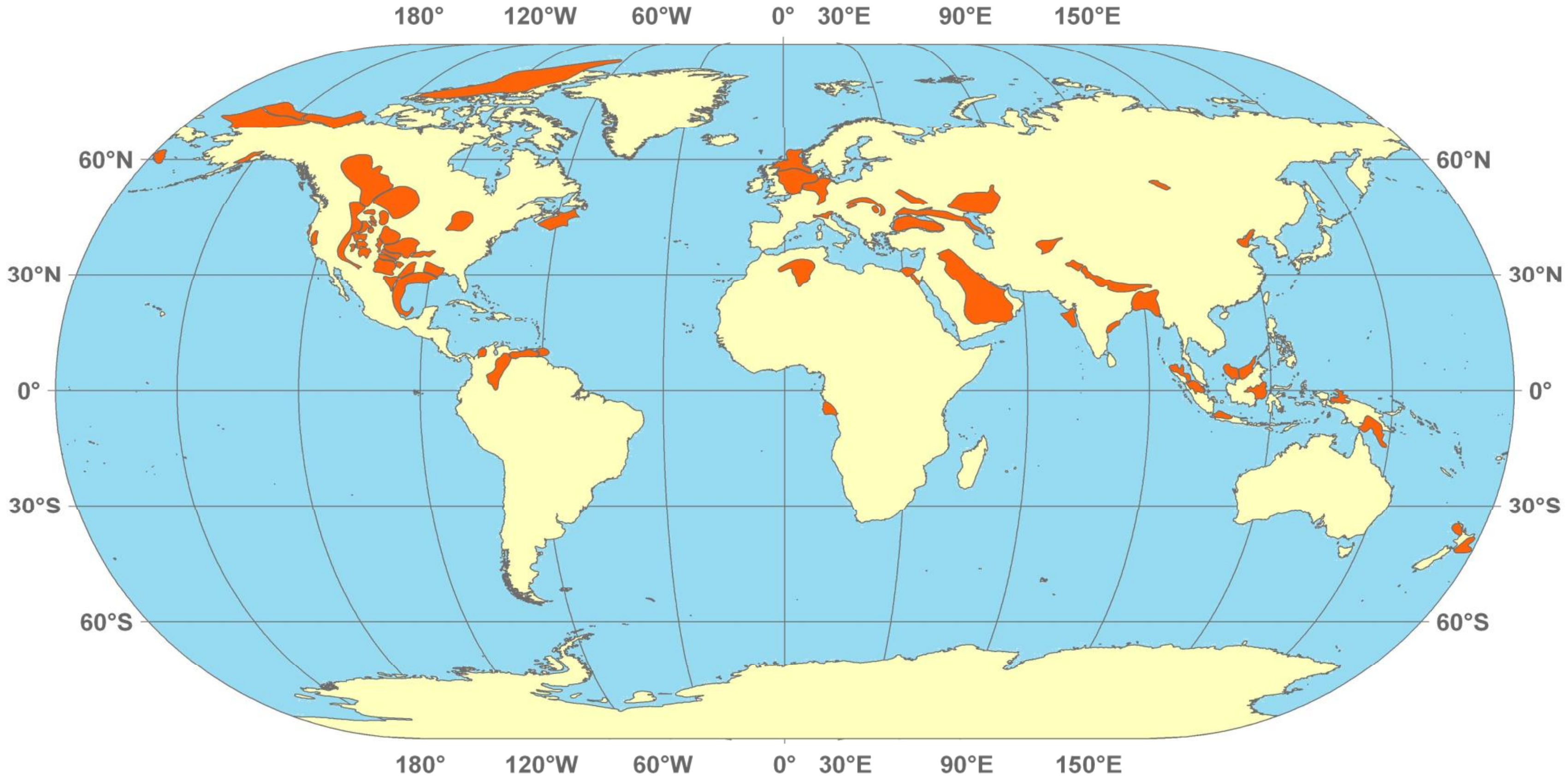
Pressure Distribution in Sedimentary Basins

Recessed - Tiered Pressure System

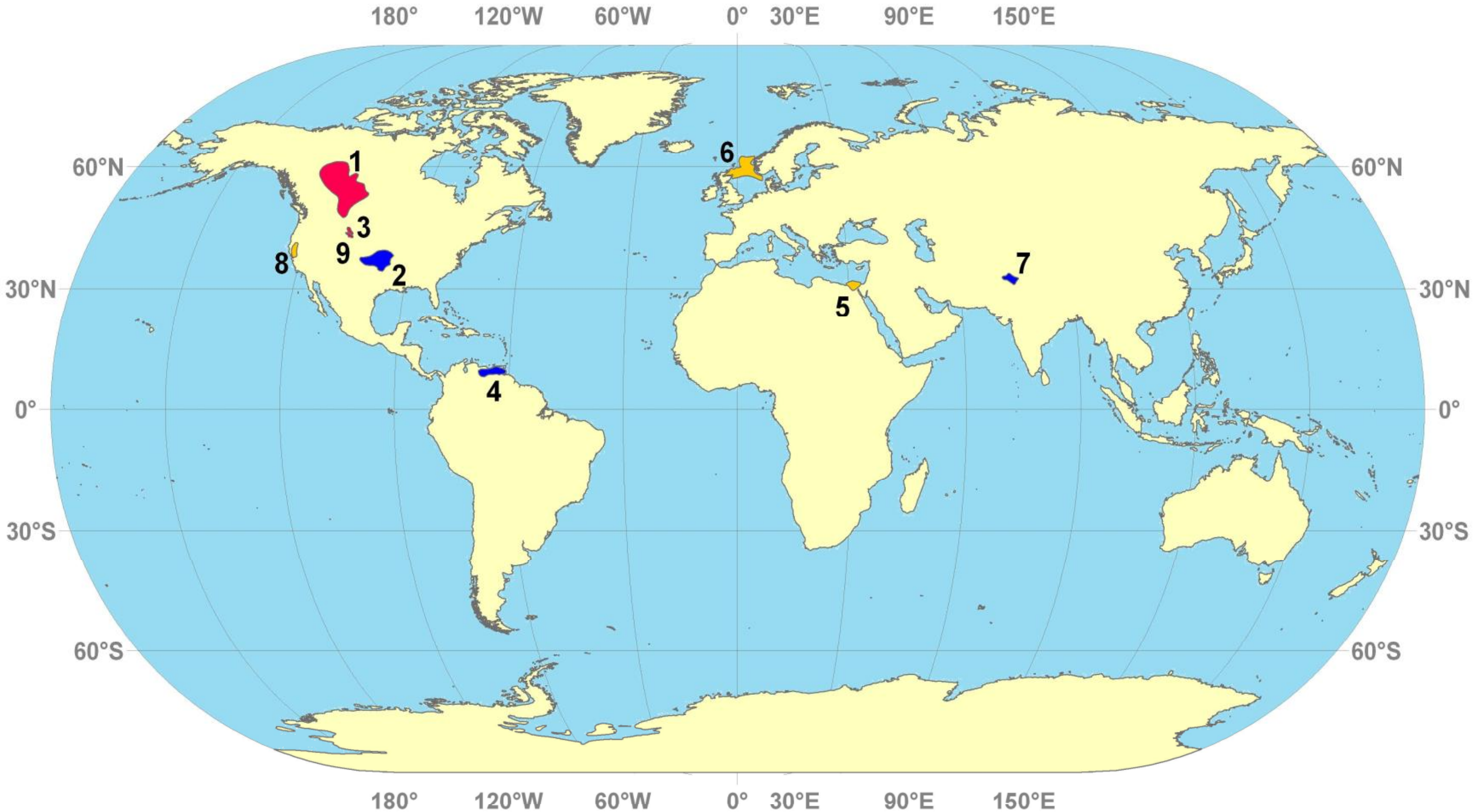


Pressure Distribution in Sedimentary Basins





The Study Area: Global Distribution of Sedimentary Basins Examined in this Study



Ledged

Recessed

Stepped

Basins

1 Alberta
2 Anadarko
3 Big Horn
4 Maturin
5 Nile Delta
6 Northern North Sea
7 Potwar
8 Sacramento
9 Wind River

John Tackett
March 2008

Selected Basins to Illustrate Pressure Architecture

Abnormal Pressure Mechanisms

Overpressures

Stress Related

Disequilibrium Compaction	→	poor fluid expulsion during compaction
Tectonic Stress	→	reservoir compacted by compressive stress

Fluid Volume Changes

Temperature Increase	→	fluids heated to increase volume
Mineral Transformation	→	H_2O released: smectite-illite transformation
Hydrocarbon Generation	→	fluid HC generated from solid kerogen
Cracking of Oil and Gas	→	gas generated from oil

Fluid Movement and Buoyancy

Osmosis	→	fluid movement based on concentration
Hydraulic Head	→	potential energy of recharge
Buoyancy	→	density differences of gas, oil and water

Transference — higher pressure communicates with lower pressure

Abnormal Pressure Mechanisms

Underpressures

Stress Related

Rock Dilatancy → pore dilation from uplift & erosion

Fluid Volume Changes

Thermal Effects → fluids cool and volume decreases

Fluid Movement & Buoyancy

Osmosis → fluids react to concentration gradient

Differential Gas Flow → gas expels faster than generated

Groundwater Flow → groundwater discharges faster than recharge

Leaking Reservoir → reservoir seal broken; pressure equilibrates with potentiometric head of reservoir fluid. If gas, pressure will be abnormally low.

Stepped Pressure System

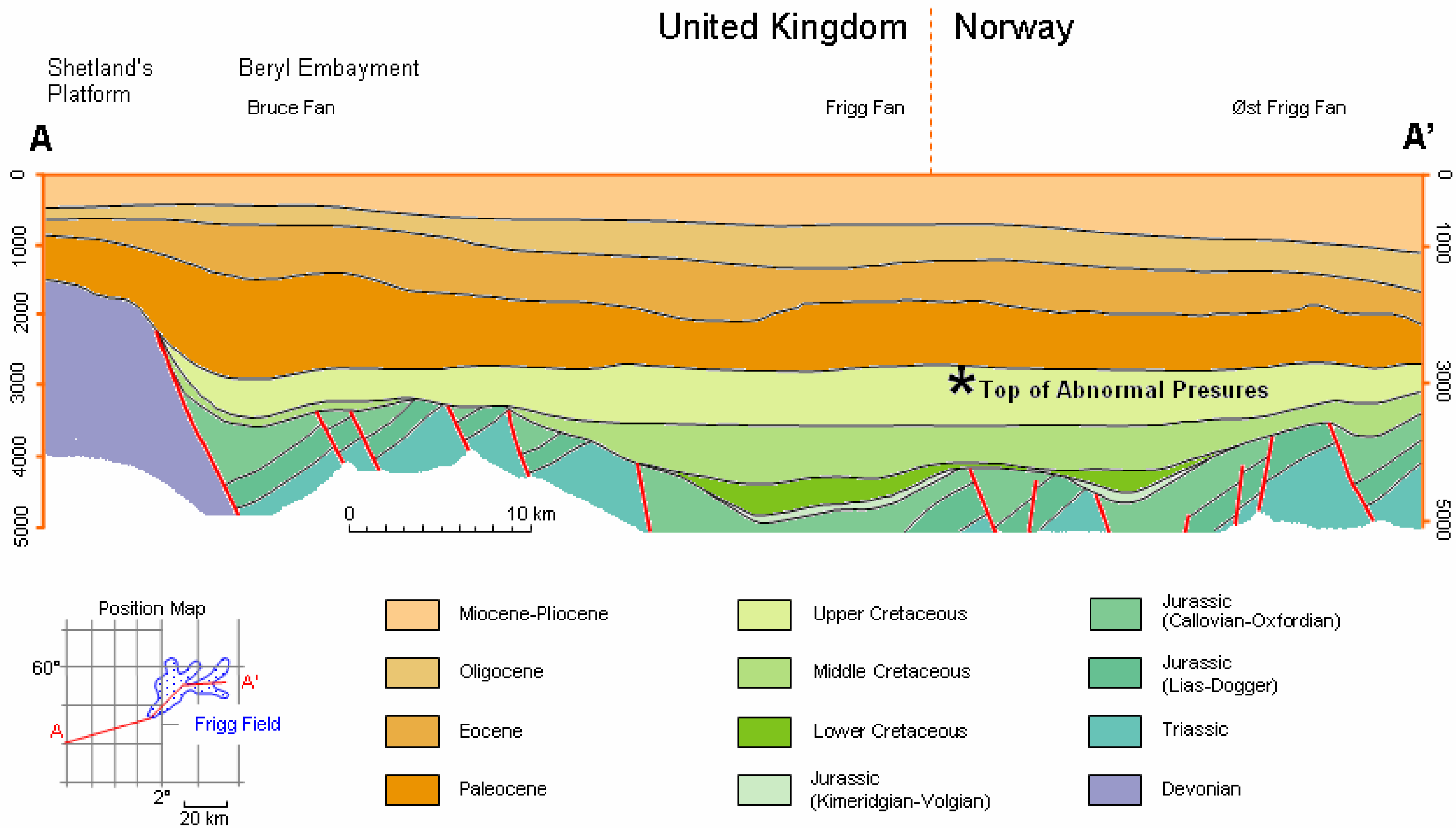
- North Sea
- Sacramento
  - Thick sections of shale with intervening oil- and gas-bearing sandstones
  - Tiers represent increases in pressure with depth
  - Common in dynamic basins that continue to generate HC or transform oil to gas

North Sea Basin

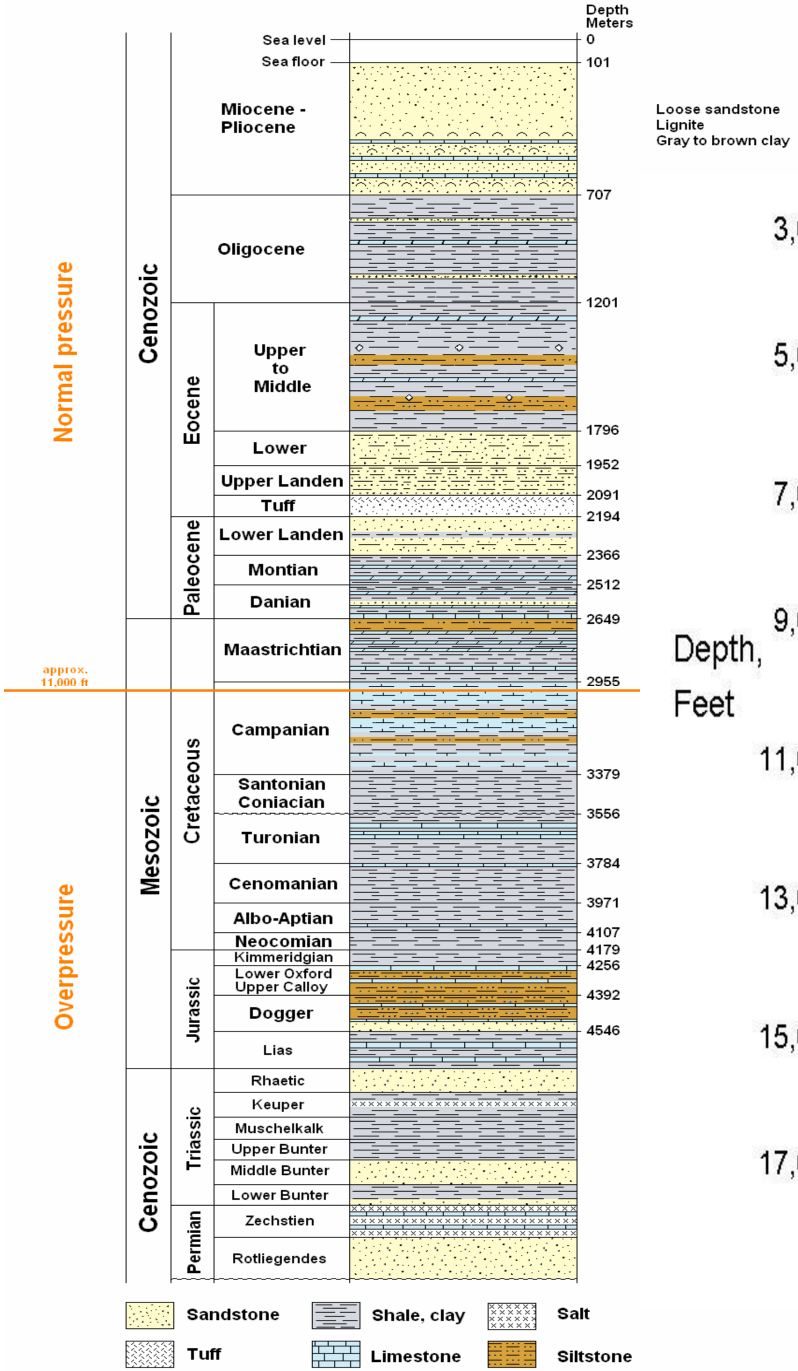
Frigg Field
Northern North Sea

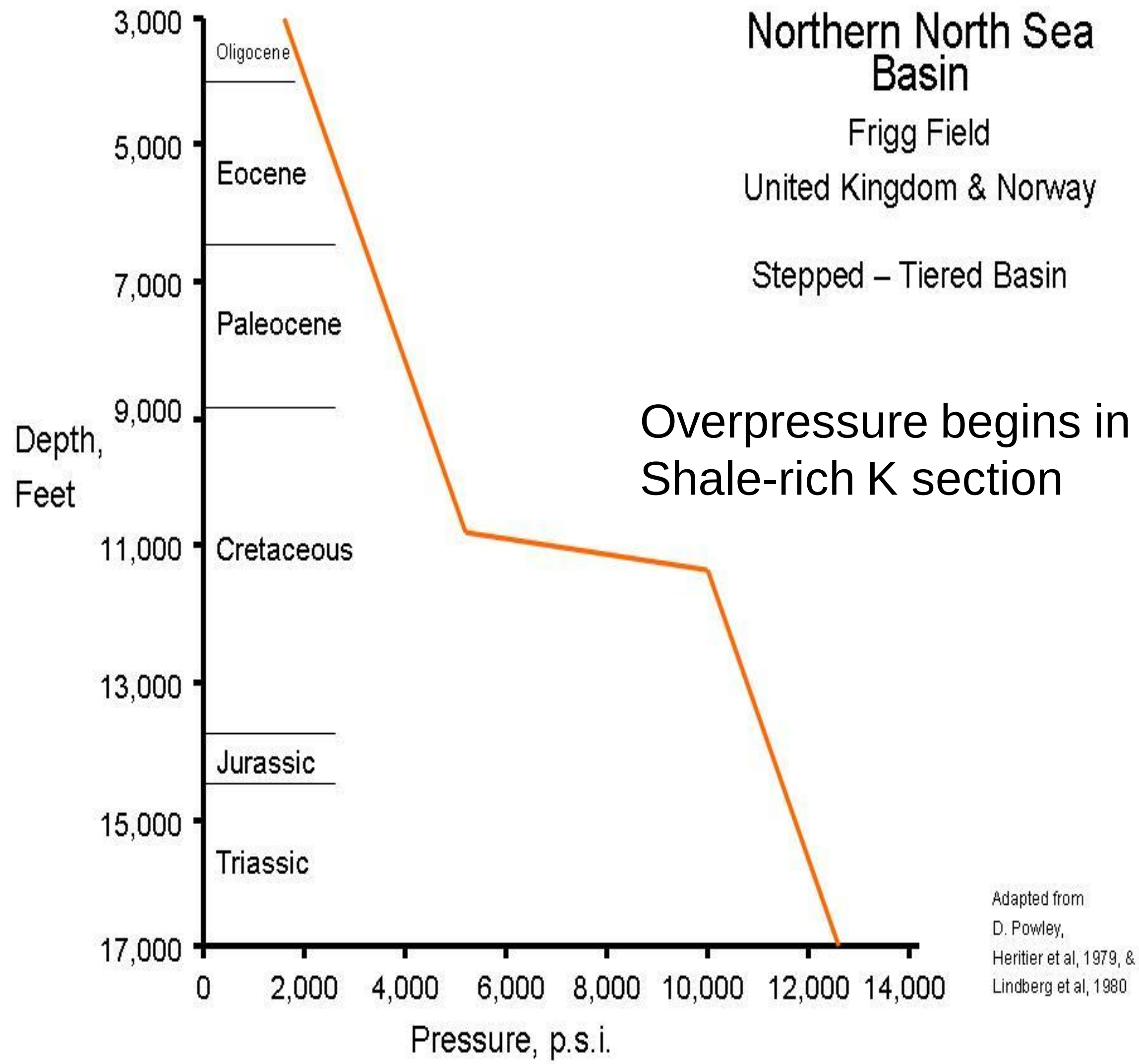
Stepped -Tiered Basin

North Sea Basin



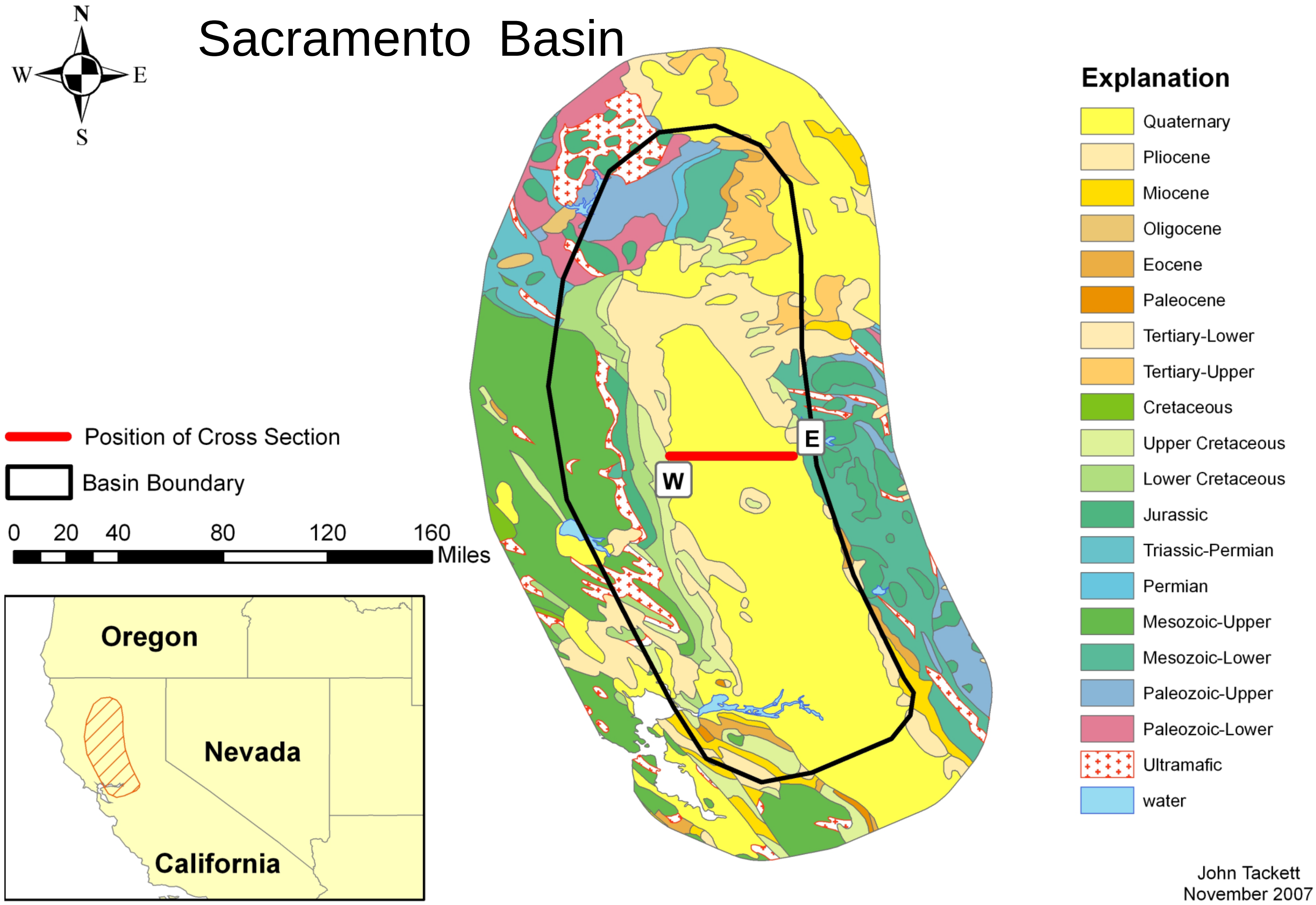
Generalized cross section (A-A') of Frigg Field, Northern North Sea Basin, United Kingdom and Norway (adapted from Heritier et al., 1979 and Chiarelli and Duffaud, 1980).





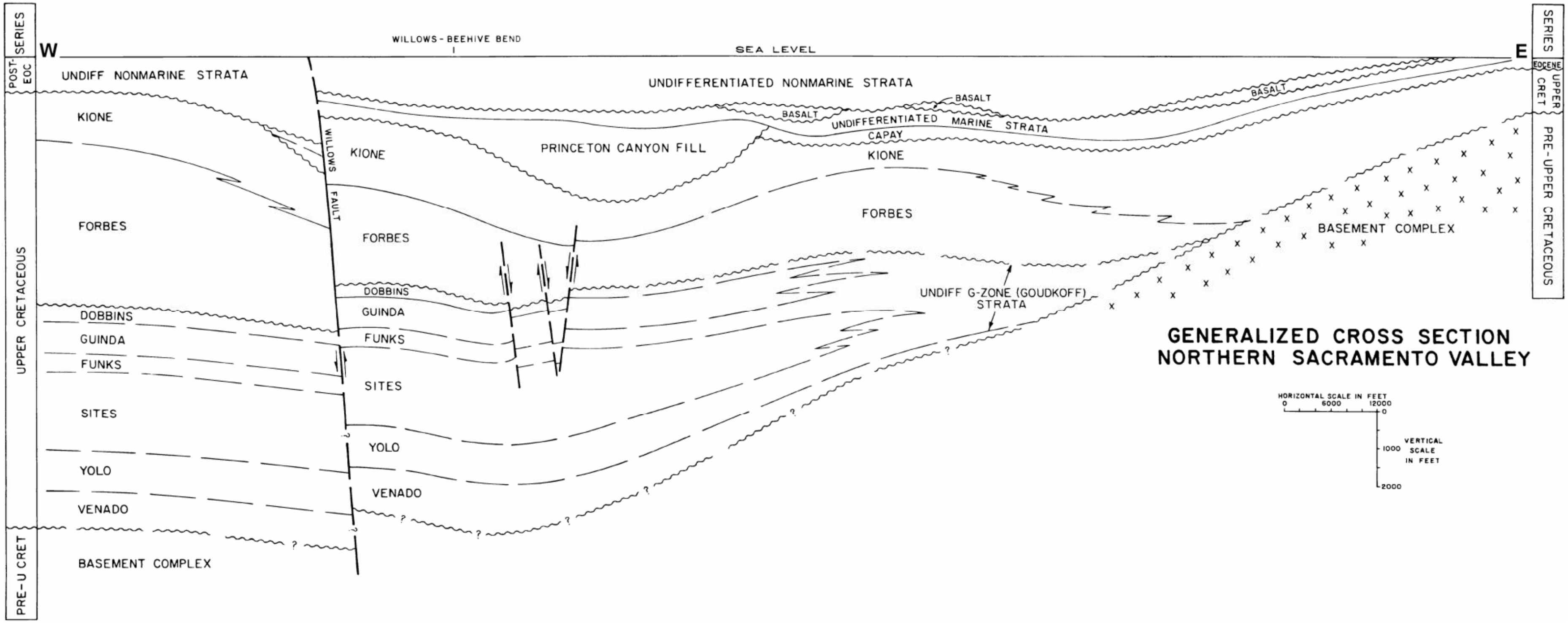
Overpressure begins in Shale-rich K section

North Sea Basin

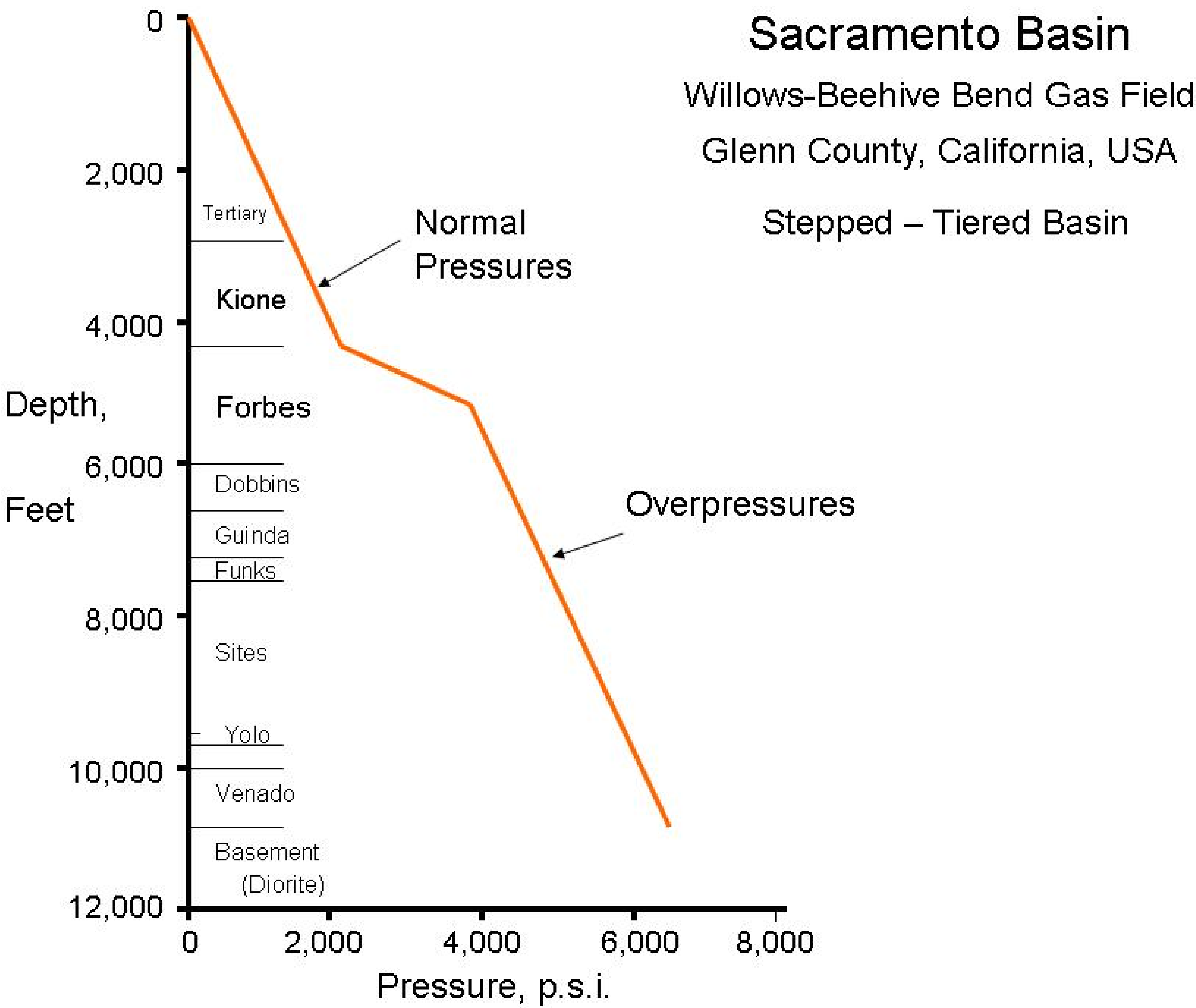


Generalized geologic map of the Sacramento Basin showing the location of the cross section. Map data from United States Geological Survey

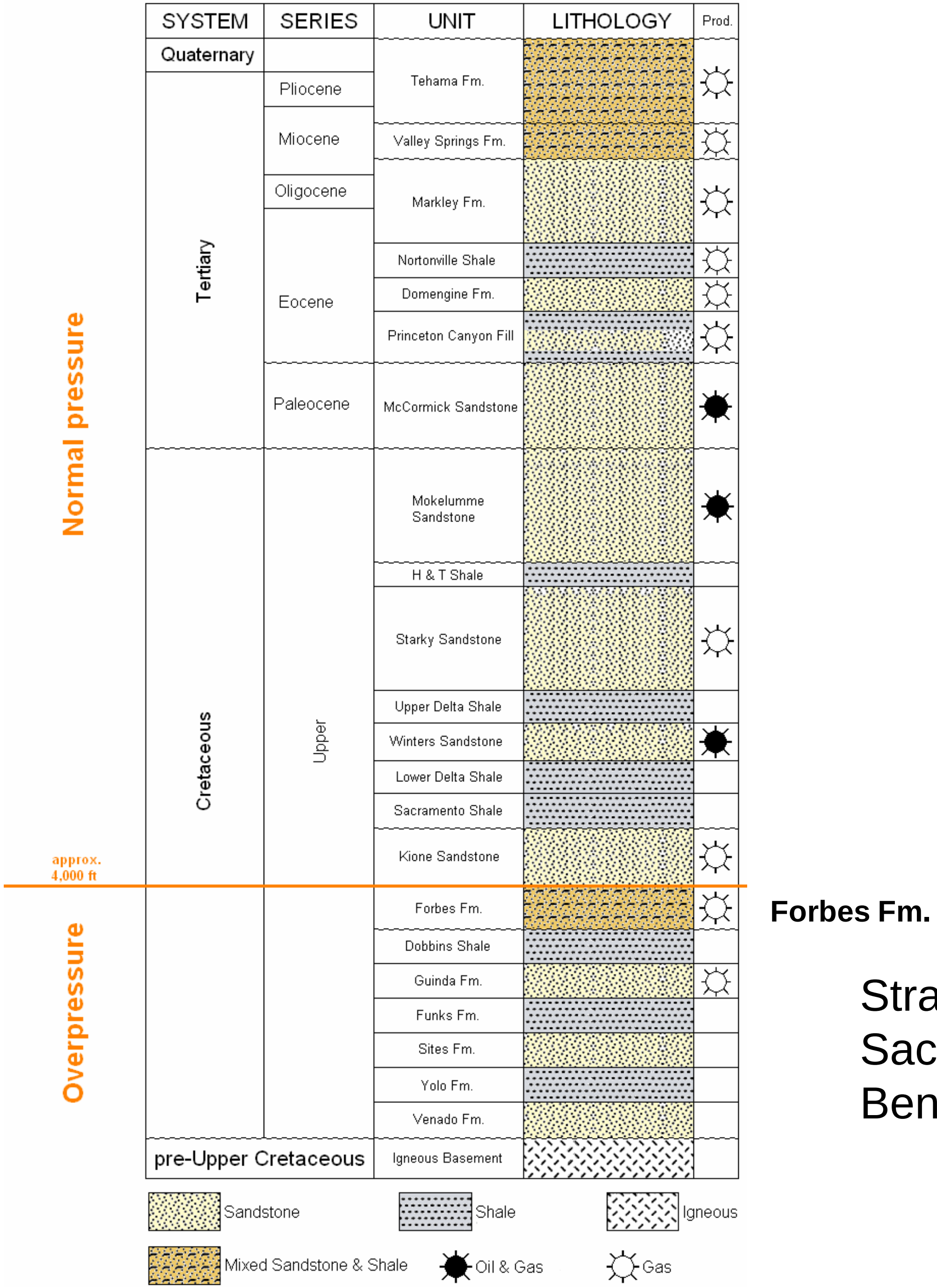
Sacramento Basin



Geologic cross section (W-E) through Willows-Beehive Bend Gas Field, Sacramento Basin, California, USA (adapted from California Department of Oil, Gas, and Geothermal Resources, 1982).


Sacramento Basin
Willows-Beehive Bend Gas Field
Glenn County, California, USA
Stepped – Tiered Basin
Normal Pressures
Overpressures
Depth, Feet
Pressure, p.s.i.
0
2,000
4,000
6,000
8,000
10,000
12,000
Tertiary
Kione
Forbes
Dobbins
Guinda
Funks
Sites
Yolo
Venado
Basement (Diorite)

Sacramento Basin



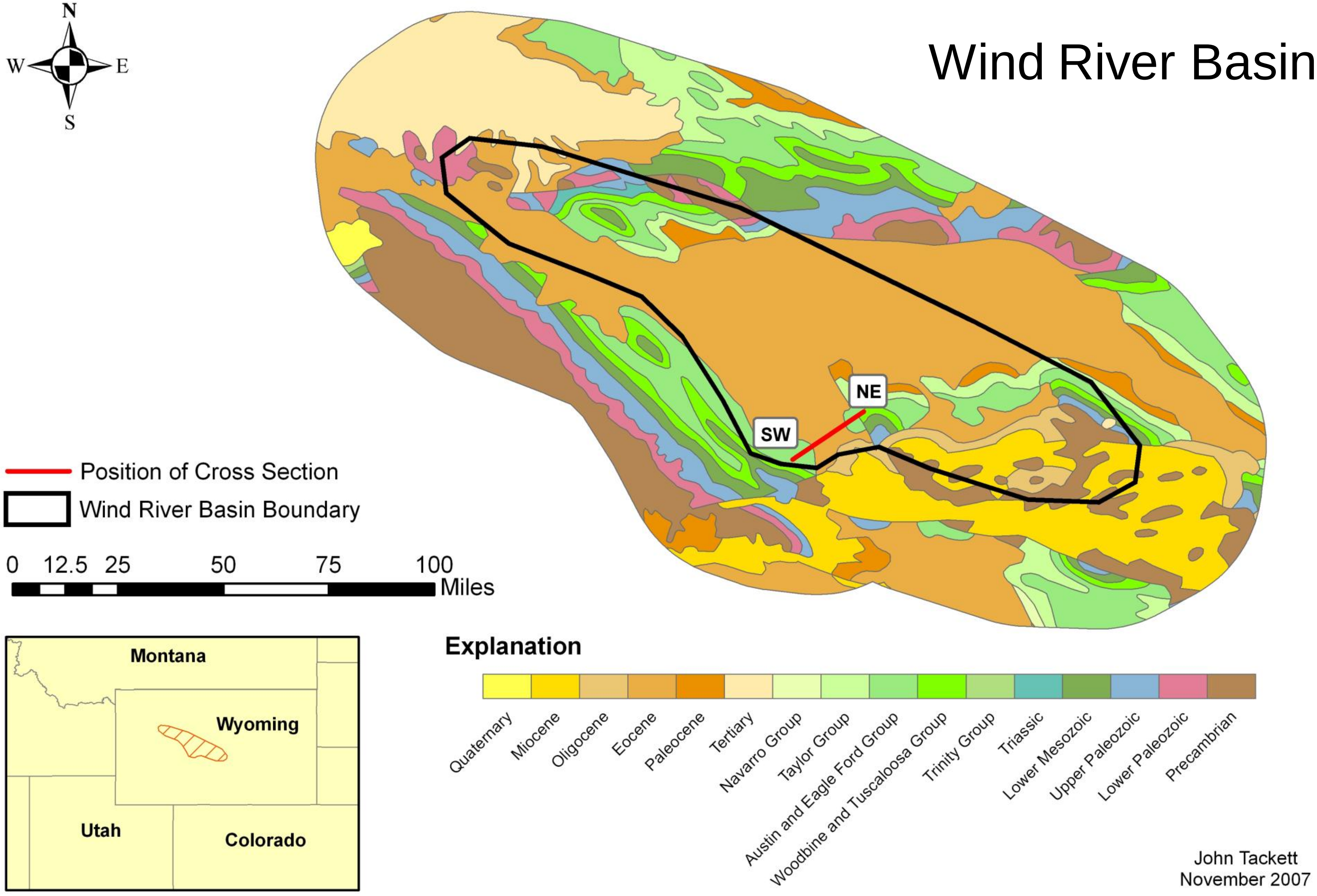
Shallow sandstone-rich interval is normally pressured.

Overpressures coincide with shale-rich formations beginning with Forbes Formation.

Stratigraphic column of the PDP for the Sacramento Basin, Willows-Beehive Bend area.

Recessed Pressure System

- Wind River Basin
- Big Horn Basin
- Alberta Basin
  - Subnormally pressured interval bounded above and usually below by normal pressures
  - Common in uplifted basins with breached reservoirs



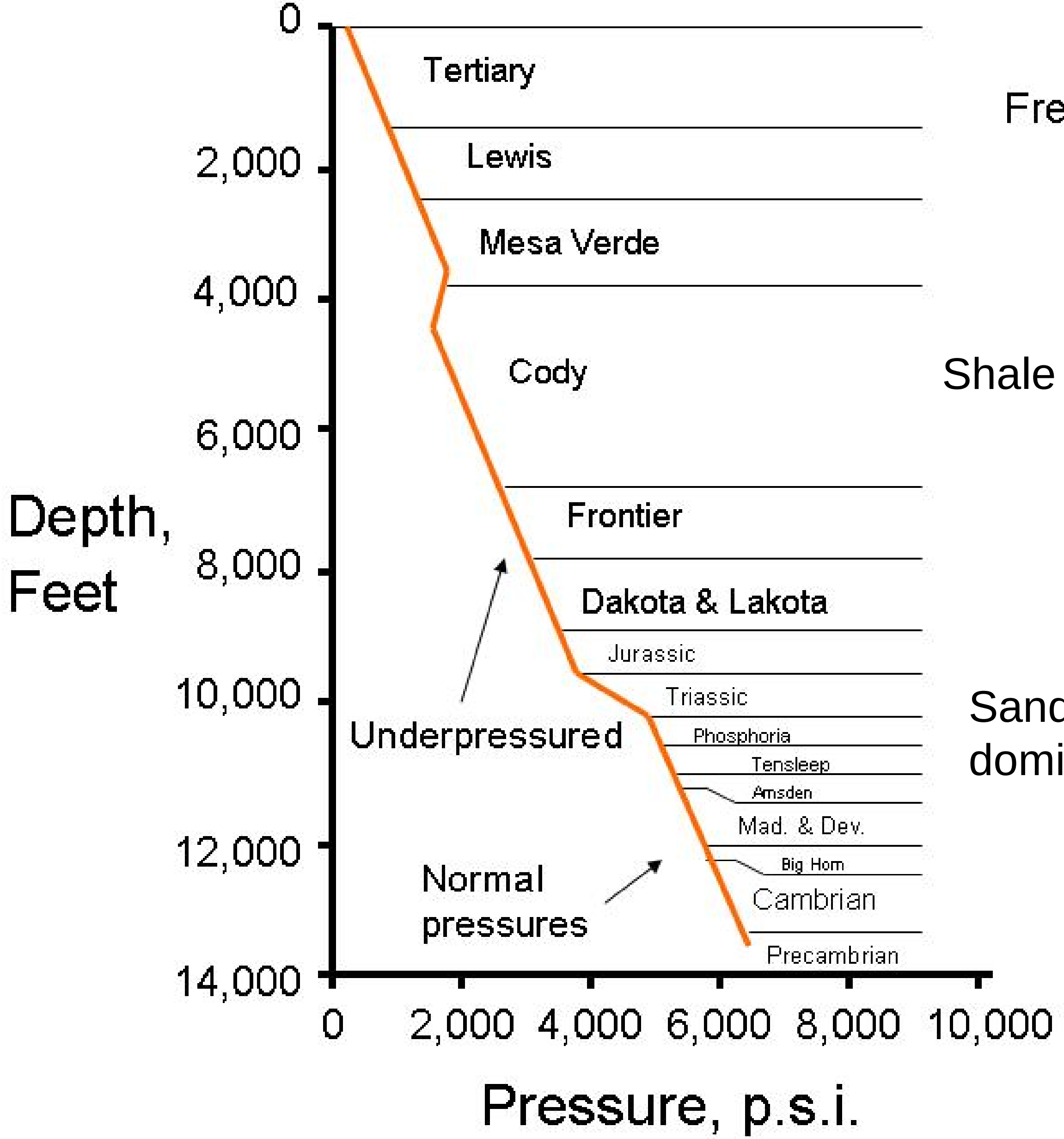
Generalized geologic map of the Wind River Basin showing the location of the cross section. Map data adapted from the United States Geological Survey.

Wind River Basin

Beaver Creek Field

Fremont County, Wyoming, USA

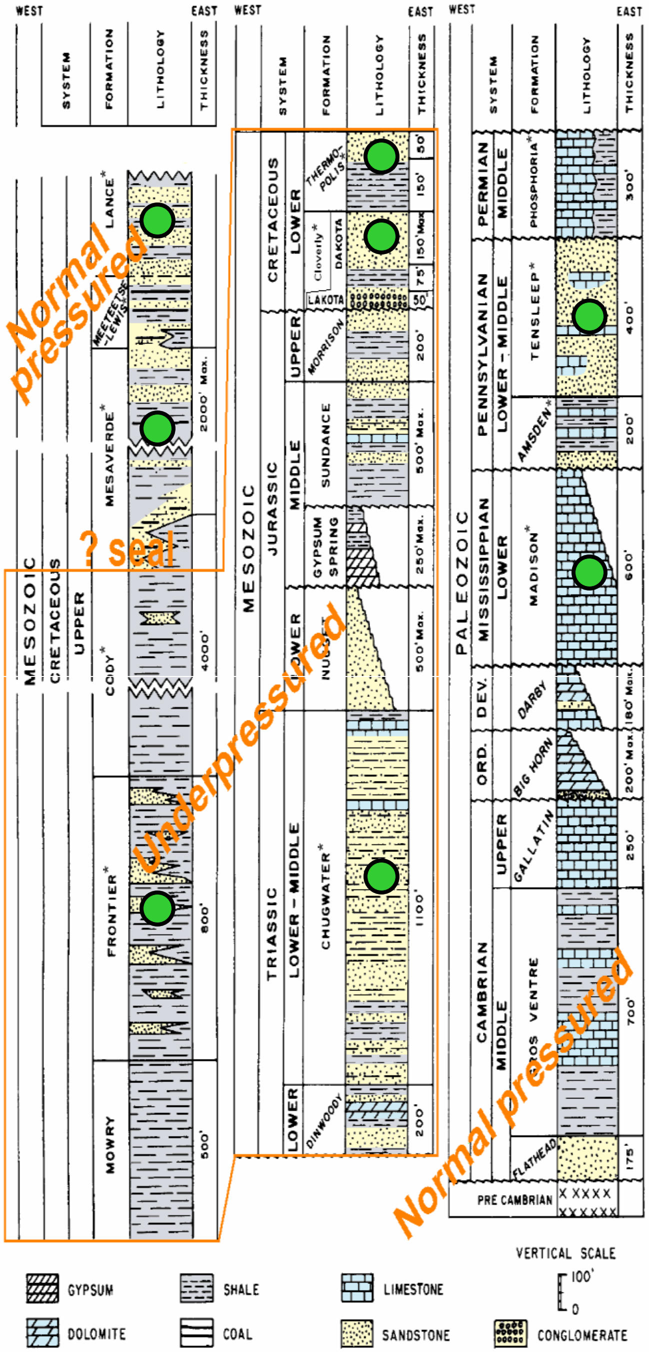
Recessed – Tiered Basin



Shale dominated

Sandstone and carbonate dominated

Adapted from D. Powley



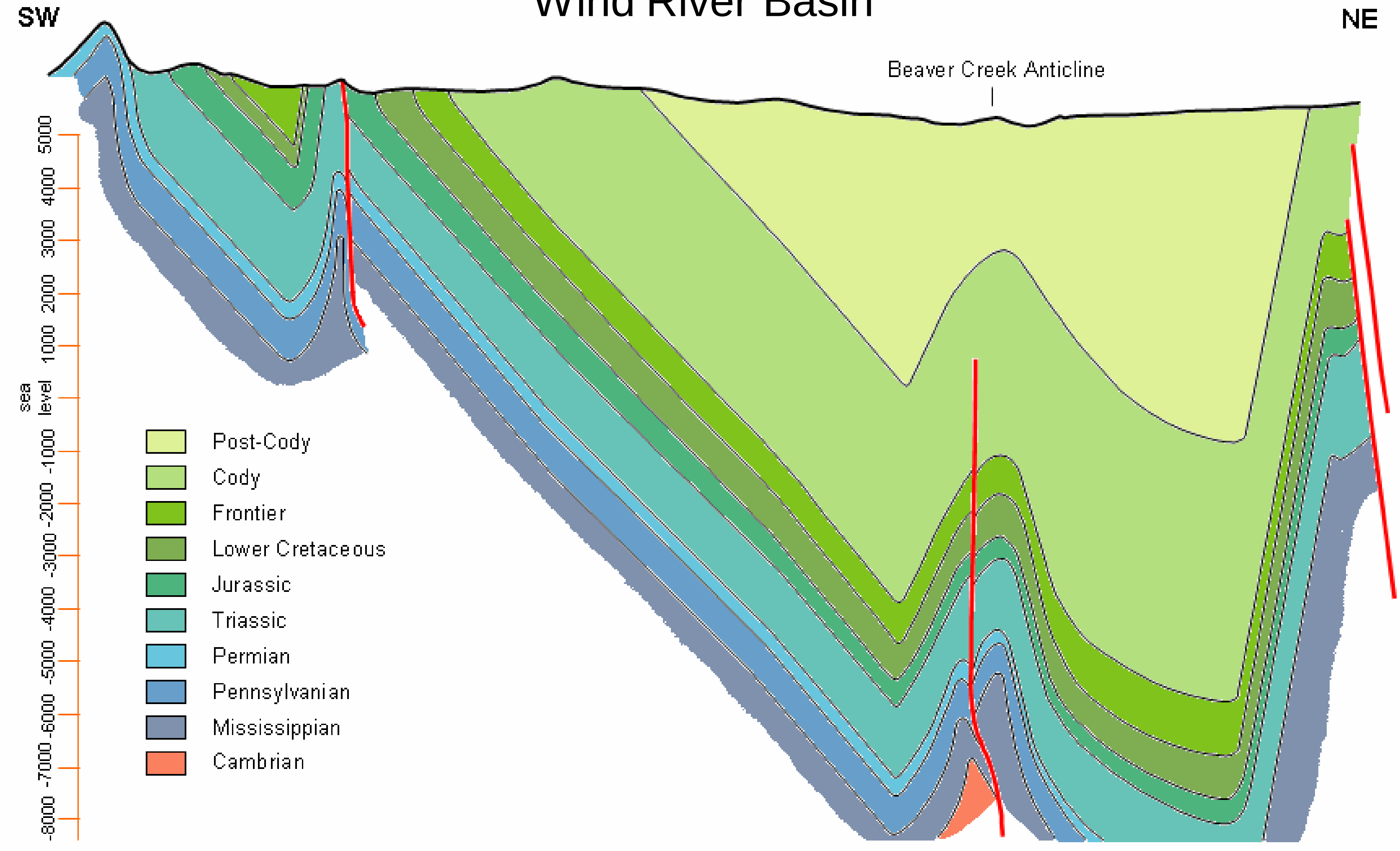
Wind River Basin

Stratigraphic column of the PDP for the Wind River Basin, Beaver Creak area.

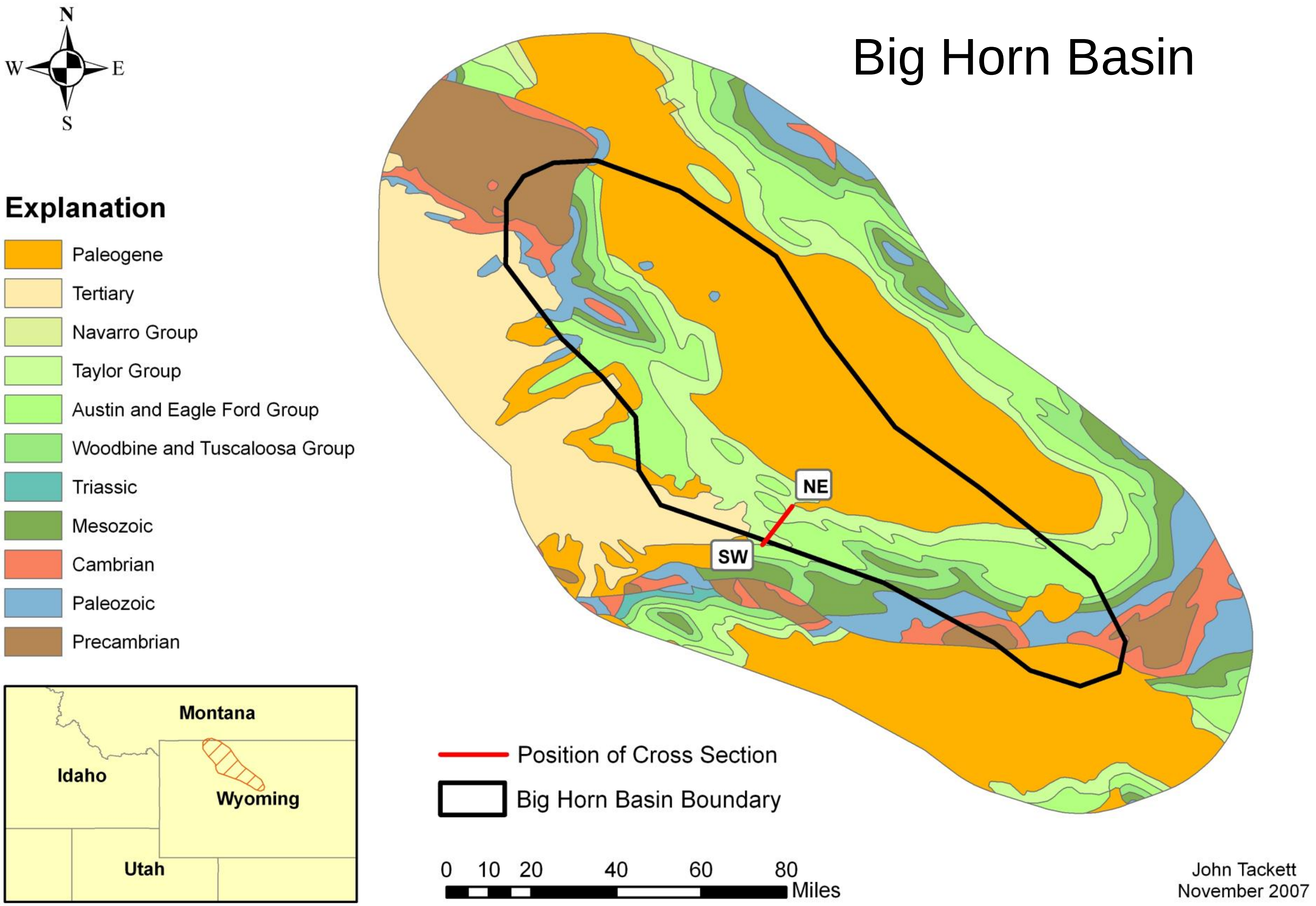
Underpressuring begins in the shale-dominated Cody interval and extends to the Chugwater. Sandstones and carbonates below Chugwater are normally pressured.

Generalized stratigraphic column of the Wind River Basin (adapted from Paape, 1968) Petroleum-producing formations are marked with a circle (Keefer and Johnson, 1993).

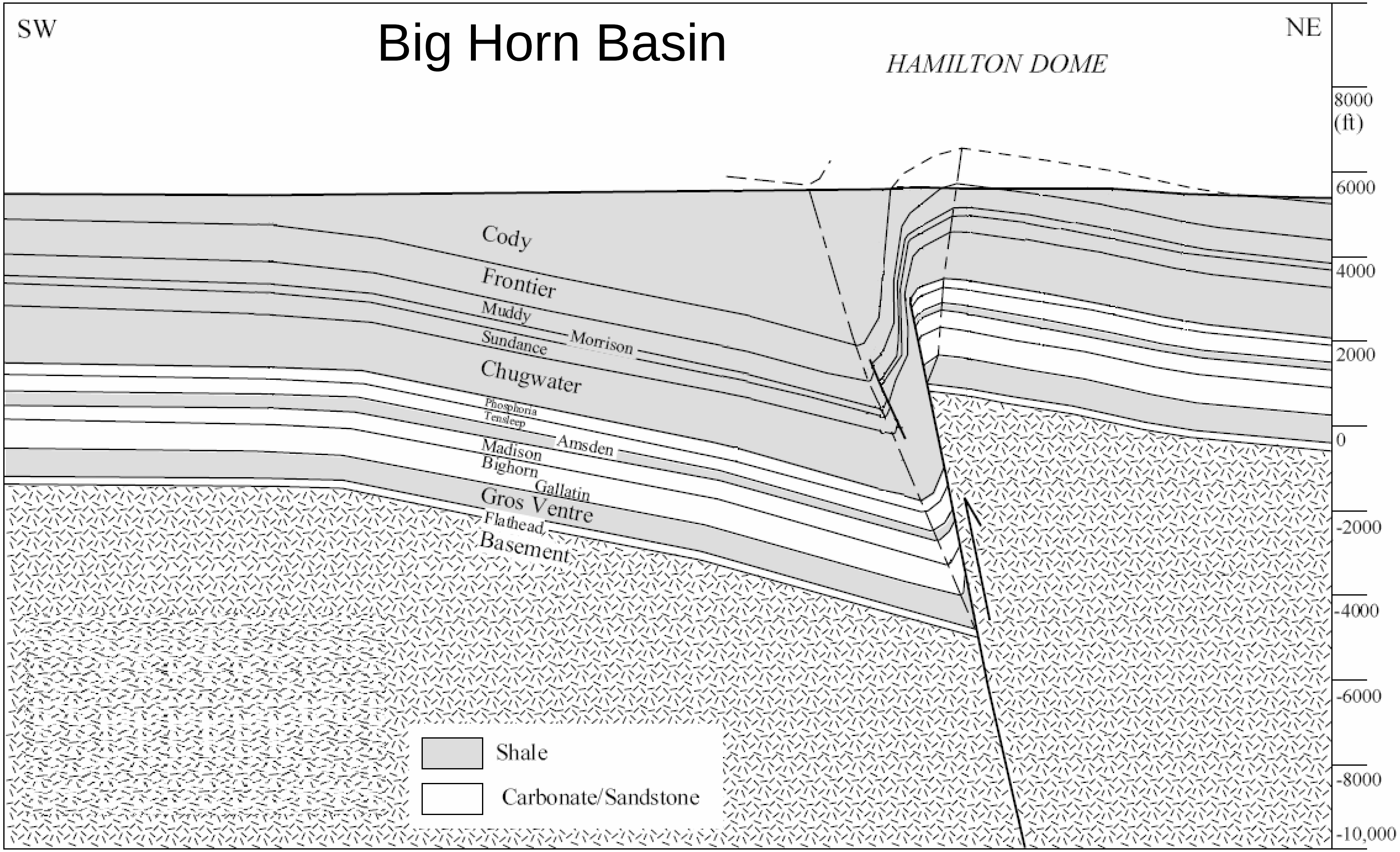
Wind River Basin



Generalized cross section (SW-NE) through the Beaver Creek Anticline, Wind River Basin, U.S.A. (adapted from Kewanee Oil Co, 1961).



Generalized geologic map of the Big Horn Basin showing the location of the cross section. Map data adapted from the United States Geological Survey.



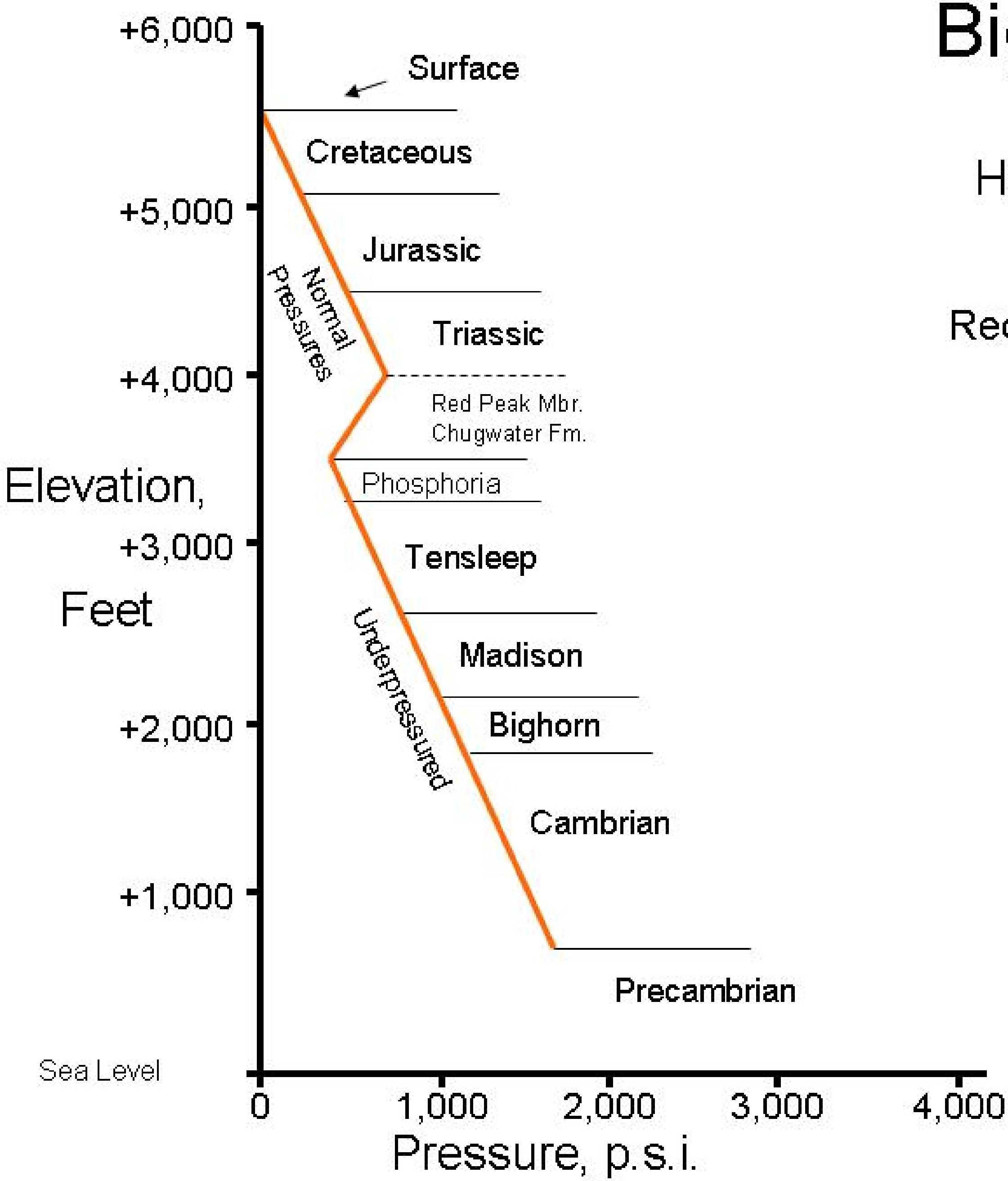
Geologic cross section (SW-NE) through the Hamilton Dome Area, Big Horn Basin, U.S.A. (from Mitra and Mount, 1998).

Big Horn Basin

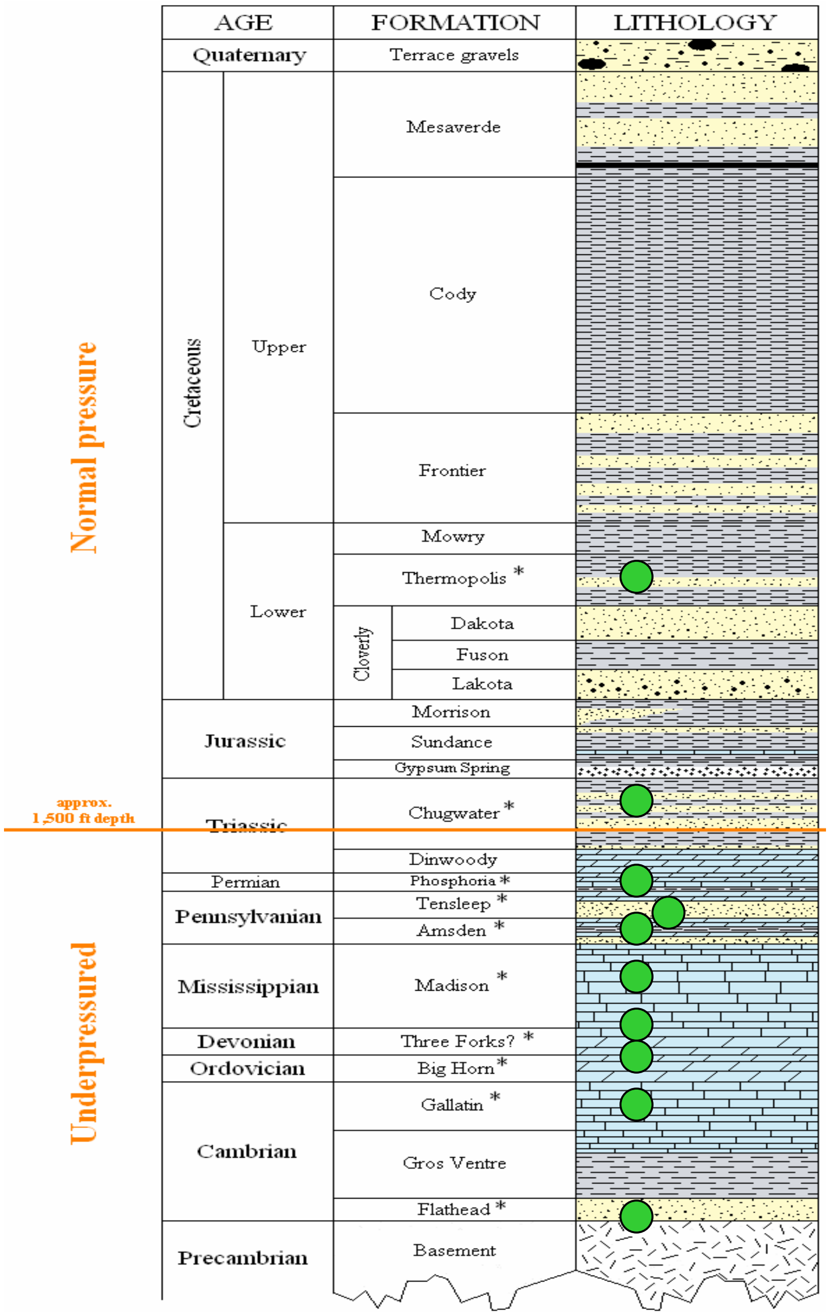
Hamilton Dome

Hot Springs County, Wyoming, USA

Recessed – Tiered Basin



Adapted from
D. Powley

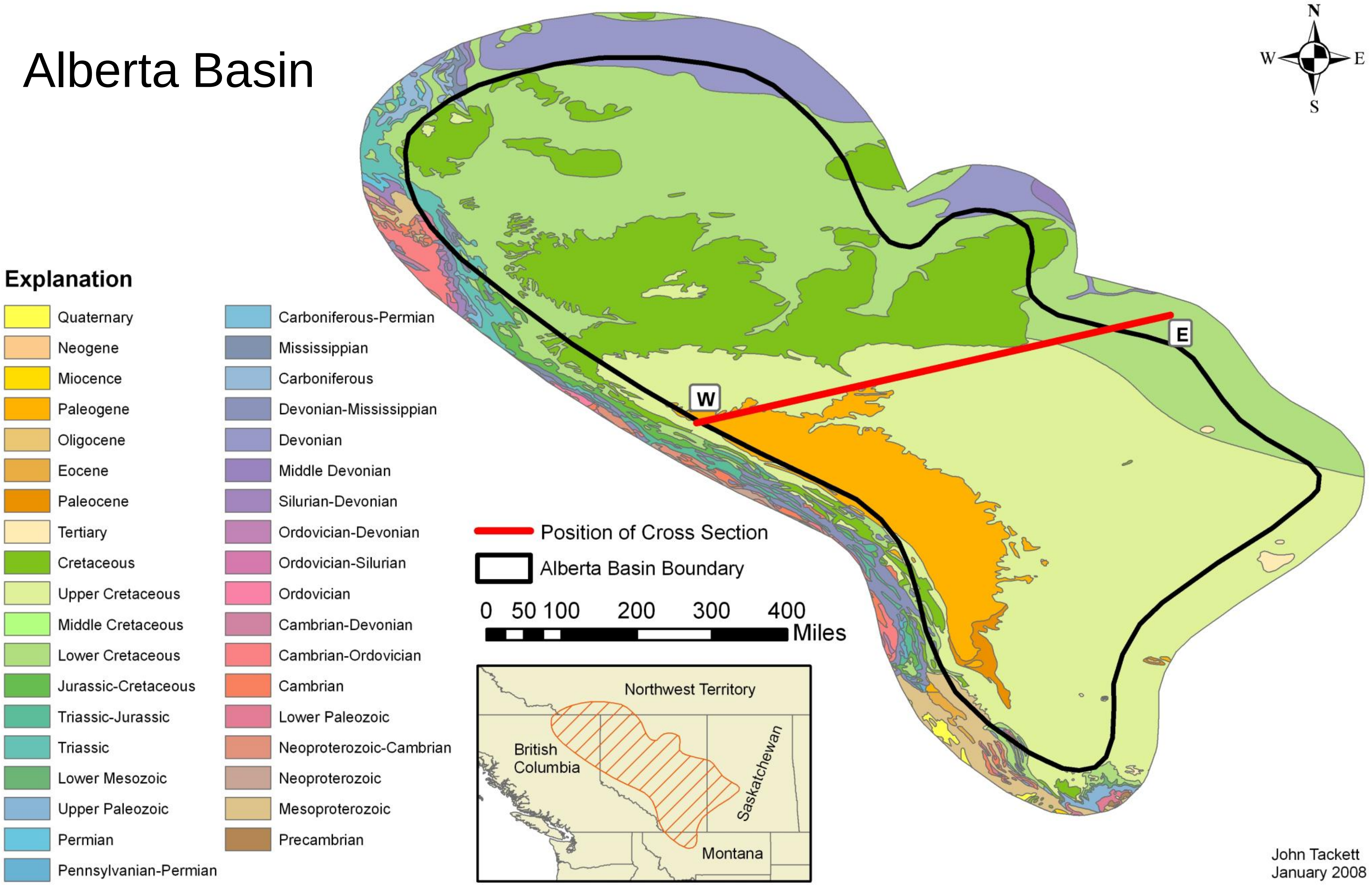


Big Horn Basin

Normal pressures extend to the Chugwater. Underpressures on the Hamilton Dome extend from the Chugwater to the top of Precambrian

Stratigraphic column of the Hamilton Dome, Big Horn Basin (adapted from Krampert, 1947, Mitra and Mount, 1998, and WGA, 1952). Petroleum producing formations are marked with a circle ● (Chapman, 1989).

Alberta Basin



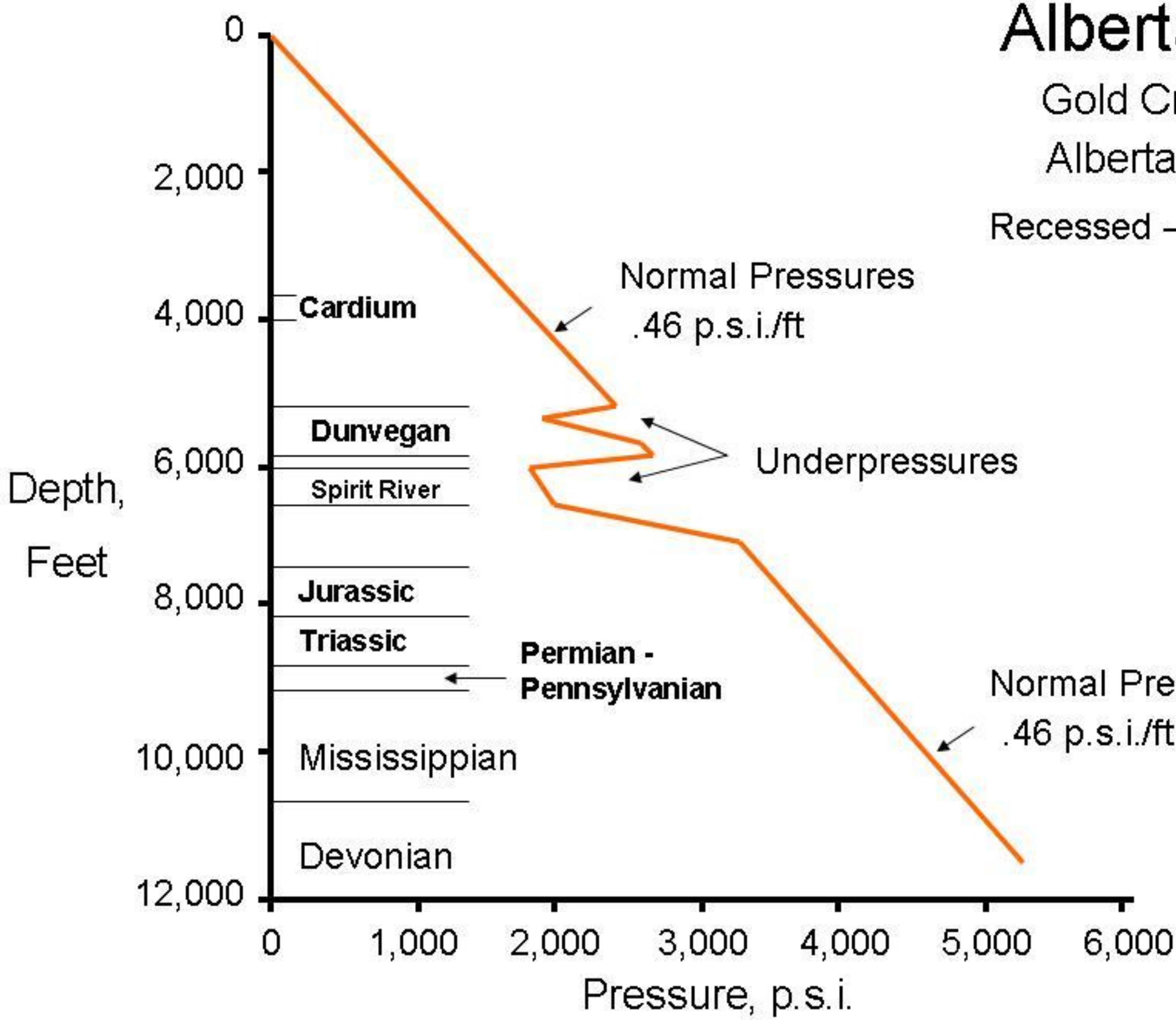
Generalized geologic map of the Alberta Basin showing the location of the cross section. Map data from the Geological Survey of Canada and USGS.

Alberta Basin

Gold Creek Field

Alberta, Canada

Recessed – Tiered Basin



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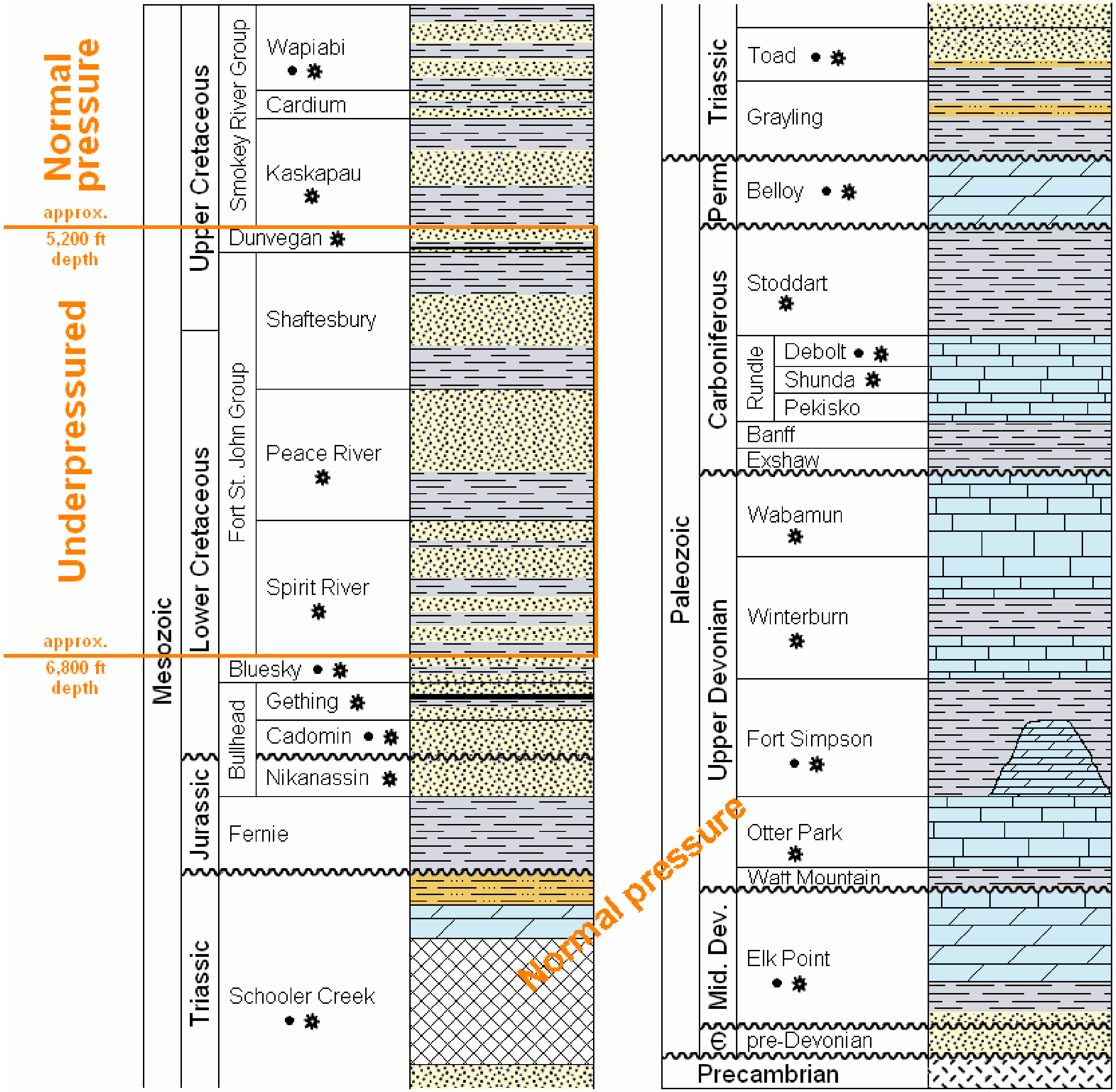
D. Powley

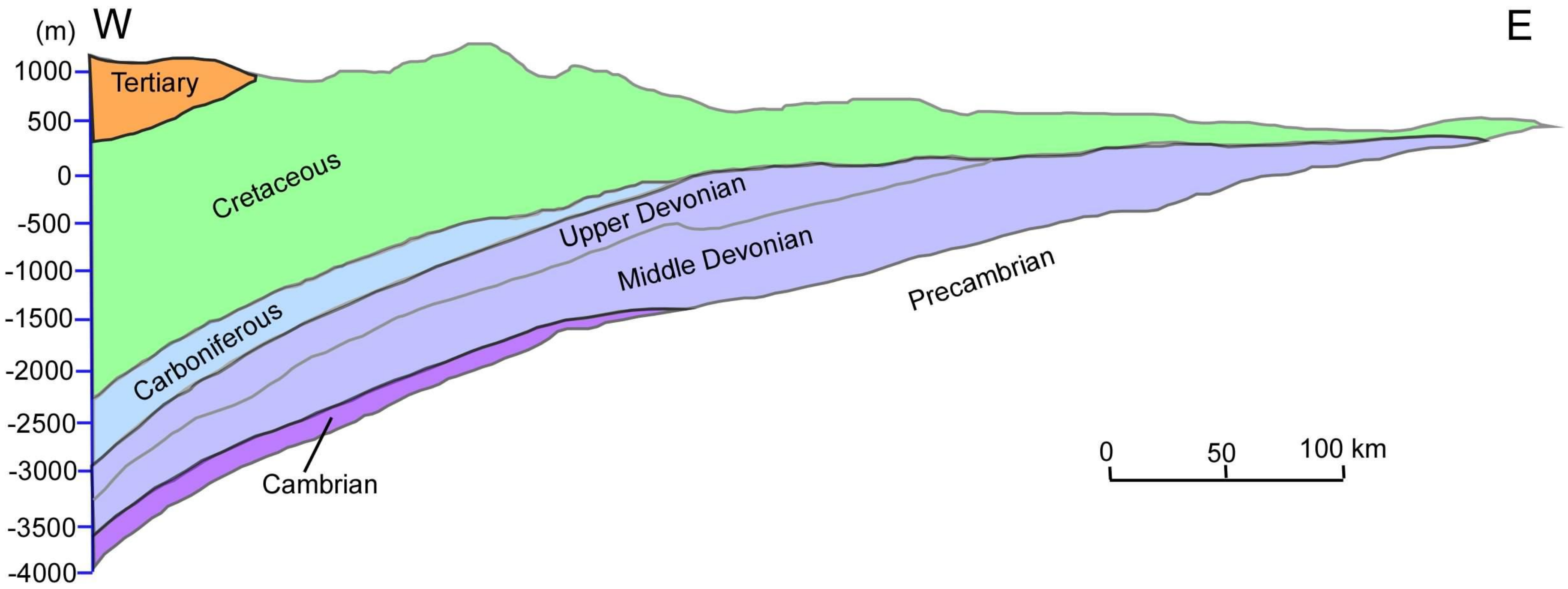


Alberta Basin

Underpressure occurs in K rocks exposed to surface. Normal pressure returns in deeper shale-rich strata

Generalized stratigraphic column, Peace River Area, Alberta Basin (adapted from Alberta Study Group, 1954, Clark et al., 1968, Gleddie, 1954, Hunt and Radcliffe 1959, Lackie, 1958, and Macauly, 1958). Petroleum-producing formations are marked (Clark et al., 1989).

Alberta Basin

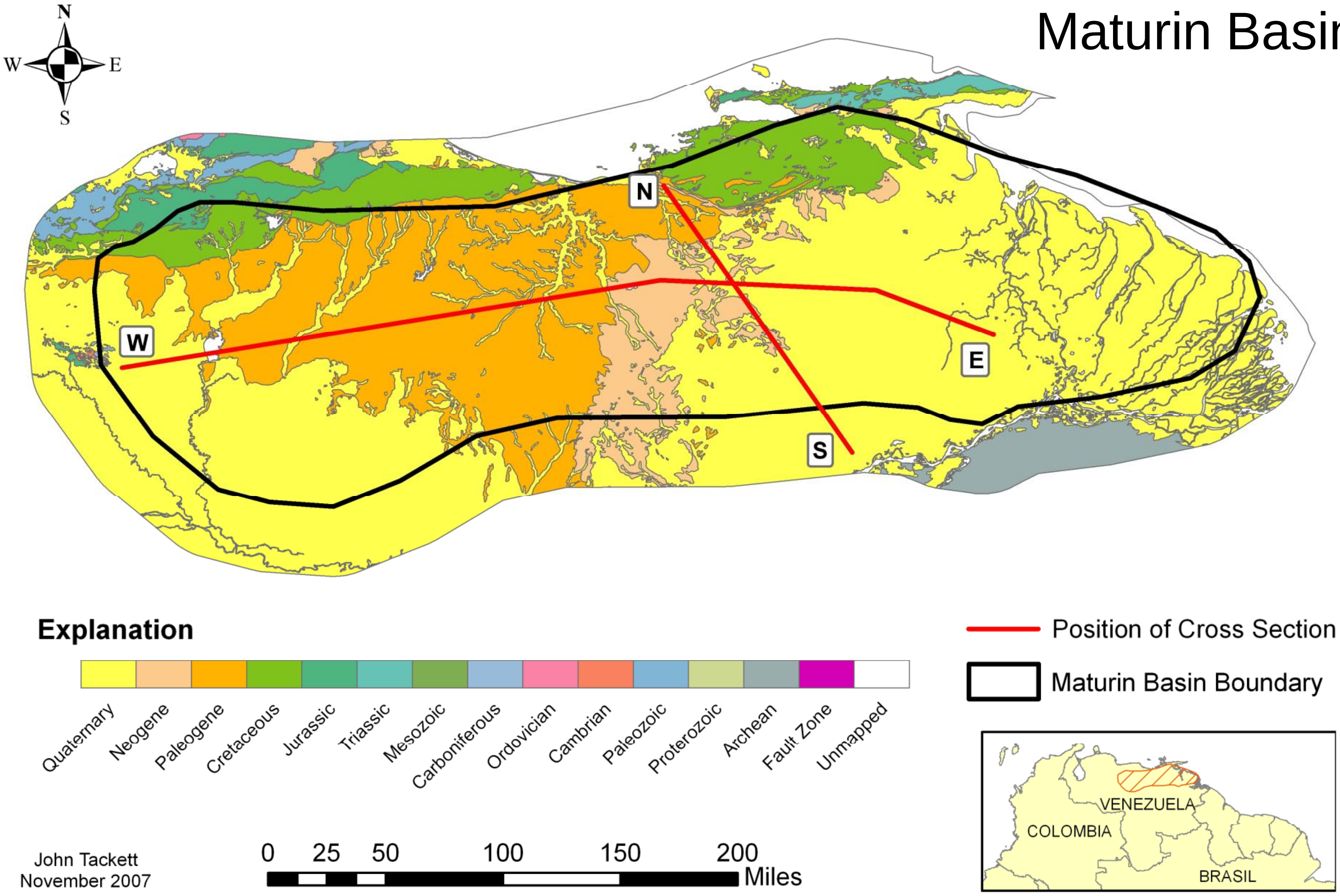


Geologic cross section (W-E) across central Alberta Basin, Alberta, Canada (adapted from Bachu, 1999).

Ledged Pressure Systems

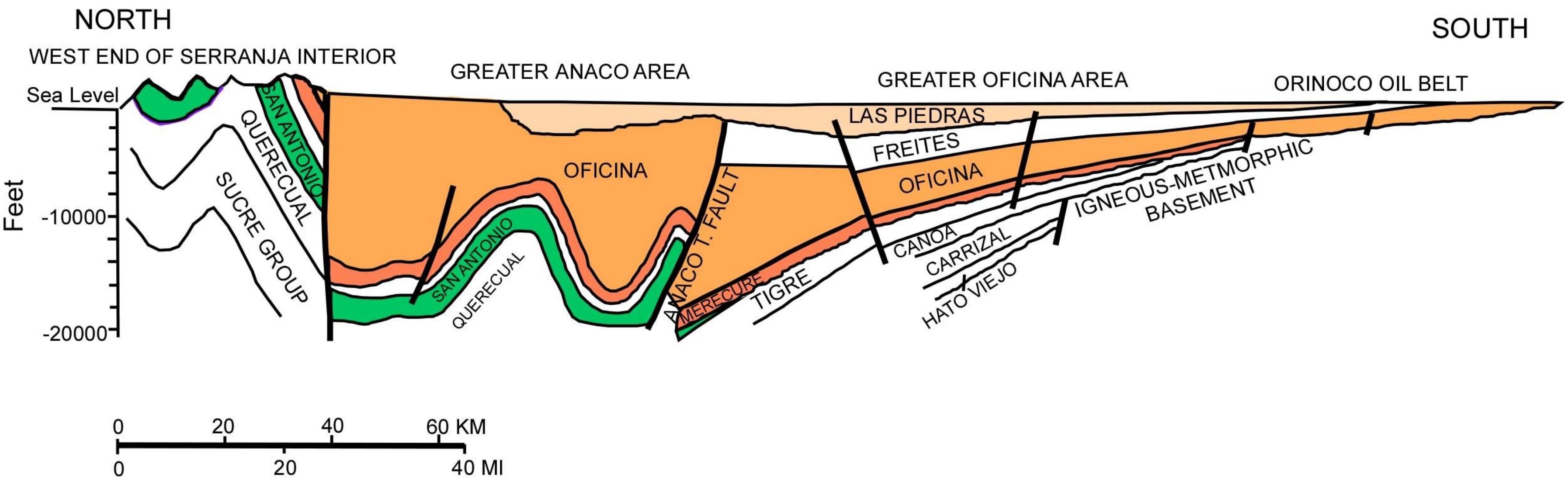
- Maturin Basin
- Anadarko Basin
  - Shallow normal pressure in sandstone-rich interval
  - Shale-dominated overpressured interval with discontinuous sandstones or very low porosity carbonates or coarse siliciclastics (GW)
  - Deeper normally pressured interval with reservoirs in continuity with the outcrop

Maturin Basin



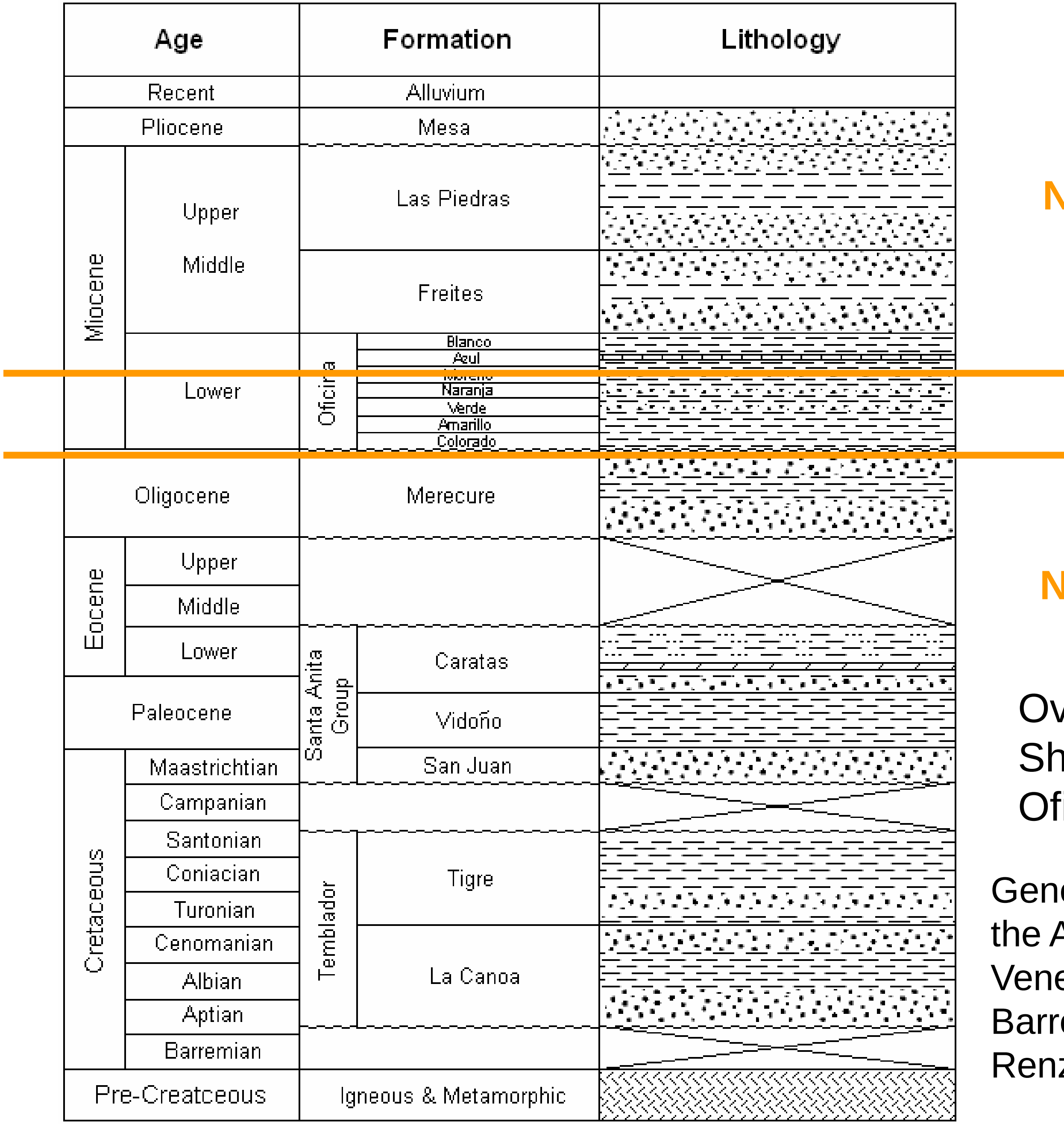
Generalized geologic map of the Maturin Basin showing the location of the cross section. Map data from the United States Geological Survey.

Maturin Basin



Geologic cross section (N-S) through the central portion of the Maturin Basin, Venezuela (adapted from Villaroel, 1993).

Maturin Basin



Normal Pressure

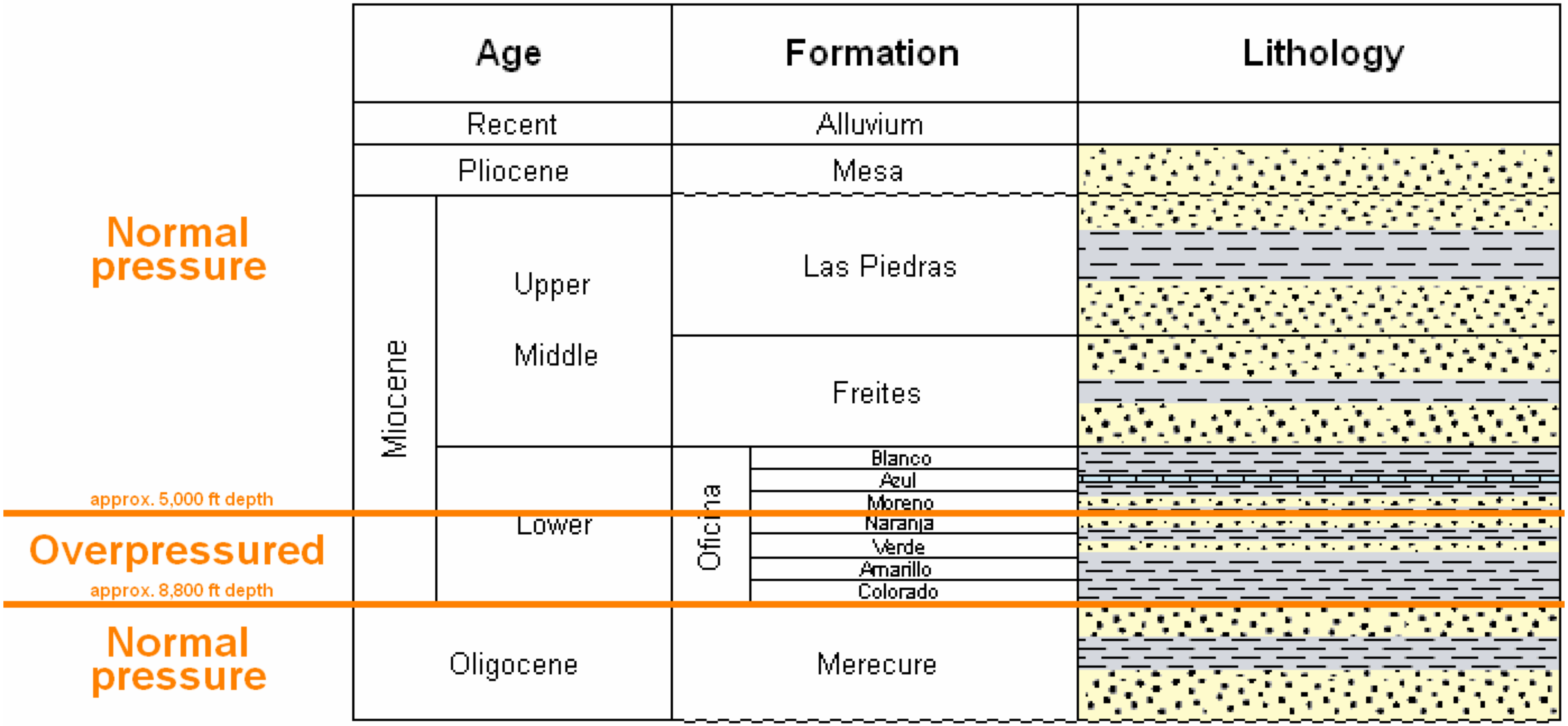
Overpressured

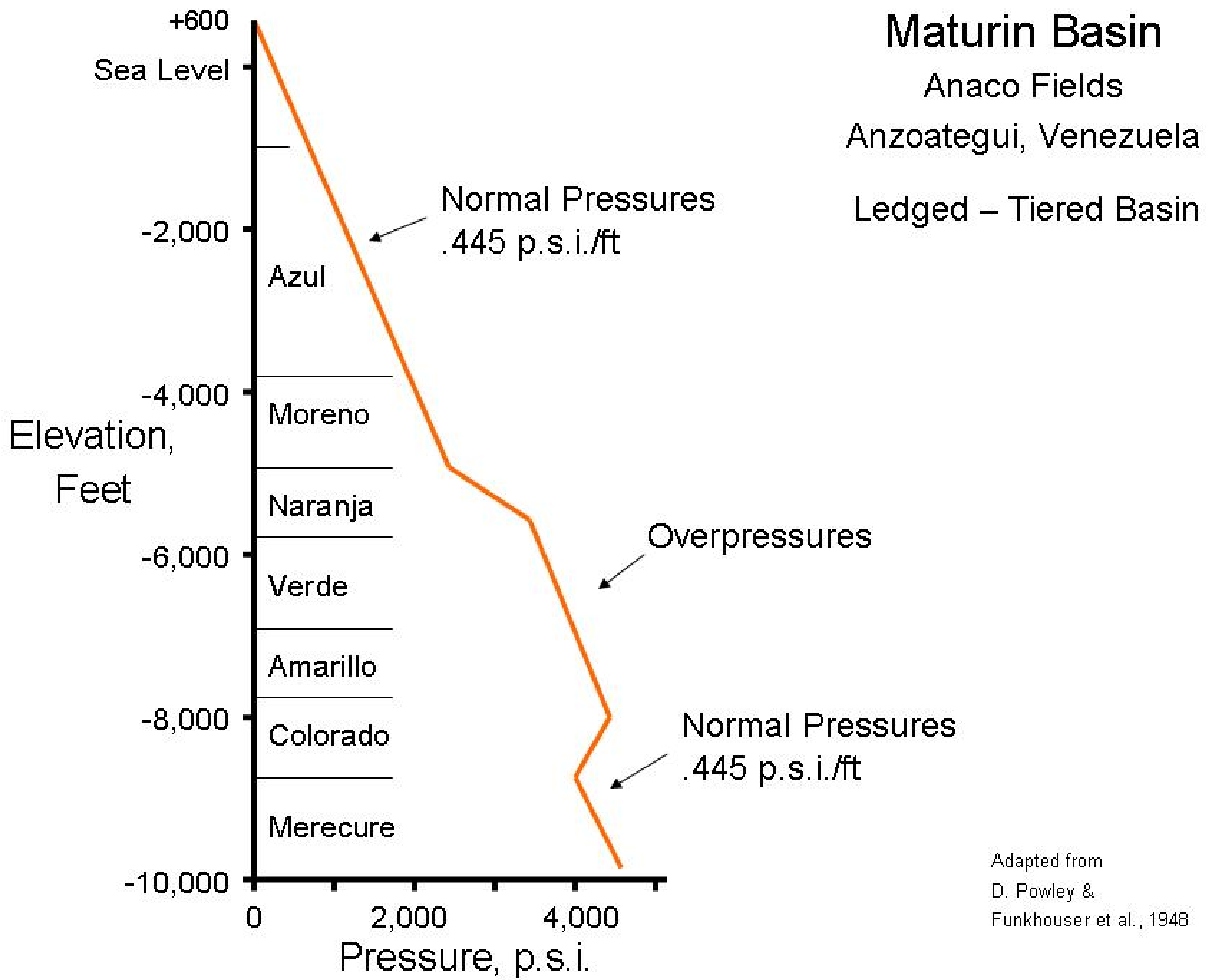
Normal Pressure

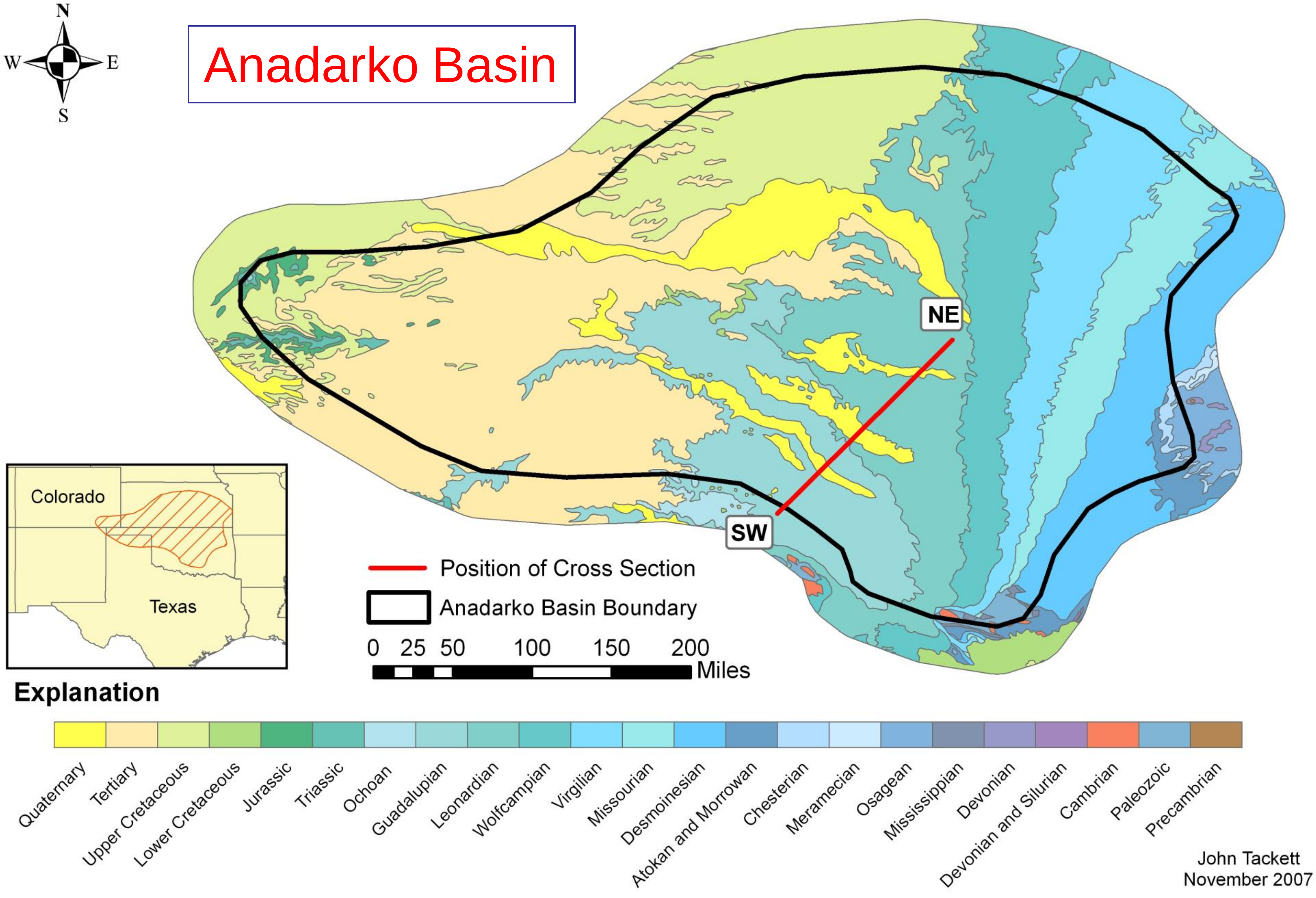
Overpressure Confined to Shale-rich Members of the Oficina Formation

Generalized stratigraphic column of the Anaco field area, Maturin Basin, Venezuela (adapted from Erlich and Barrett, 1992, Murany, 1972, and Renz et al., 1958).

Maturin Basin

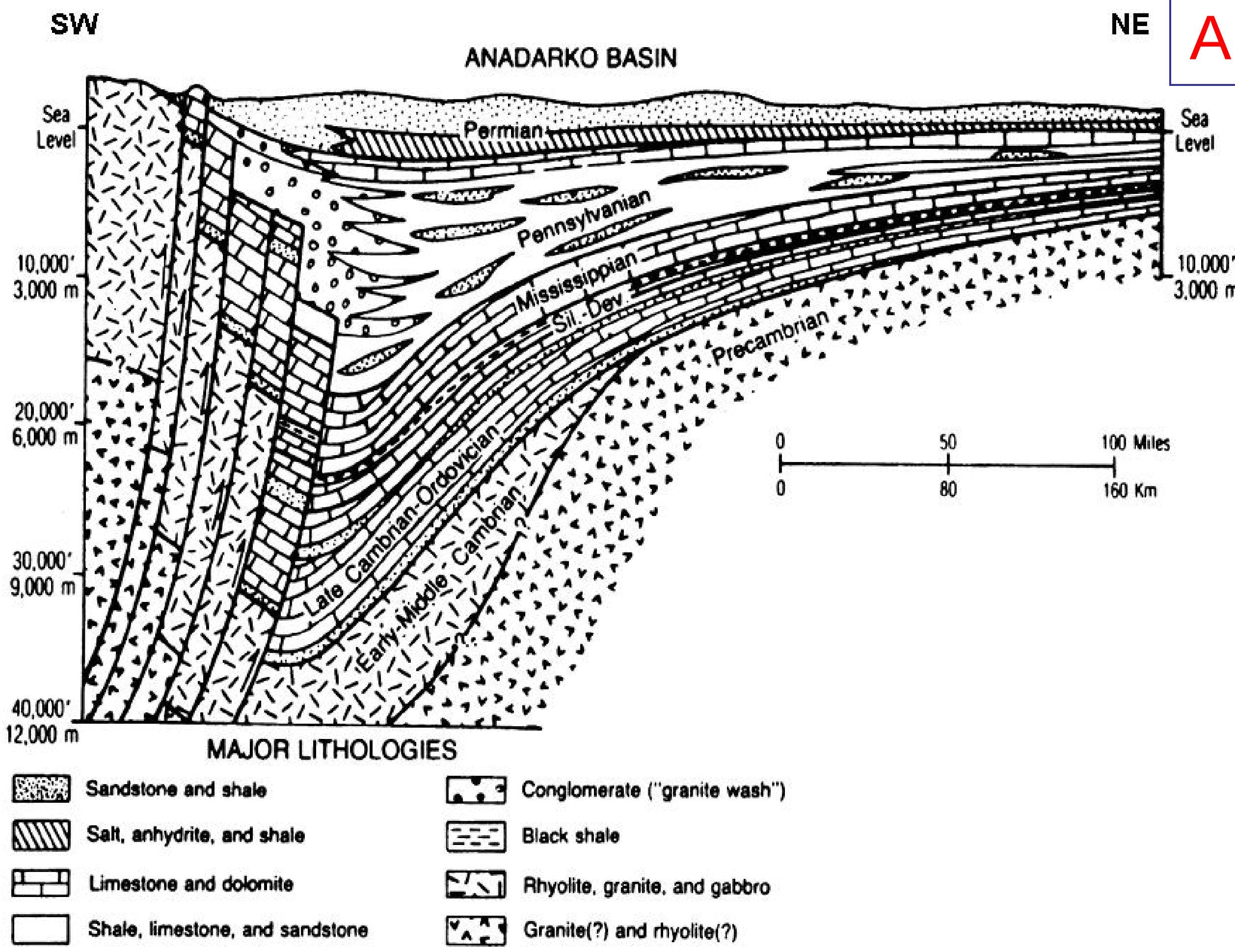



Maturin Basin
Anaco Fields
Anzoategui, Venezuela
Ledged – Tiered Basin
+600
Sea Level
-2,000
-4,000
-6,000
-8,000
-10,000
Elevation, Feet
Azul
Moreno
Naranja
Verde
Amarillo
Colorado
Merecure
Normal Pressures
.445 p.s.i./ft
Overpressures
Normal Pressures
.445 p.s.i./ft
0
2,000
4,000
Pressure, p.s.i.
Adapted from
D. Powley &
Funkhouser et al., 1948



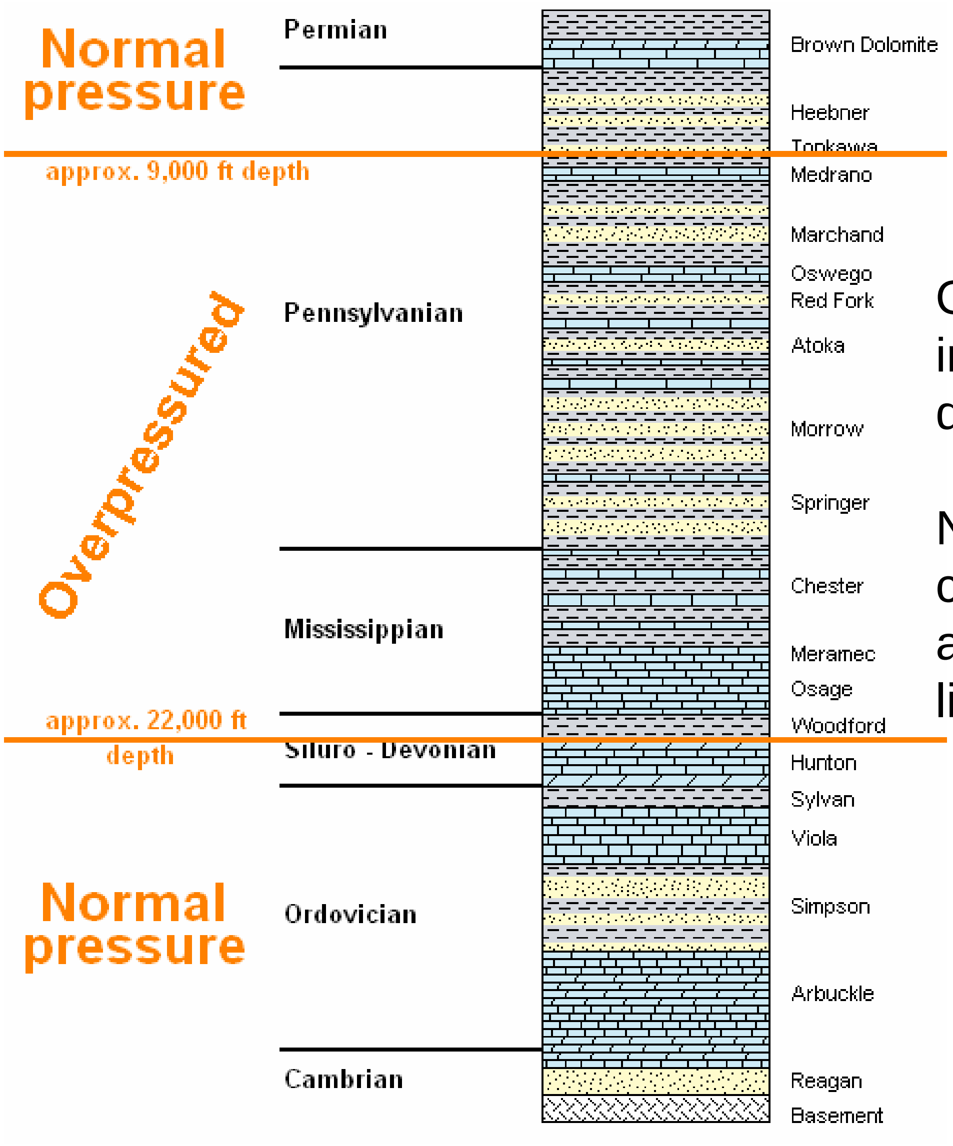
Generalized geologic map of the Anadarko Basin showing the location of the cross section. Map data from the USGS.

Anadarko Basin



Generalized cross section (SW-NE) through the Anadarko Basin, U.S.A. (from Johnson, 1989).

Anadarko Basin



Overpressure occurs in shale-rich intervals below 8,000 to 10,000 ft with discontinuous reservoirs.

Normal pressure returns in regionally continuous reservoirs of the Hunton Gp. and Arbuckle Gp. that are hydraulically linked to surface.

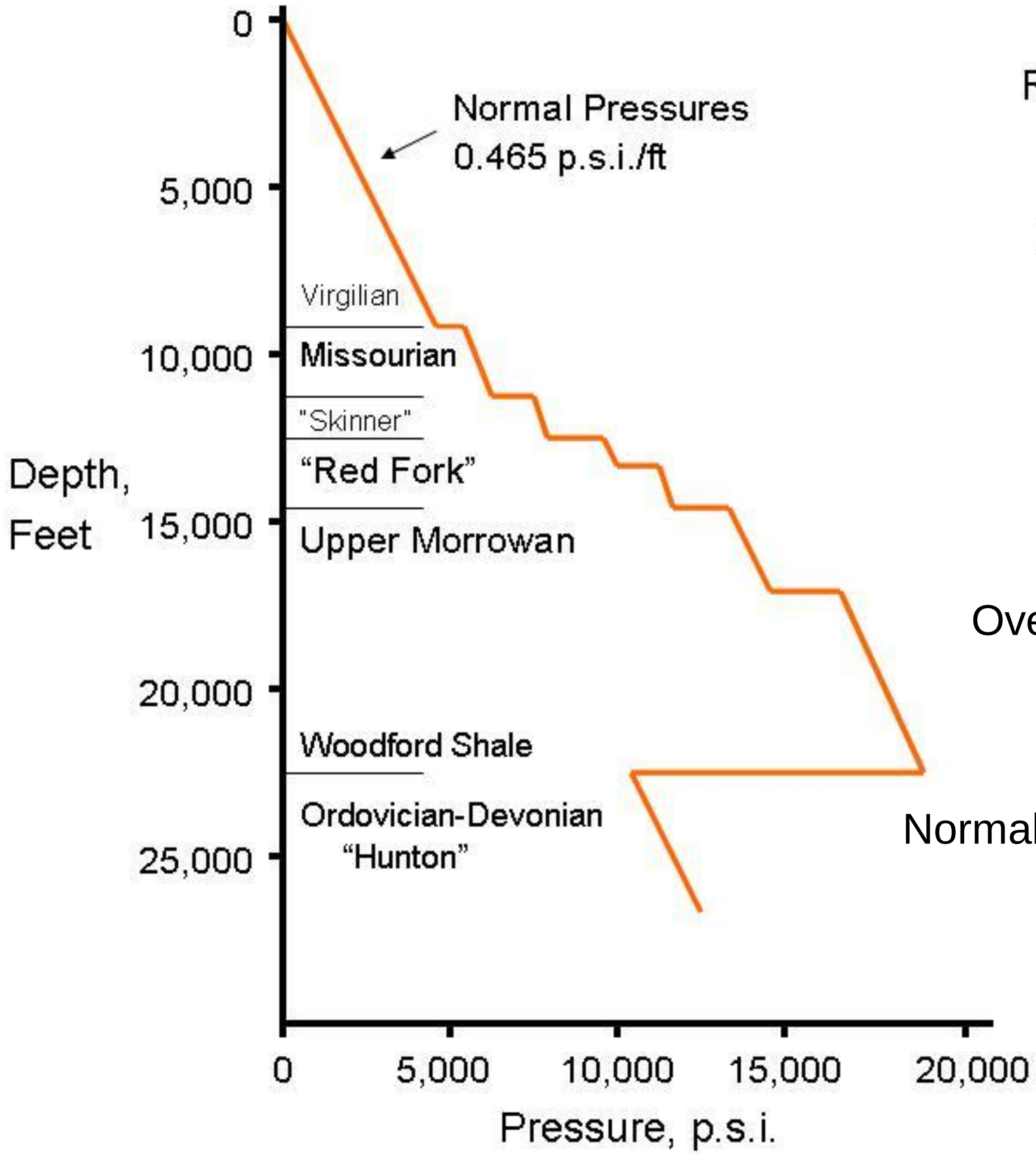
Generalized stratigraphic column of the Anadarko Basin (adapted from Al-Shaieb et al., 1999) No scale is intended.

Anadarko Basin

Reydon-Cheyenne Area

Oklahoma, USA

Ledged – Tiered Basin



Overpressured MCC

Normally Pressured Hunton Group

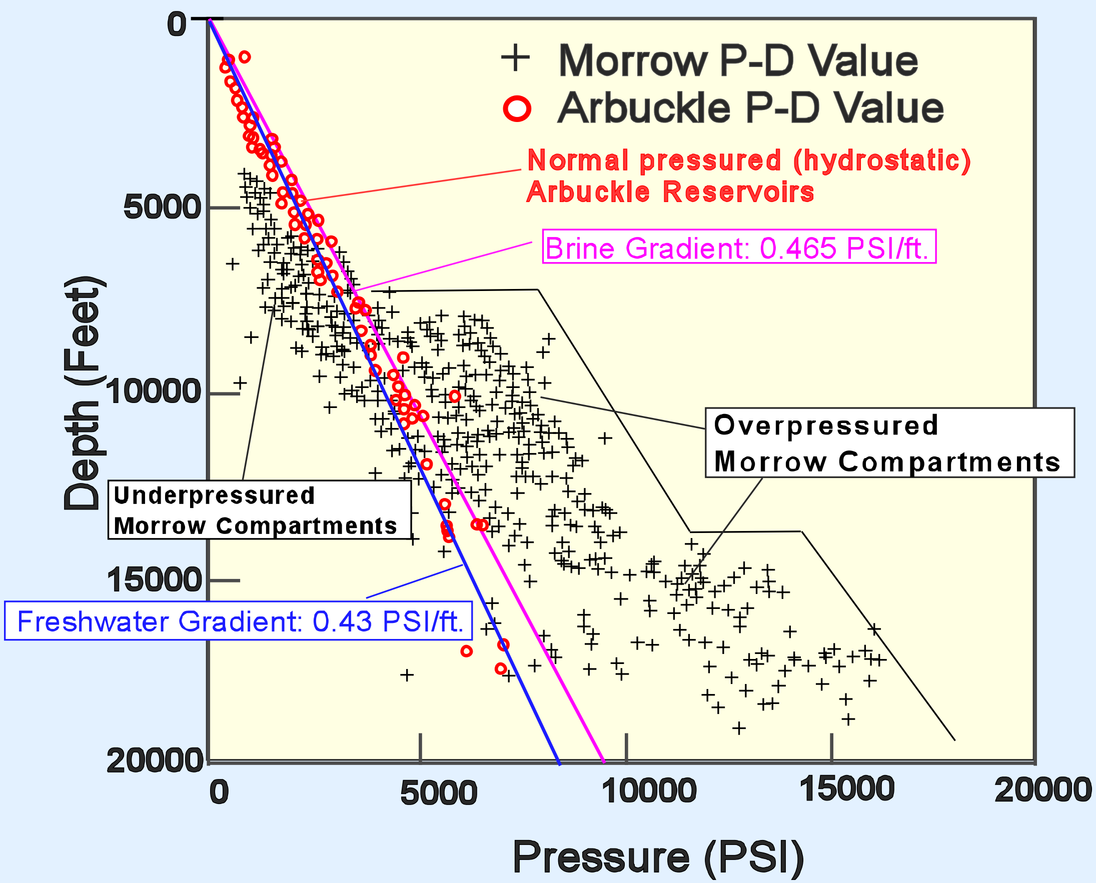
Adapted from
Al-Shaieb et al, 1994

Anadarko Basin

- Prior to recent drilling activity, Woodford pressure was only known from a few vertical wells and mud-weight-derived values
- Reservoir pressures in CANA area show Woodford to be slightly overpressured with pressures increasing to the west, with P-D values reaching (0.65+) in Dewey County
- Hunton Group carbonates below the Woodford are mostly normally pressured creating a potential for communication and flow from higher to lower pressure
- Hunton communicated with outcrop in Pennsylvanian; it continues today

Deep Normal Pressure

- Deep normally pressured interval is of interest to industry because of fluid-disposal potential
- Arbuckle Group reservoirs are mostly normal to slightly subnormal across Oklahoma
- Areas of slight overpressure exist where elevation of recharge creates potential energy
- Overpressure in Wilburton field is likely increased as a result of buoyancy-related compression



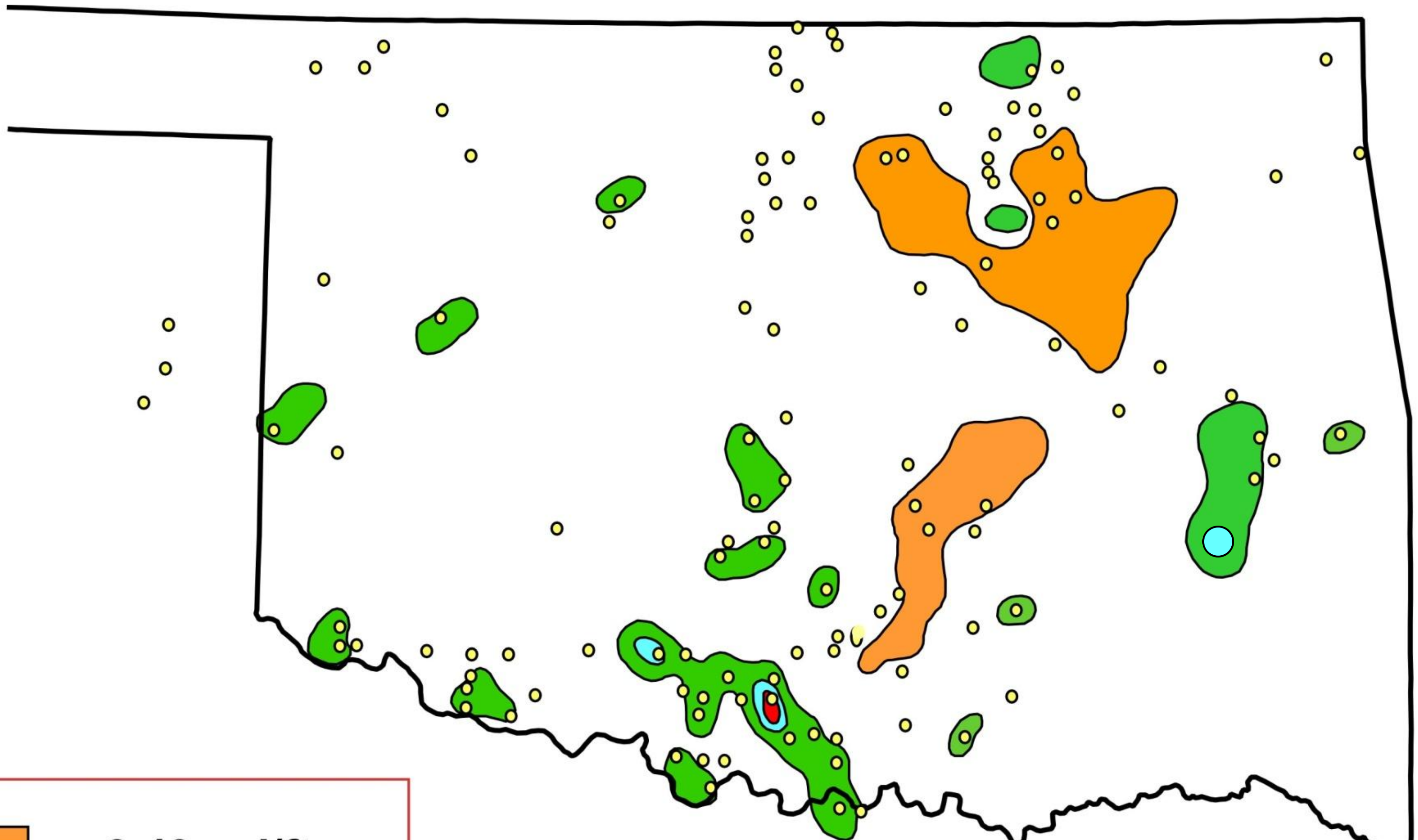
Pressure-Depth Relationship:

Compartmentalized and Hydrostatic Reservoirs

Puckette, 1996

Anadarko Basin

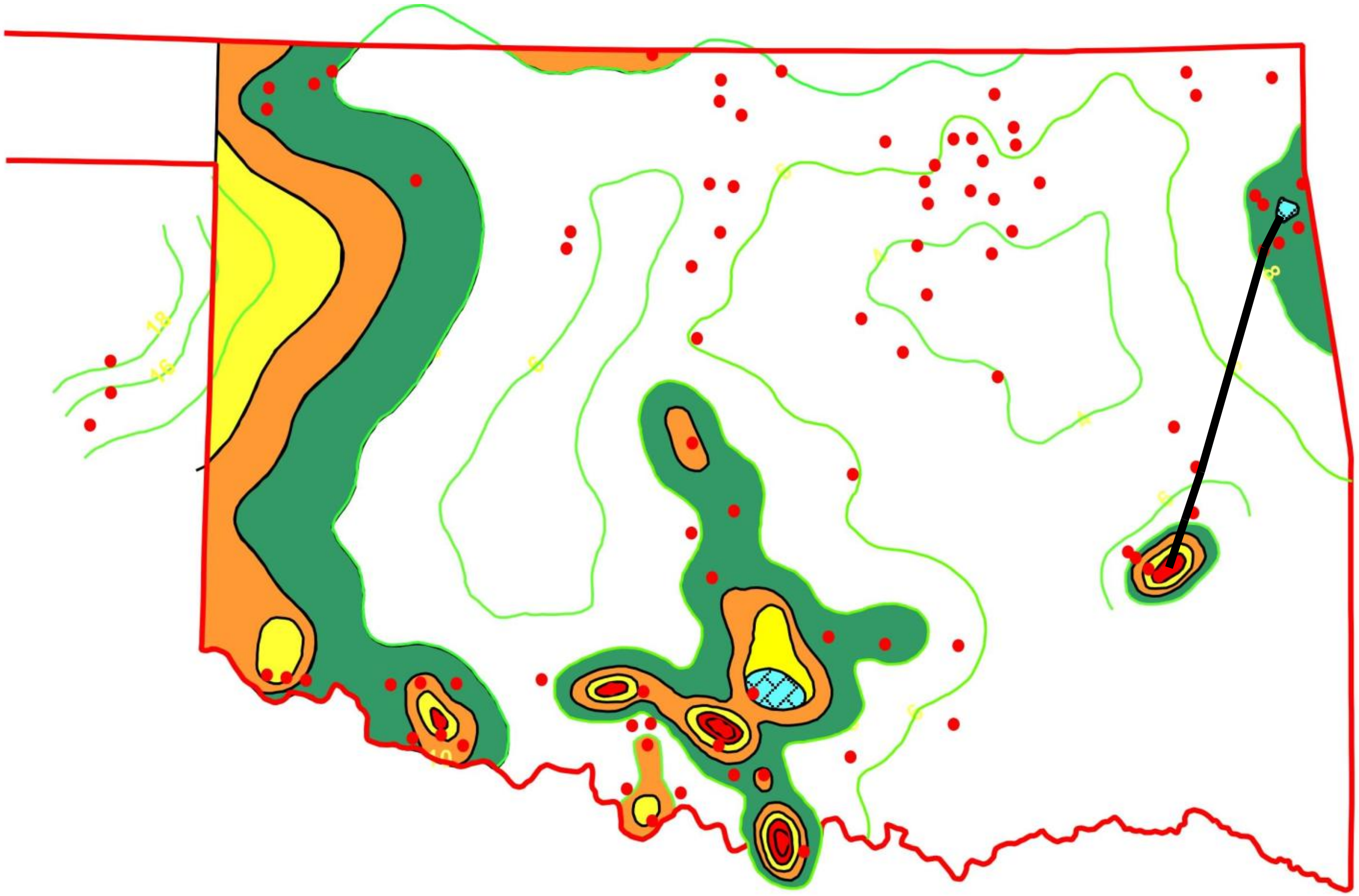
Comparison of compartmentalized and overpressured Morrow reservoir pressures with normally pressured Arbuckle Group



(orange)	< 0.40 psi/ft
(green)	> 0.45 psi/ft
(cyan)	> 0.50 psi/ft
(red)	> 0.55 psi/ft

ARBUCKLE P-D GRADIENTS

Puckette, 1996



>14

>12

>10

>8

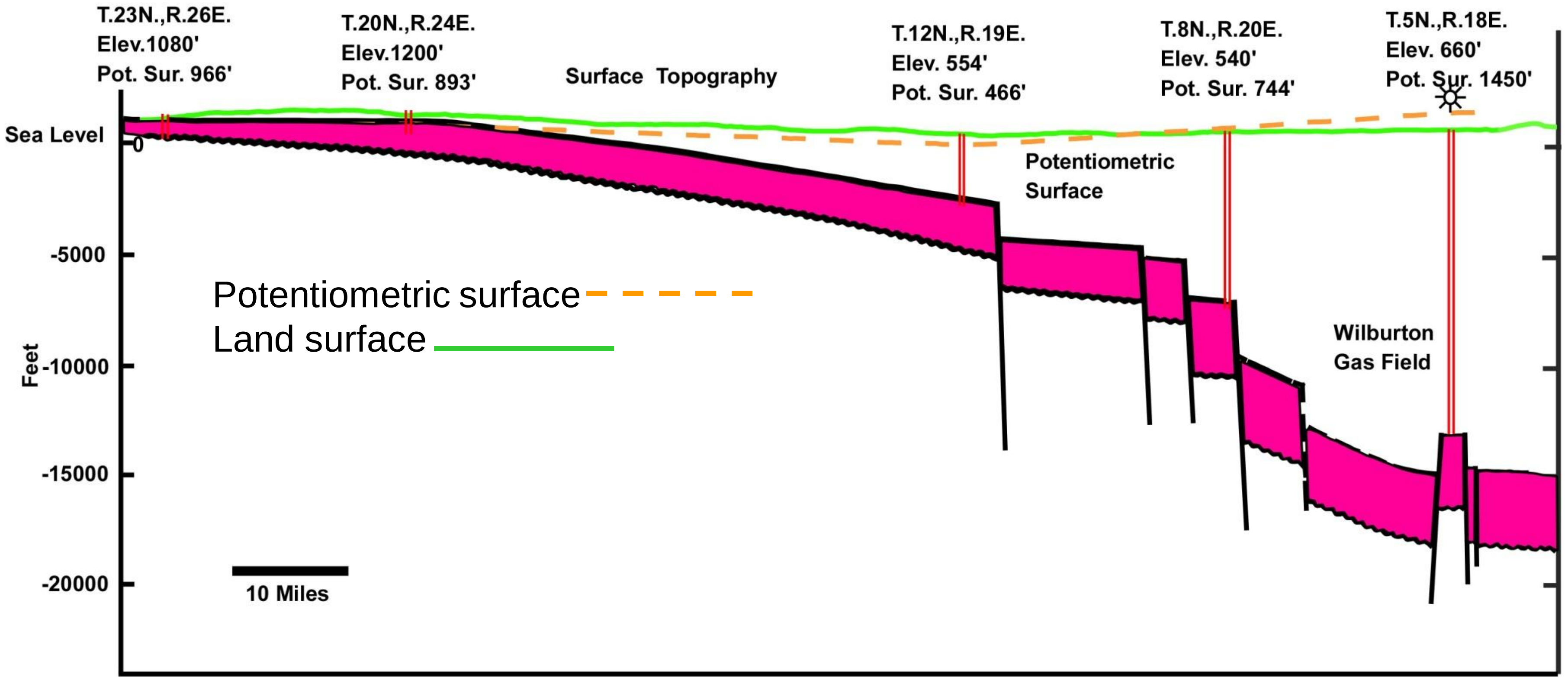
Potentiometric Values in 100's of feet

Outcrop Recharge Areas

Arbuckle Group Potentiometric Surface Map

Reconstructed in NE OK

Puckette, 1996



Buoyancy and higher elevation of the recharge zone combine to generate overpressure in the Arbuckle Group reservoir, Wilburton Field. From Puckette (1996).

Conclusions

1. Combination of sealing and conduit lithologies create an environment where either normal or abnormal pressure is maintained
2. Stepped-Tiered Basins with upper normal and deeper overpressure:

    Normal pressure occurs mostly in coarser clastics

    Overpressure occurs in intervals with seal-forming shales and chalks; it is result of disequilibrium compaction and HC generation

Conclusions

3. Recessed-Tiered Basins with upper normal, middle underpressured and deep normal or upper normal and deeper underpressured.

    Normal pressure occurs in shale with interbedded sandstones

    Underpressure occurs in regionally deposited coarser-grained clastic material that has active water drive; or exposed at surface

    Deeper normal pressure, if present, occurs in intervals dominated by carbonates that are continuous to the surface

Conclusions

4. Ledged-Tiered Basins: upper normal, middle overpressured and deep normal
   - Normal pressure occurs in intervals with sandstone, shale and carbonate
   - Overpressured interval is dominated by shale with laterally discontinuous reservoirs
   - Deep normal pressure occurs in laterally extensive sandstones and carbonates with reservoir continuity to the surface
5. Normally pressured intervals in all types usually require a structural component to trap oil and gas as these reservoirs have strong water drive

References

Alberta Study Group, 1954, Lower Cretaceous of the Peace River region, *in* AAPG Special Publication 15: Western Canada Sedimentary Basin, pp. 268-278.

Al-Shaieb, Z., J. O. Puckette, A. A. Abdalla, and P. B. Ely, 1994, Megacompartment Complex in the Anadarko basin: a completely sealed overpressured phenomenon, *in* P. J. Ortoleva, ed., Basin compartments and seals: AAPG Memoir 61, pp. 55-68.

Al-Shaieb, Z., J. Puckette, and P. Deyhim, 1999, Compartmentalization of the Overpressured interval in the Anadarko basin, *in* D. F. Merriam, ed., Transactions of the American Association of Petroleum Geologist Midcontinent Section Meeting (Wichita, KS), pp. 63-70.

Bachu, S., 1999, Flow systems in the Alberta Basin: Patterns, types, and driving mechanisms: Canadian Petroleum Geology Bulletin, v. 47, n. 4, pp. 455-474.

Barker, C., 1972, Aquathermal pressuring – role of temperature in development of abnormal pressure zones: AAPG Bulletin, v. 56, pp. 2068-2071.

California Division of Oil, Gas, and Geothermal Resources, 1982, California oil and gas fields, northern California: Sacramento, California Department of Conservation, Division of Oil, Gas, and Geothermal Resources, Publication TR10, CD-1, variously paginated.

Chapman, C. M., 1989, Hamilton Dome, *in* Wyoming Geol. Assoc. Oil and Gas Fields Symposium; Big Horn and Wind River Basins, pp. 219-224.

Chiarelli, A., and F. Duffaud, 1980, Pressure origin and distribution in Jurassic of Viking Basin (U.K. and Norway): AAPG Bulletin, v. 64, pp. 1245-1251.

Clark, L. M., C. E. Cleveland, R. S. Johnson, and R. C. M. Budd, 1968, Geology of natural gas, Peace River Area, Canada, AAPG Memoir 9: Natural Gases of North America, pp. 683-697.

Erlich, R. N., and S. F. Barrett, 1992, Petroleum geology of the eastern Venezuela foreland basin: AAPG Memoir 55, pp. 341-362.

Funkhouser, H. J., L. C. Sass, and H. D. Hedberg, 1948, Santa Ana, San Joaquin, Guario, and Santa Rosa oil fields (Anaco fields), Central Anzoátegui, Venezuela: AAPG Bulletin, v. 32, pp. 1851-1908.

Gleddie, J., 1954, Upper Cretaceous in Western Peace River Plains, Alberta, *in* AAPG Special Publication 15: Western Canada Sedimentary Basin, pp. 486-509.

Heritier, F. E., P. Lossel, and E. Wathne, 1979, Frigg Field – large submarine-fan trap in Lower Eocene rocks of the North Sea Viking Graben: AAPG Bulletin, v. 63, n. 11, pp. 1999-2020.

Hunt, A. D., and J. D. Ratcliffe, 1959, Triassic stratigraphy, Peace River Area, Alberta and British Columbia, Canada: AAPG Bulletin, v. 43, n. 3, pp. 563-589.

Johnson, K. S., 1989, Geological evolution of the Anadarko basin, *in* K. S. Johnson, ed., Anadarko basin symposium, 1988: Oklahoma Geological Survey Circular 90, pp. 3-12.

Keefer, W. R., and R. C. Johnson, 1993, Stratigraphy and Oil and Gas Resources in Uppermost Cretaceous and Paleocene Rocks, Wind River Reservation, Wyoming, *in* Wyoming Geological Association’s Special Symposium, Oil and Gas and Other Resources of the Wind River Basin, Wyoming, pp. 71-85.

Kent, P. E., 1967, Progress of exploration in North Sea: AAPG Bulletin, v. 51, n. 5, pp. 731-741.

Kewanee Oil Company, 1961, A Stratigraphic Study of the Wind River Basin, Special Study Section, Kewanee Oil Company

Krampert, E. W., 1947, Hamilton Dome, Hot Springs County, Wyoming, *in* Wyoming Geol. Assoc. Guidebook, pp. 229-233.

Lackie, J. H., 1958, Subsurface Jurassic of the Peace River Area, *in* AAPG Special Publication 17: Jurassic and Carboniferous of Western Canada, pp. 85-97.

Macauley, G., 1958, Late Paleozoic of Peace River Area, Alberta, *in* AAPG Special Publication 17: Jurassic and Carboniferous of Western Canada, pp. 289-308.

Murany, E. E., 1972, Tectonic basis for Anaco fault, eastern Venezuela: AAPG Bulletin, v. 56, no. 5, pp. 860-870.

Paape, D. W., 1968, Geology of Wind River Basin of Wyoming and its relationship to natural gas accumulation, *in* AAPG Memoir 9: Natural Gases of North America, v. 1, pp. 760-779.

Powley, D. E., 1999, Personal unpublished files

Puckette, J. O., 1996, Evaluation of underpressured reservoirs as potential repositories for liquid wastes: unpublished Ph.D. thesis, Oklahoma State University, 273 p.

Swarbrick, R. E., and M. J. Osborne, 1998, Mechanisms that generate abnormal pressures: an overview, *in* Law, B. E., G. F. Ulmishek, and V. I. Slavin eds., Abnormal pressures in hydrocarbon environments: AAPG Memoir 70, pp. 13-34.

Villaroel, V., 1993, Santa Rosa Field – Venezuela, Eastern Venezuela Basin, Structural Traps VIII: AAPG Special Volume, pp. 193-215.

WGA, 1952, Hamilton Dome field, Hot Springs County, Wyoming, *in* Wyoming Geol. Assoc. Guidebook, pp. 104-107.