Optimization of Infill Drilling in Naturally-Fractured Tight-Gas Reservoirs of the San Juan Basin

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Project Team

- **Her-Yuan Chen – Well test and production analysis**
- **Tom Engler – Reservoir characterization and simulation**
- **Bruce Hart – Geophysical studies**
- **Mike Kelly – Reservoir simulation**
- **John Lorenz – Characterization of natural fractures**

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  - **Williams Energy**

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Optimization of Infill Well Locations in Naturally-Fractured Tight-Gas Reservoirs Requires a Multi-Disciplinary Approach

- **Reservoir characterization to determine reservoir heterogeneity, net pay thickness, and effective porosity from integrated log analyses.**

- **Characterization of natural fracture systems to determine orientation, distribution, and intensity from geological and geophysical studies; and assess influence of fractures on reservoir permeability and permeability anisotropy from numerical models.**

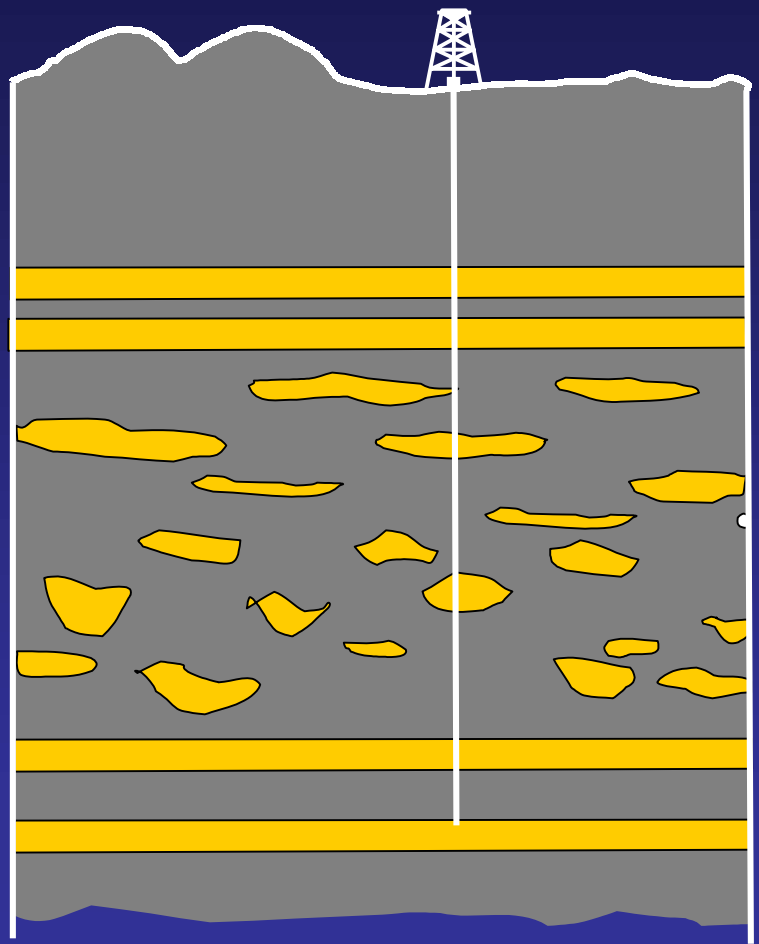
- **Analyses of well tests and production data to determine reservoir permeability and permeability anisotropy.**

- **Reservoir simulation studies to determine**
  - **distribution of net pay, effective porosity, and reservoir permeability**
  - **well drainage shape and area**
  - **distribution of reservoir pressure and potential well interference**
  - **optimal location and number of infill wells**
  - **forecast of increased gas recovery.**

Generalized Stratigraphy of San Juan Basin

ERA	SYSTEM	FORMATION		THICKNESS	PRODUCTION
CENOZOIC	TERTIARY	San Jose Formation		2500 ft	gas
		Nacimiento Formation		500 – 1300 ft	gas
		Ojo Alamo Sandstone		250 ft	gas
MESOZOIC	CRETACEOUS	Kirtland Shale Farmington Sandstone		1500 ft	gas/oil
		Fruitland Formation		500 ft	gas
		Pictured Cliffs Sandstone		250 ft	gas
		Lewis Shale Huerfanito Bentonite		500 – 1900 ft	gas
		Mesaverde Group	Cliff House Sandstone	0 – 800 ft	gas
			Menefee Formation	350 – 2200 ft	gas
			Point Lookout Fm	100 – 300 ft	gas
		MANCOS SHALE	Upper Mancos Shale/Tocito Ss	2300–2500 ft	gas/oil
			Gallup Sandstone/Carlile Sh		gas/oil
			Graneros Shale		
		Dakota Sandstone		150 – 200 ft	gas/oil
	JURASSIC	Morrison Formation		400 – 900 ft	
		Wanakah Formation Todito Limestone		50 – 200 ft	
		Entrada Sandstone		100 – 300 ft	oil
	TRIASSIC	Chinle Formation		500 – 1600 ft	

San Juan Basin



Naturally-Fractured Tight-Gas Sandstone Reservoirs

Mesaverde Group

Porosity : 6 – 12%

Permeability : < 0.01 m D (Matrix)

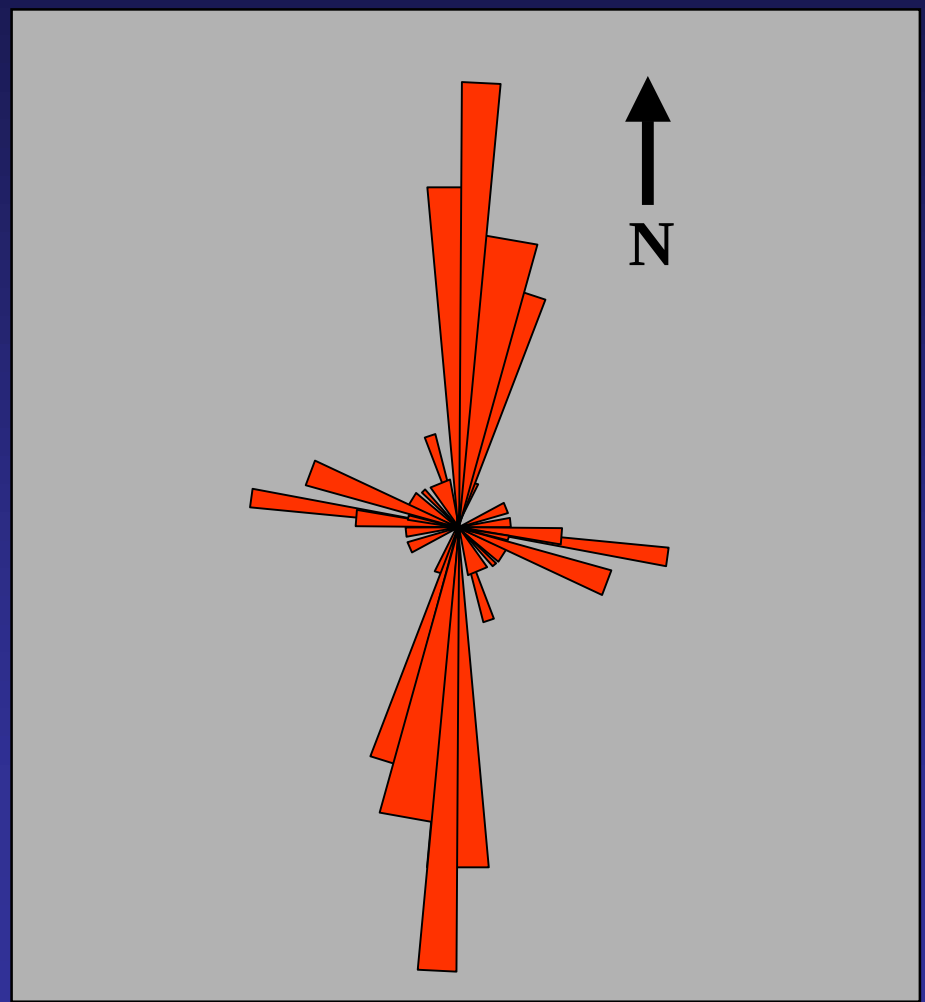
0.01– 60 m D (Reservoir)

Pore Pressure : 0.23 psi/ft

Overburden Stress : 1.03 psi/ft

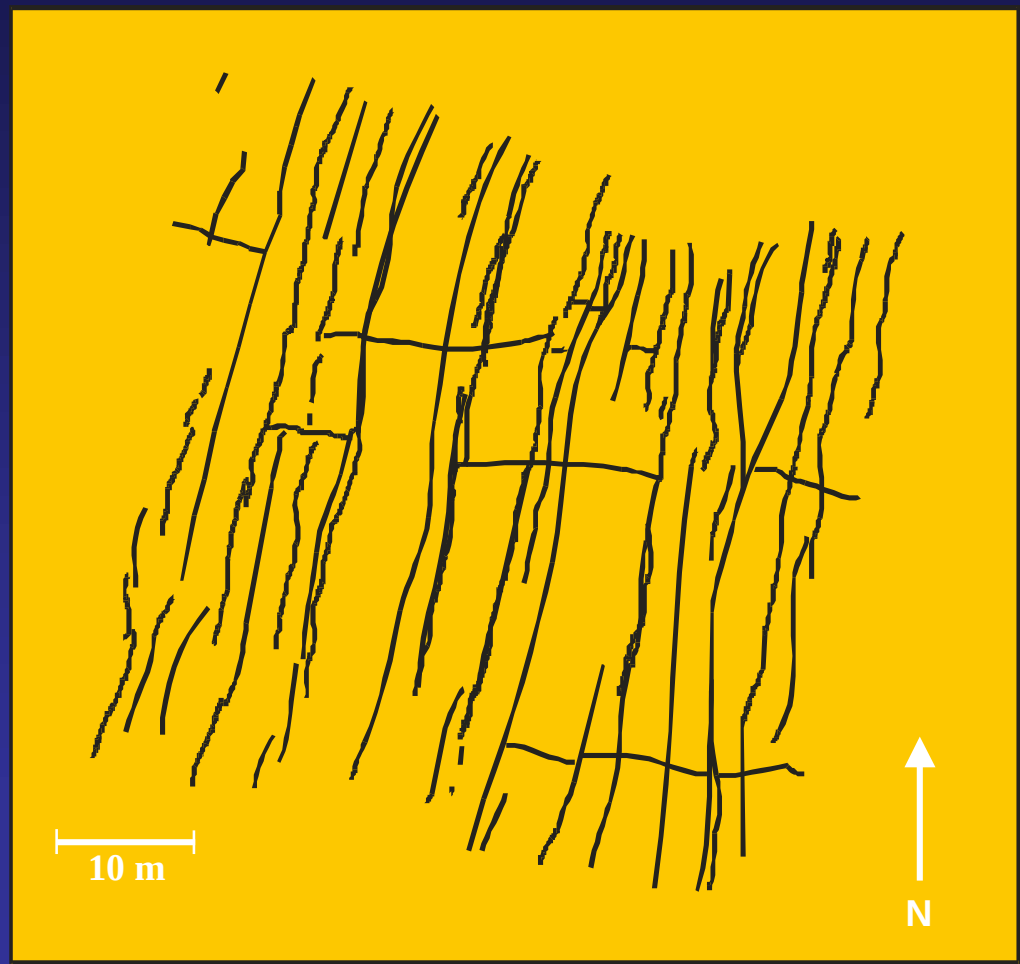
Vertical Partially-Filled Extension Fracture in Mesaverde Core

Orientations of Natural Fractures in Mesaverde Sandstone at Heron Lake, NM

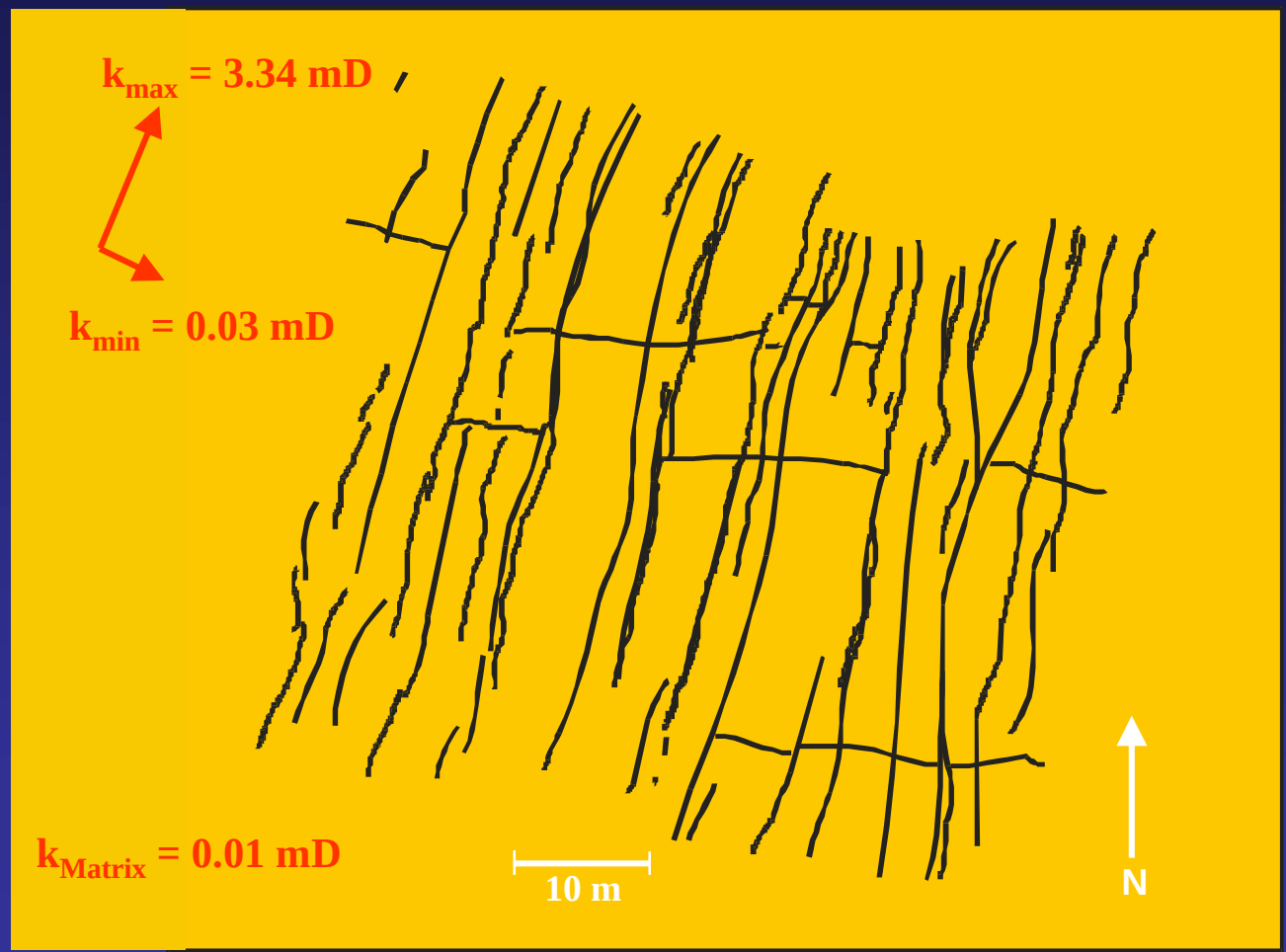


Fracture Network in Dakota Sandstone Outcrop

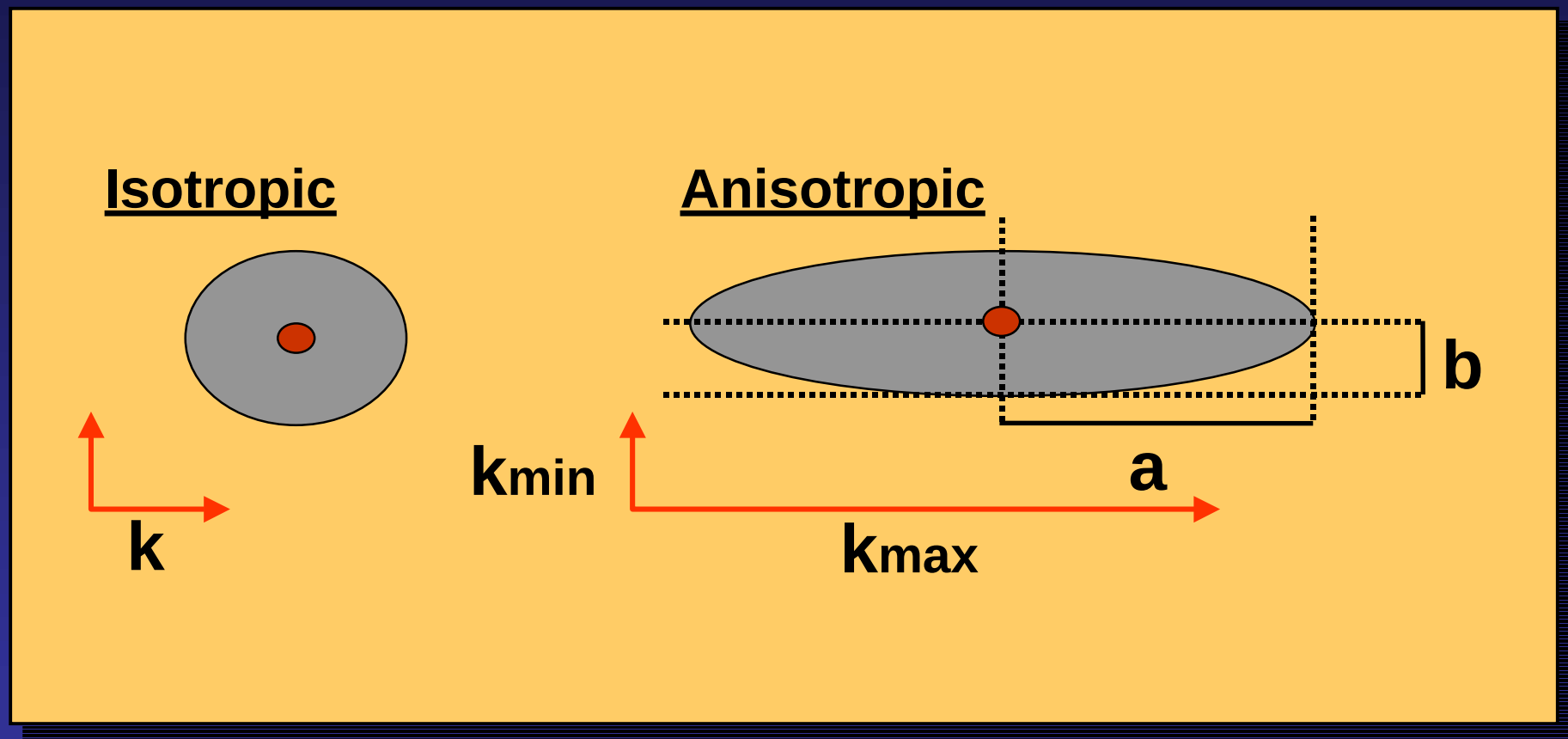
Fracture Network Map



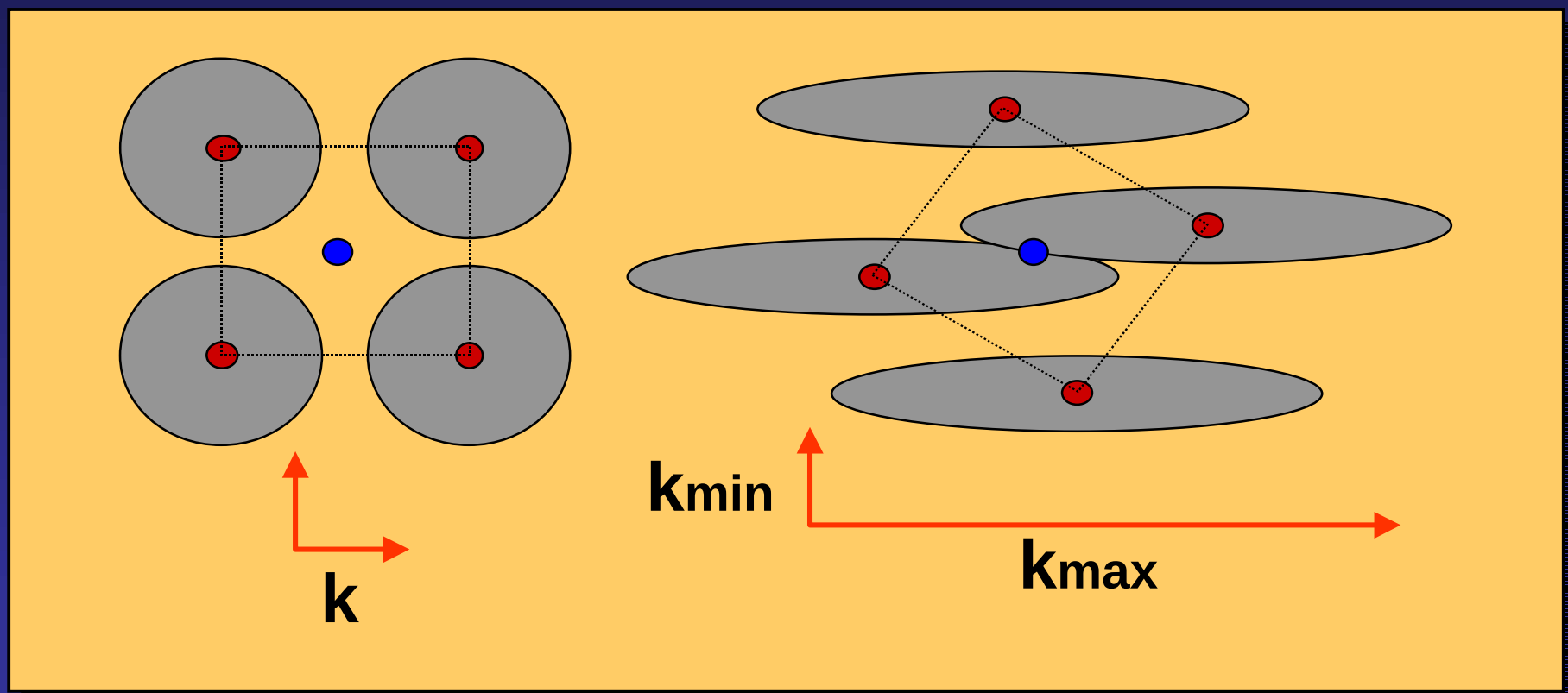
Reservoir Permeability is Anisotropic



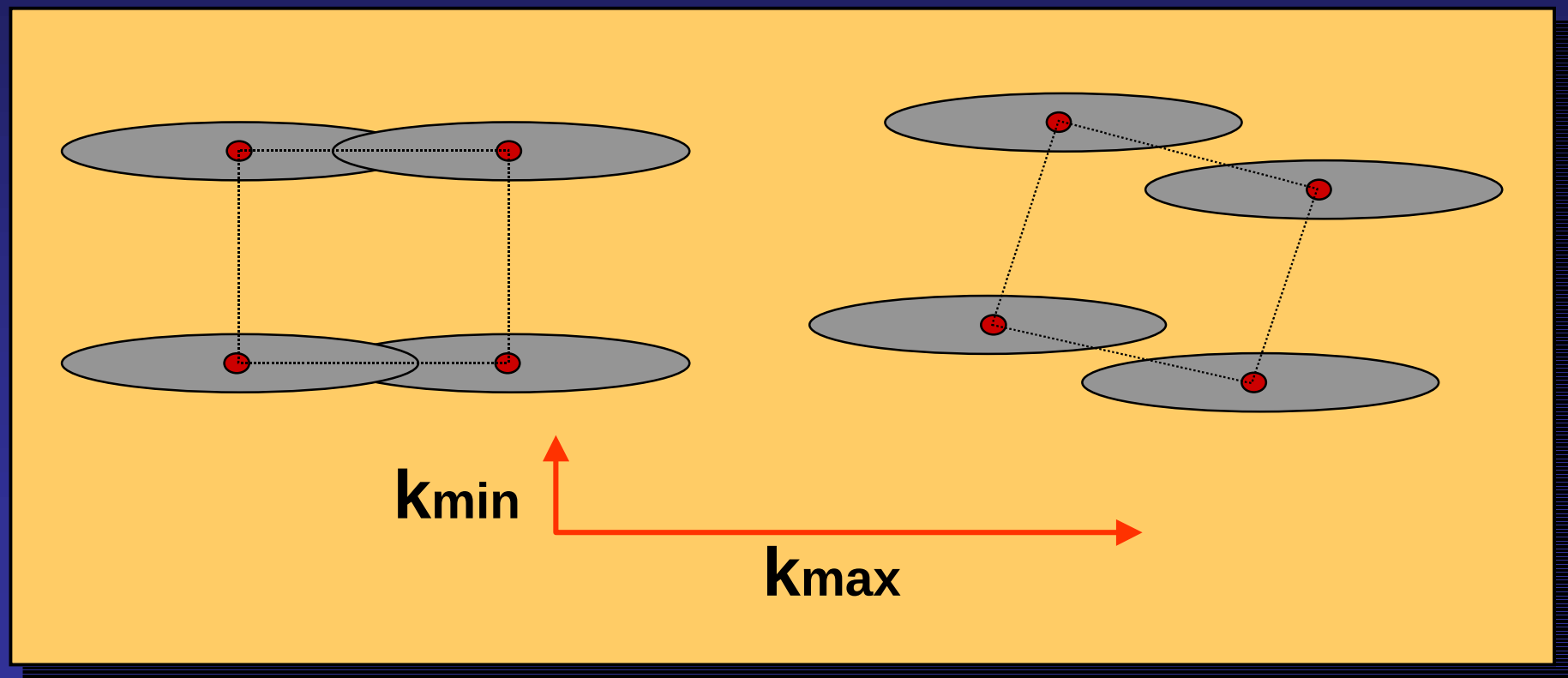
Comparison of Well Drainage Areas



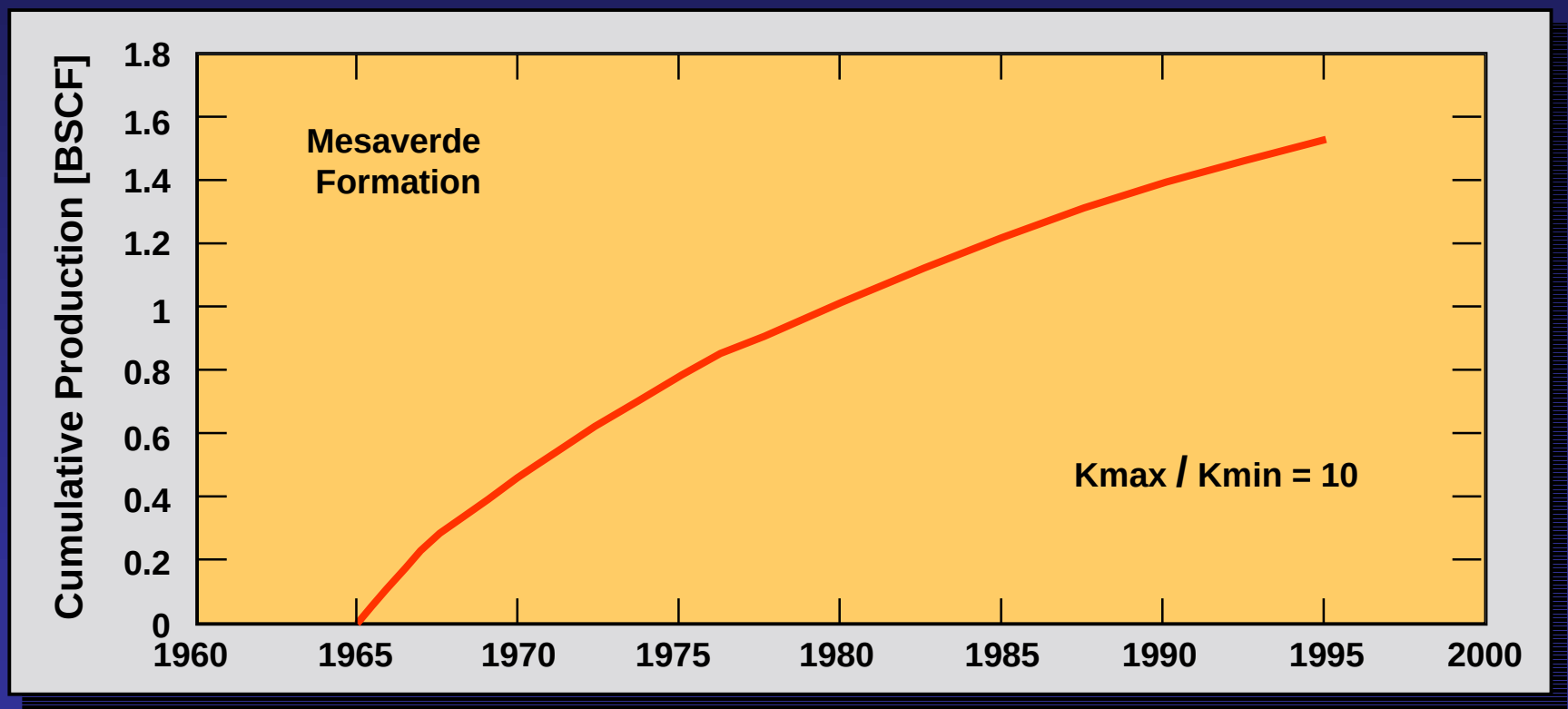
Optimal Location of Infill Wells is Dependent on Shape of Drainage Area



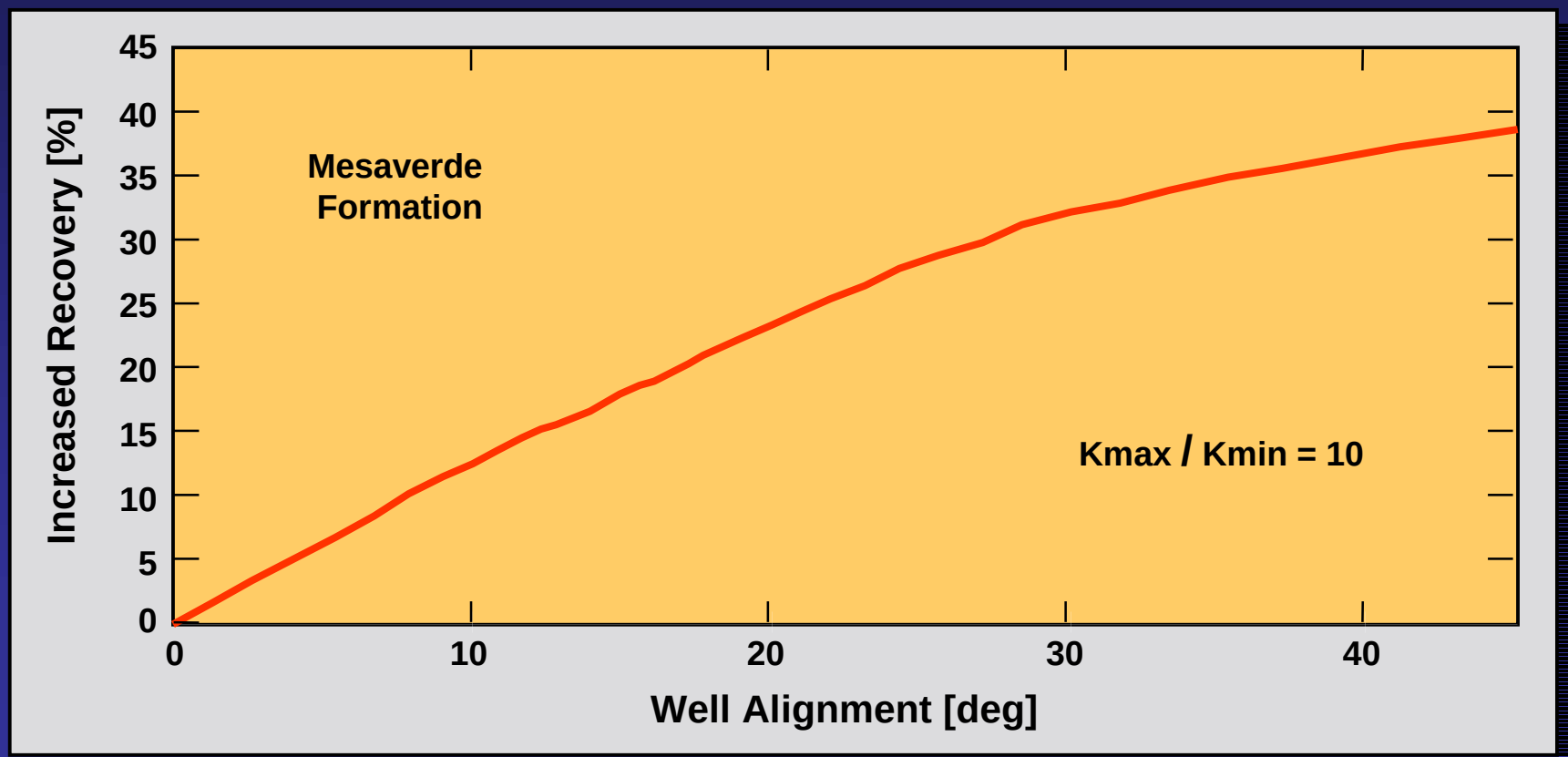
Rotation of Offset Wells Eliminates Drainage Overlap and Increases Drainage of Reservoirs with Anisotropic Permeability



Increase in Cumulative Production for Offset Well Rotated 10° from Maximum Permeability Direction



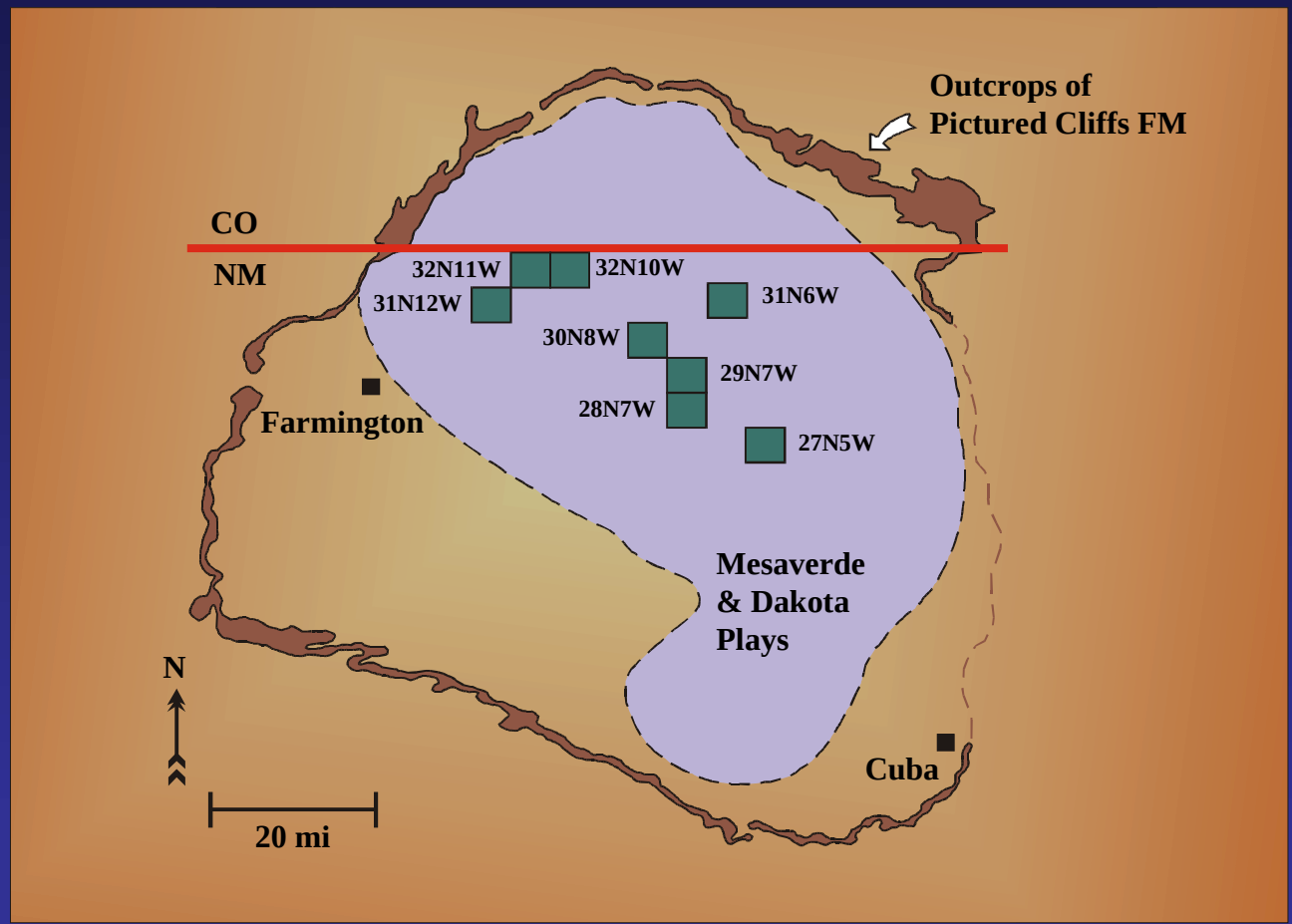
Gas Recovery Increases with Rotation Of Well Alignment from Direction of Maximum Permeability



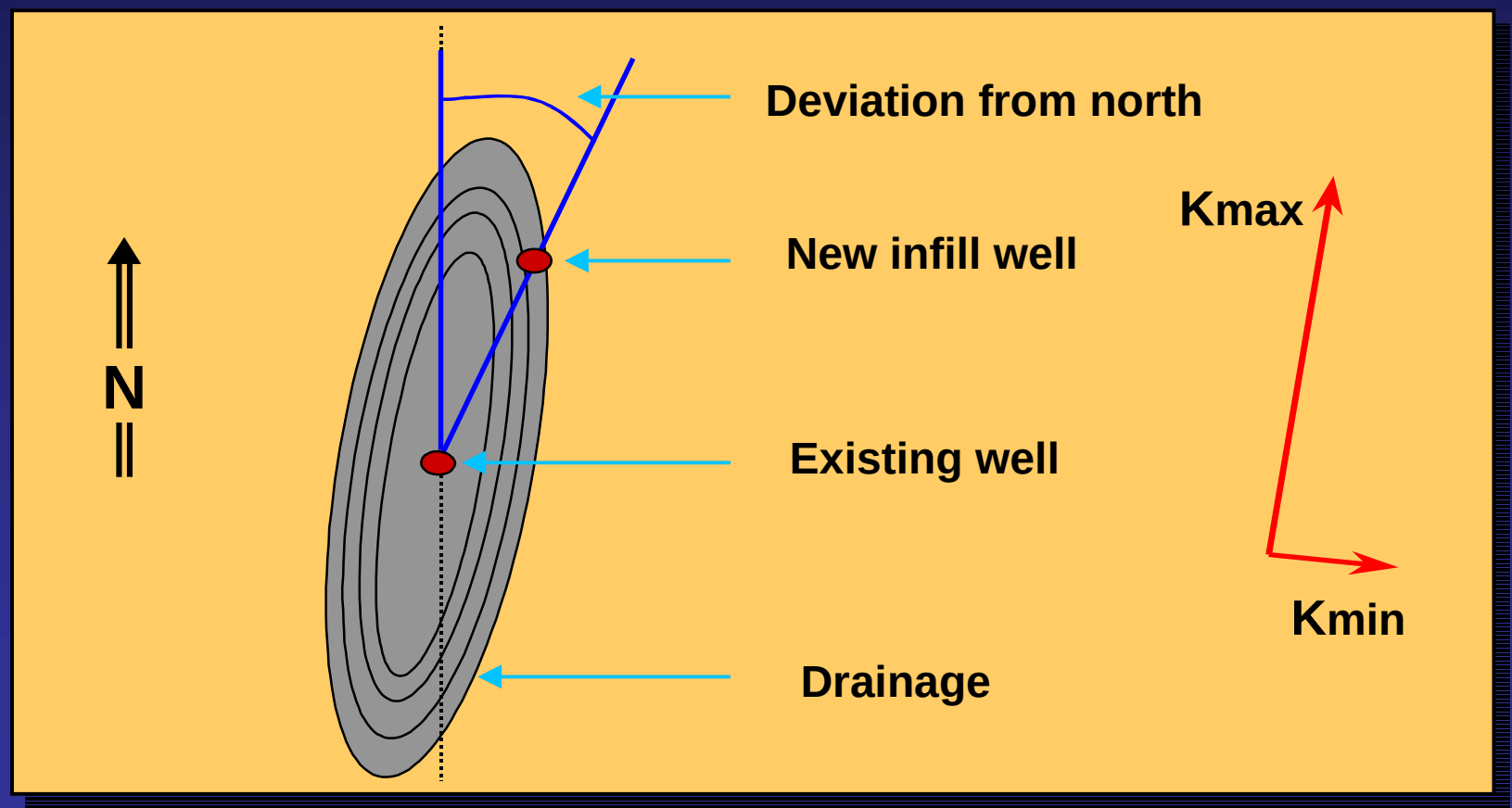
Natural Fractures and Drainage Area

- Production from tight-gas sandstone reservoirs of the Mesaverde and Dakota formations in the San Juan Basin is highly dependent on natural fractures.
- Fractures not only enhance the overall permeability of these reservoirs, but also create significant permeability anisotropy.
- Permeability anisotropy causes the drainage area around wells to be elliptical.
- Elongated drainage creates more production interference and drainage overlap between adjacent wells and increase the potential for leaving large sections of the reservoir undrained.

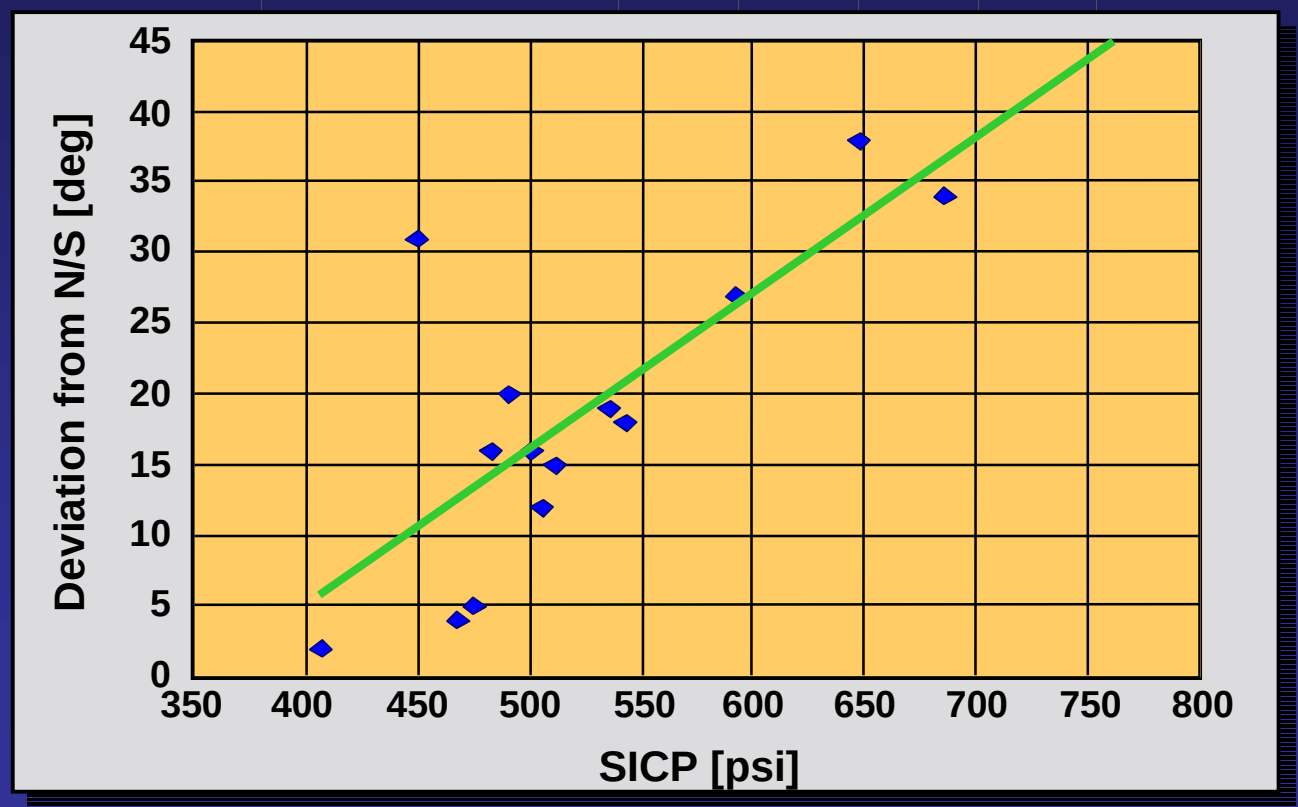
Pilot Study Areas in San Juan Basin



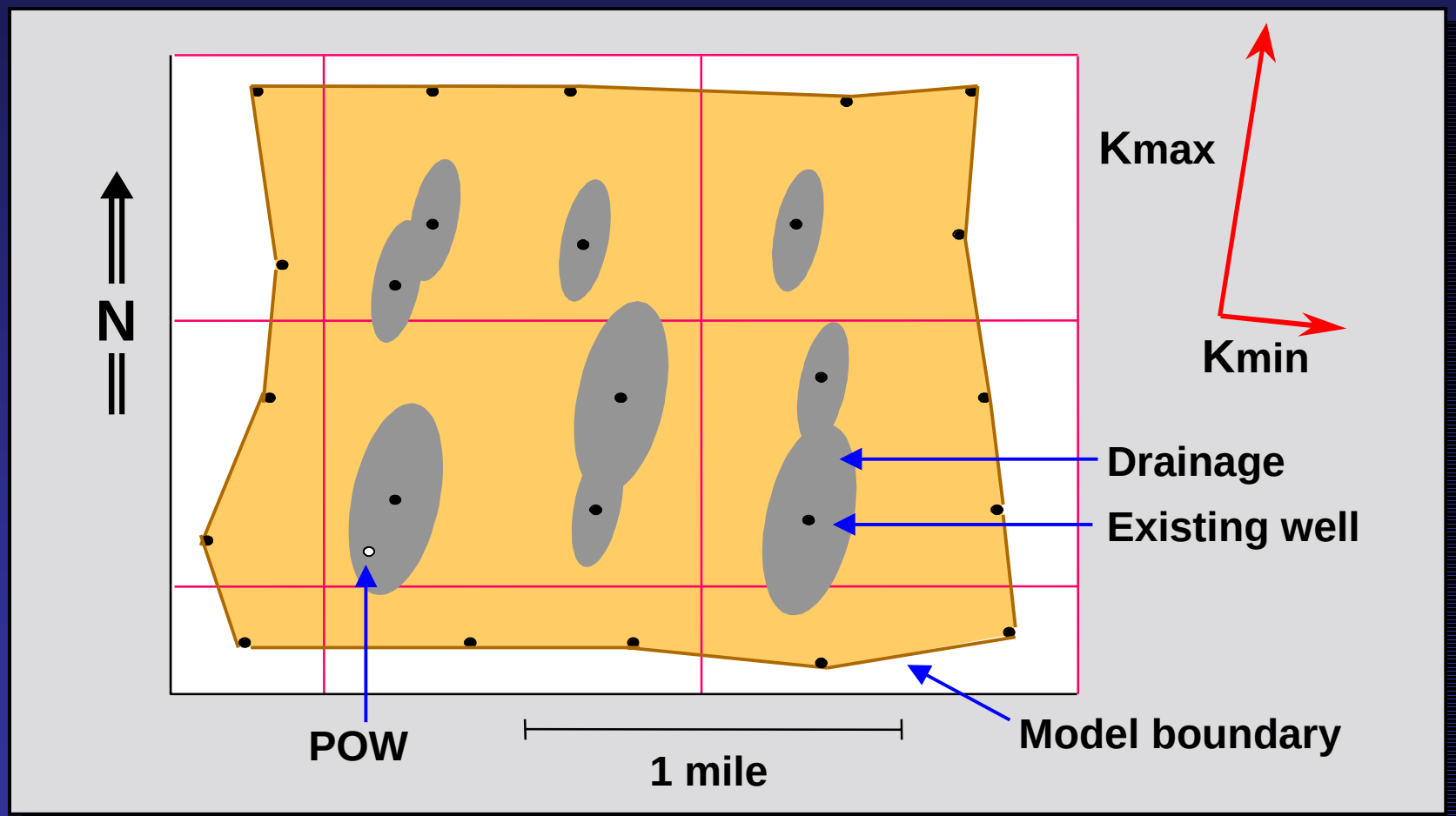
Well Drainage Area in Reservoir with Anisotropic Permeability



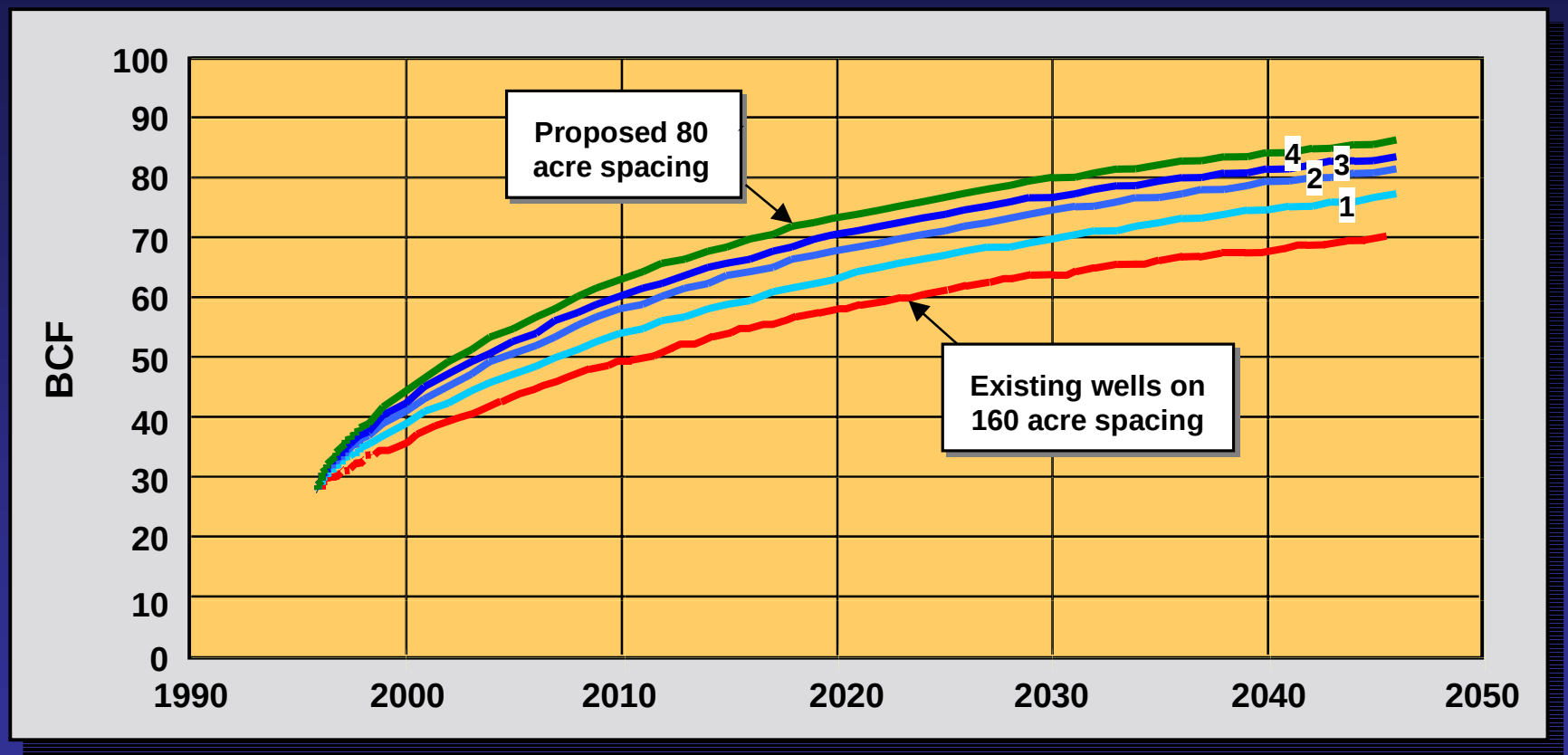
Formation Pressure in Offset Wells Increases with Increasing Rotation from Direction of Maximum Permeability



Elliptical Drainage Area Is Aligned with Maximum Permeability Direction



Infill Drilling Will Increase Gas Recovery



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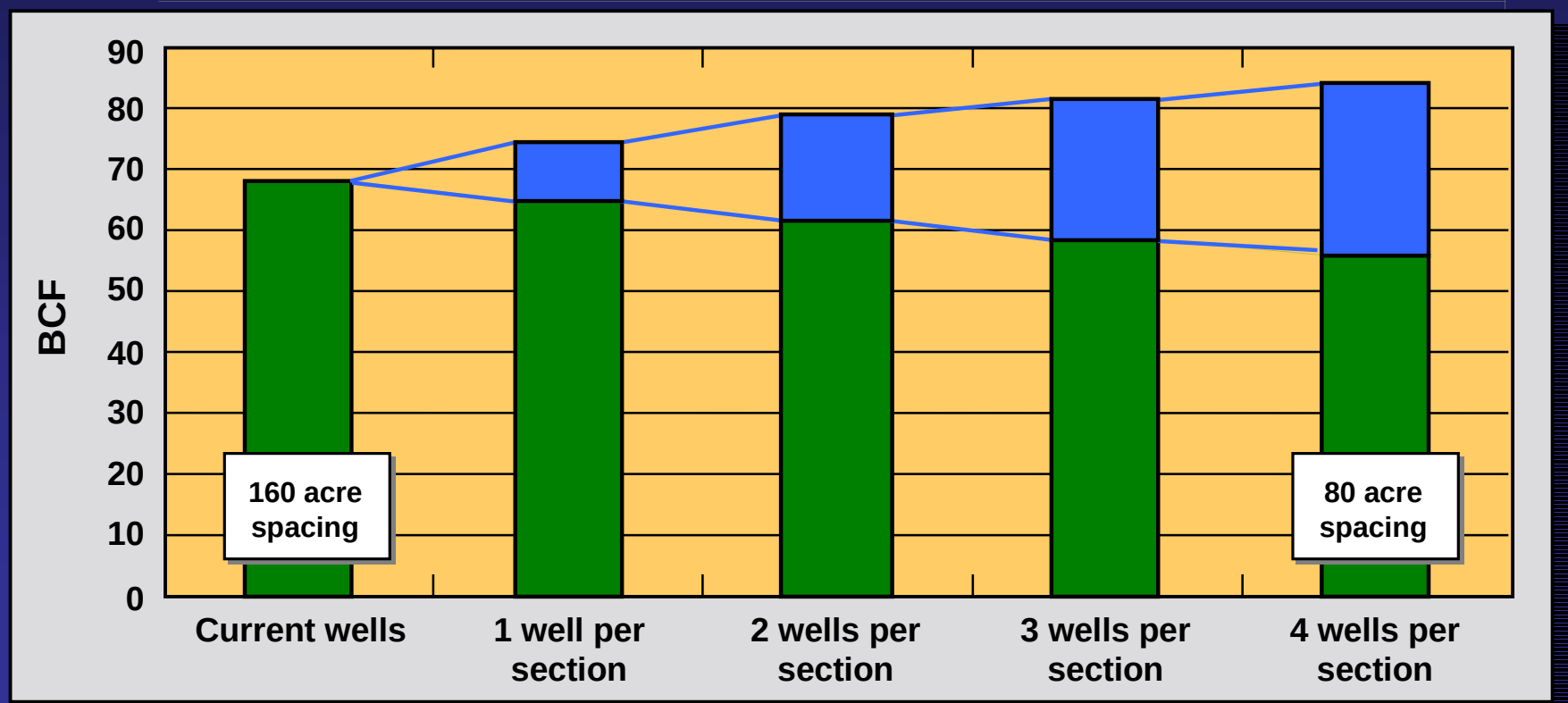
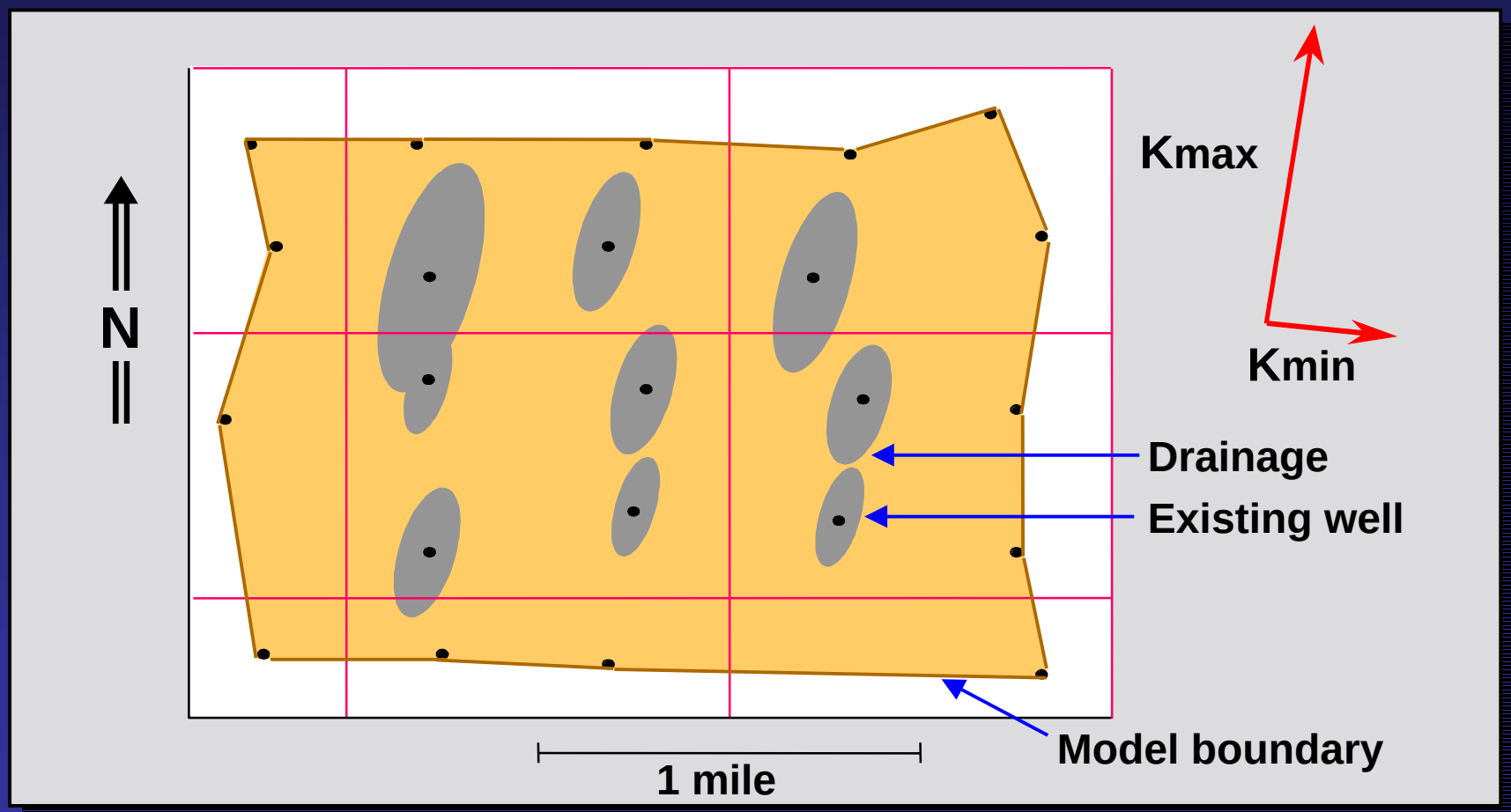


Elliptical Drainage of Wells Is Aligned With Maximum Permeability Direction



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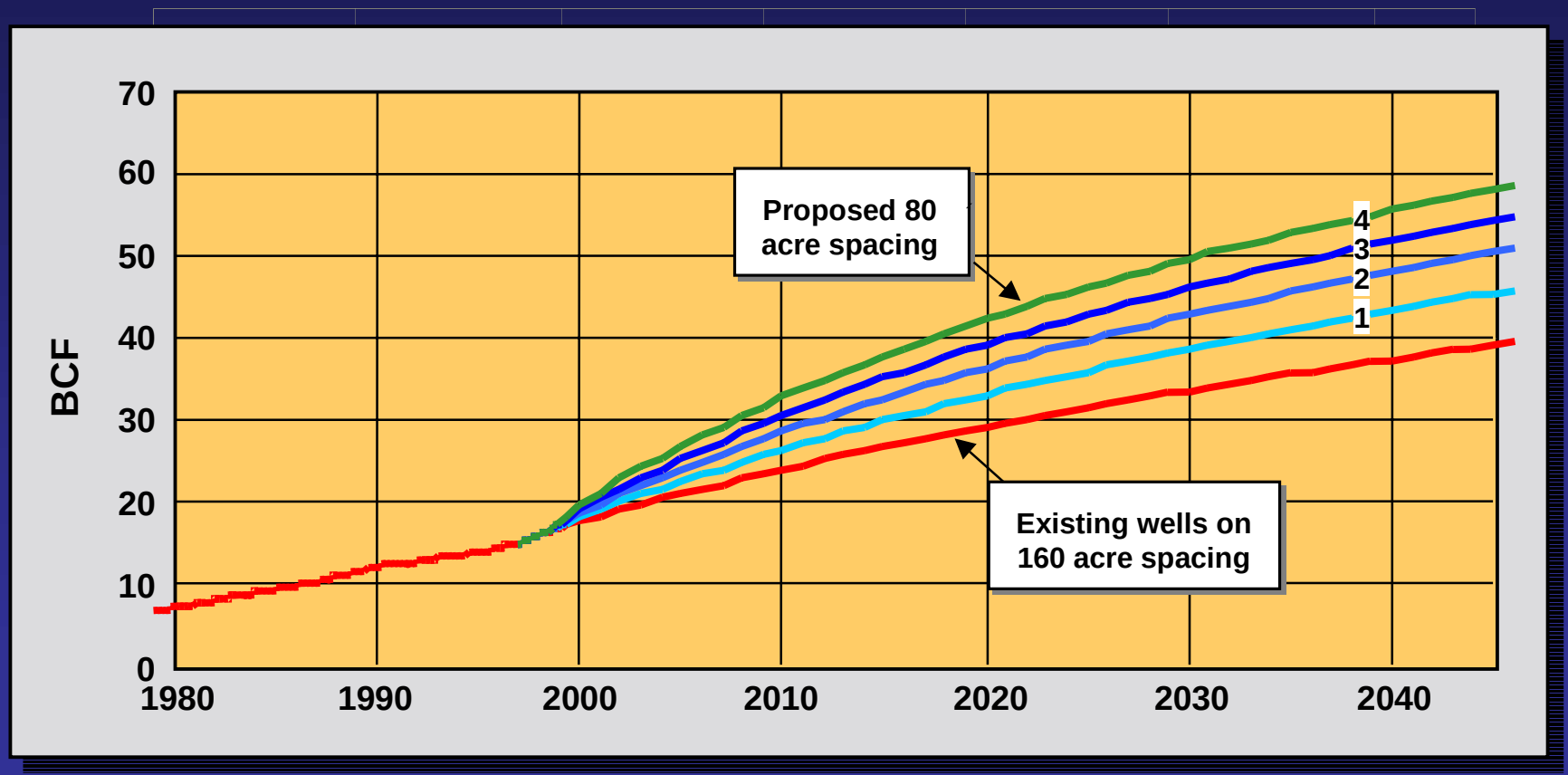
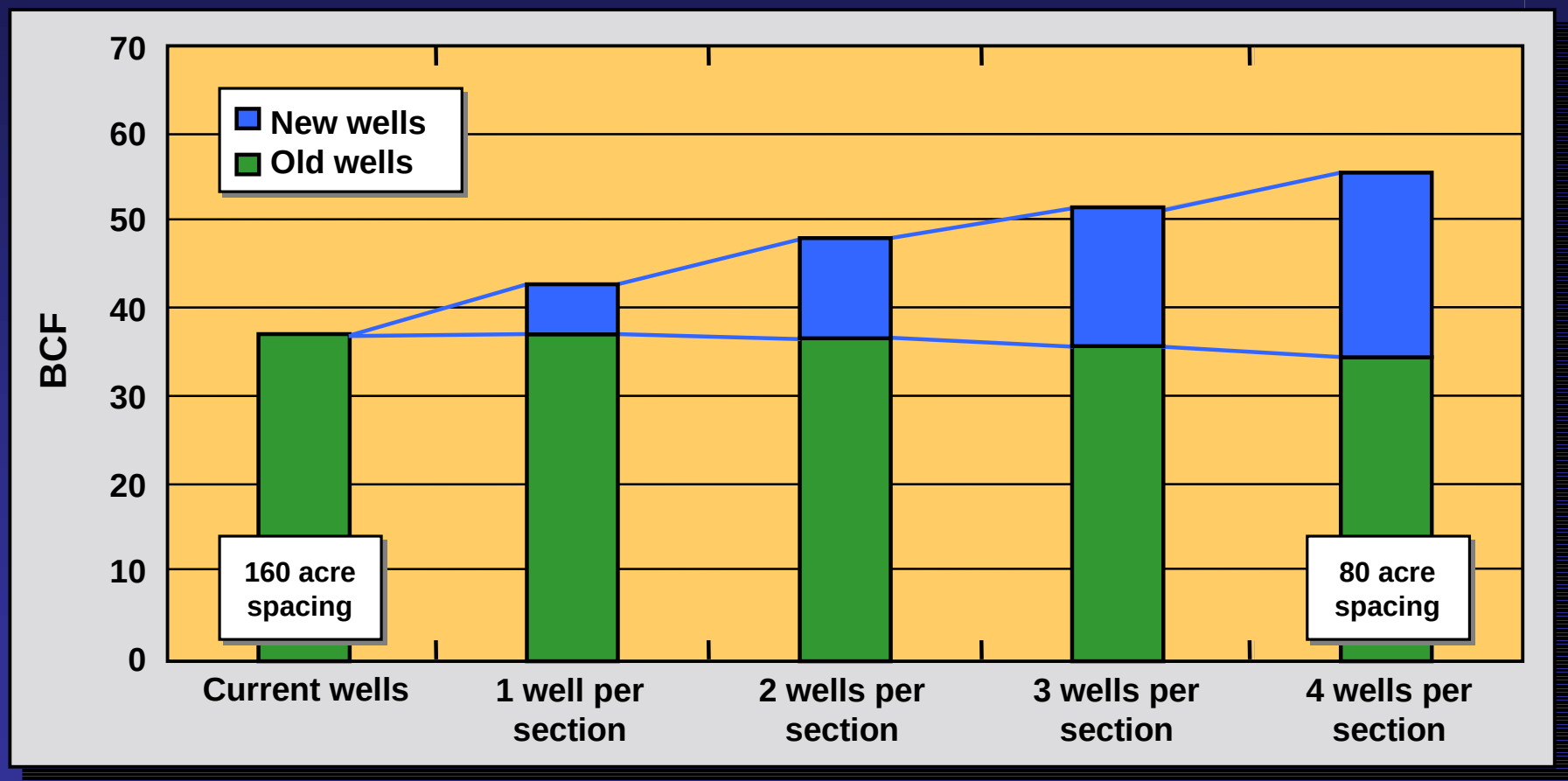
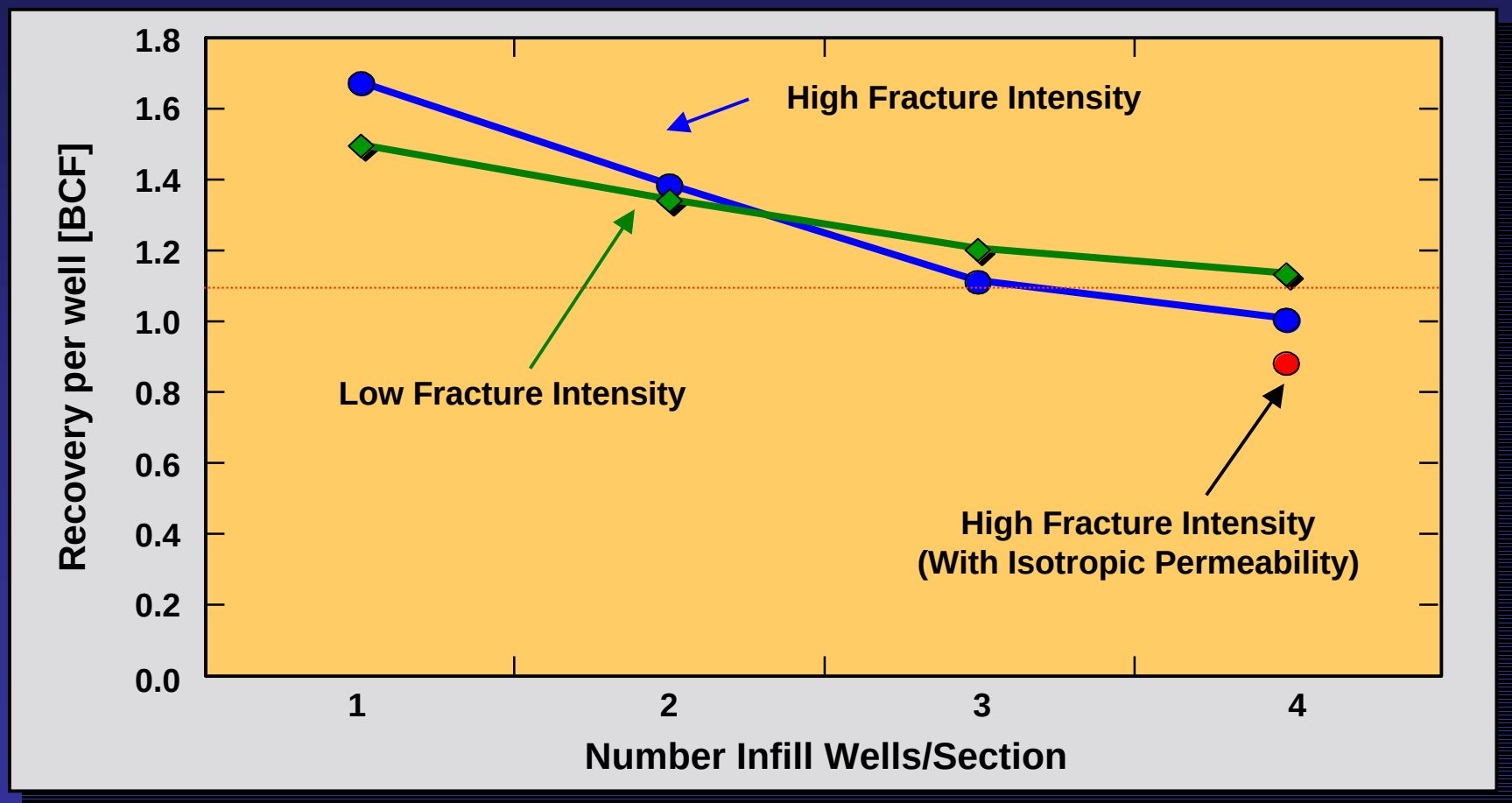


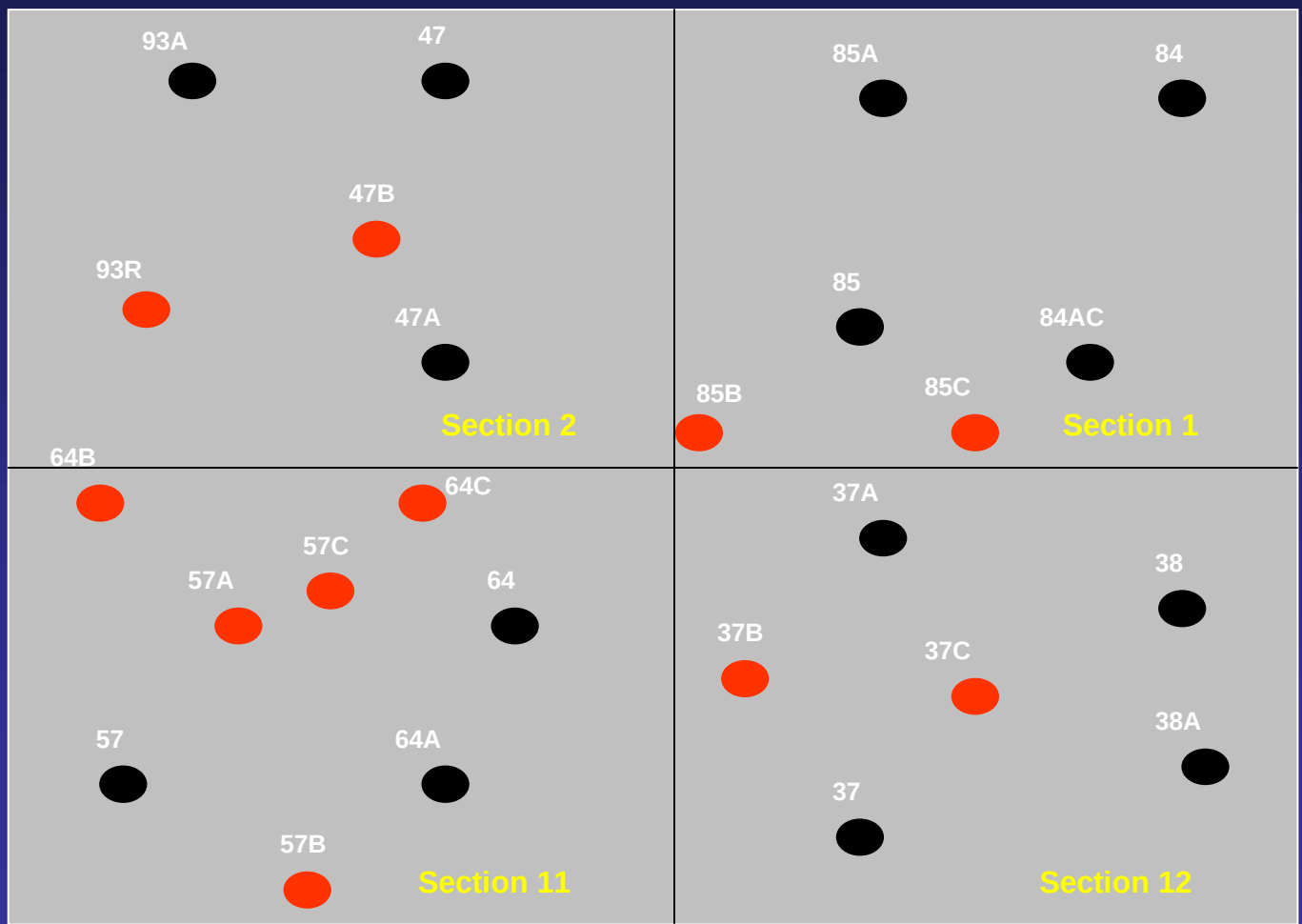
Infill Drilling Will Increase Gas Recovery



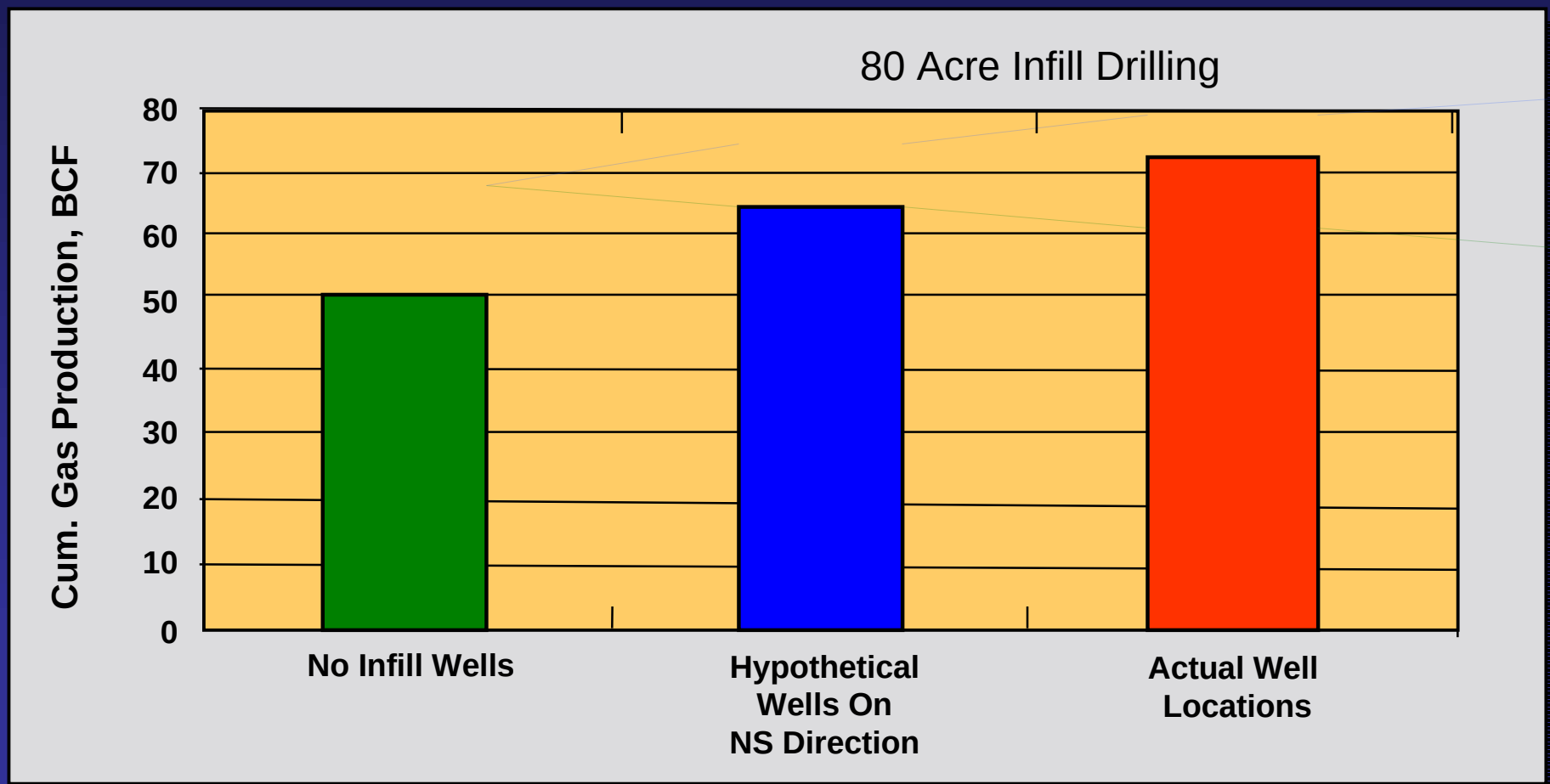
Potential for Increased Recovery Is Greater In Reservoirs with Low Fracture Intensity



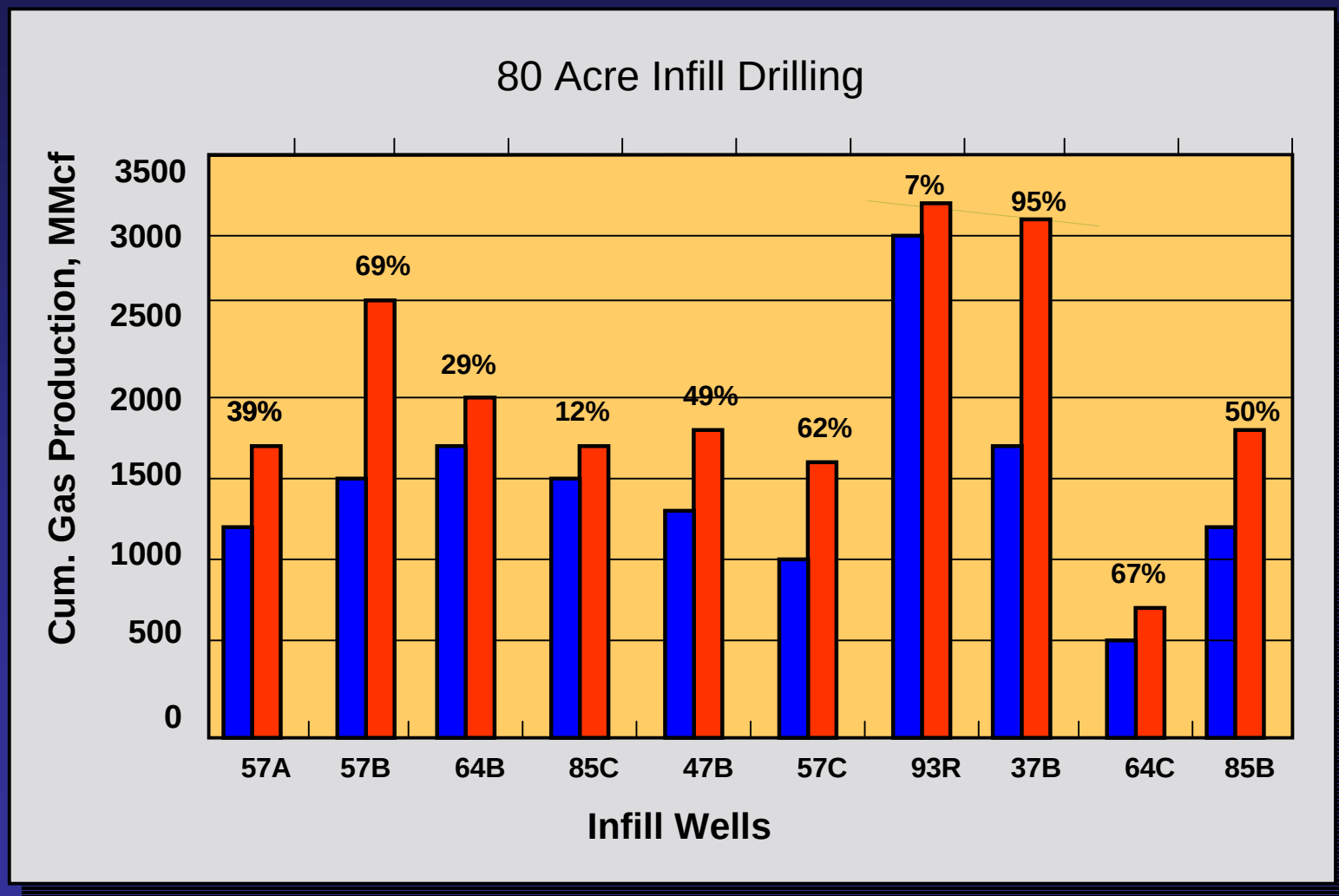
Well Locations for Pilot 29N7W



Cumulative Gas Production Forecast for Pilot 29N7W



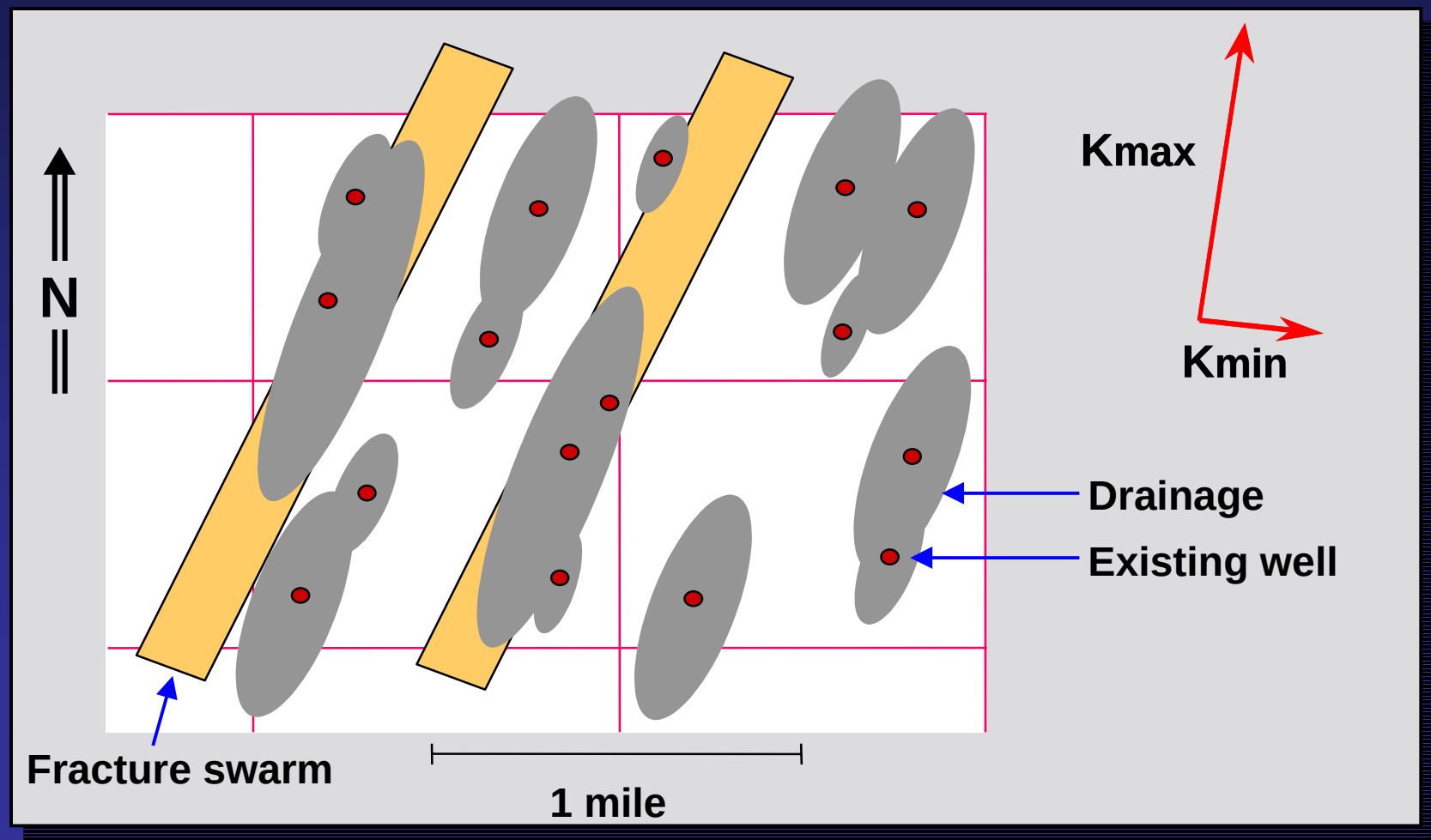
Production Forecast of Infill Wells for Pilot 29N7W



Actual Well Location

Hypothetical Well on NS Direction

Fracture Swarms Enhance Reservoir Permeability Anisotropy



SUMMARY

Reservoir characterization and simulation studies are being conducted on naturally-fractured tight-gas reservoirs in the San Juan Basin to

(1) Define the elliptical drainage area and recoverable gas for existing wells,
(2) Determine the optimal location and number of new infill wells to maximize economic recovery,
(3) Forecast the increase in total cumulative gas production from infill drilling at different locations in the basin.

Optimal infill drilling of the Mesaverde formation in the San Juan Basin may increase recoverable gas by 7.8 TCF.