Advanced geomechanics - WP3

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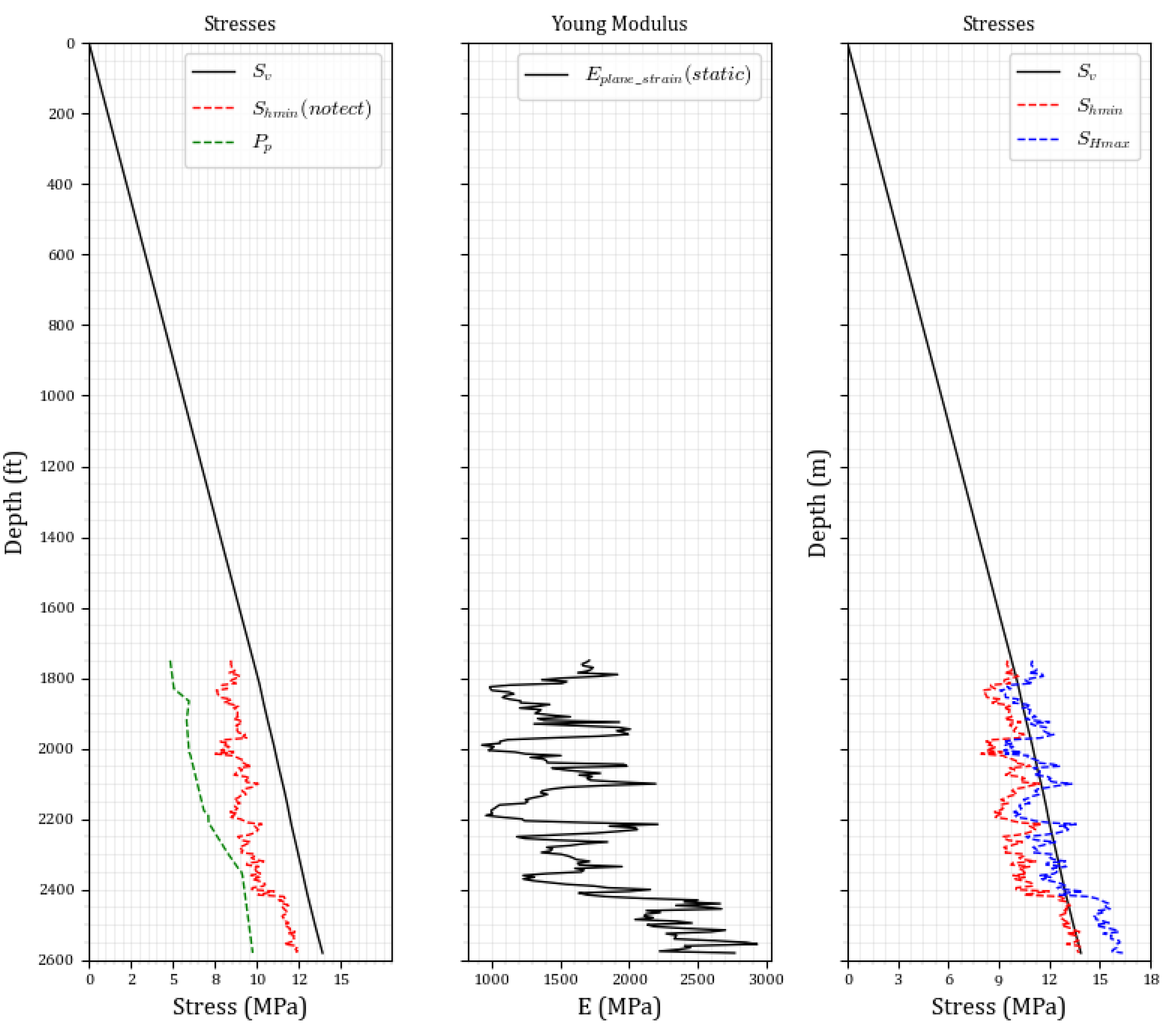
In [1]:

```
import pandas as pd
import matplotlib.pyplot as plt
import numpy as np

plt.style.use('default')   ## reset!
plt.style.use('paper.mplstyle')

# depth_ft      Pp_psi  dens_g_cc       dtc_us_ft       dts_us_ft       por
# [ft]      [psi]   [g/cc]      [us/ft]     [us/ft]     [-]
df = pd.read_excel("LostHills.xlsx")

# Convert to SI
df["depth"] = df.depth_ft * 0.3048    # m
df["dens"] = df.dens_g_cc * 1000      # kg/m3
df["Pp"] = df.Pp_psi * 6894.76        # Pa
df["dtc"] = df.dtc_us_ft * 1e-6 / 0.3048 # s/m
df["dts"] = df.dts_us_ft * 1e-6 / 0.3048 # s/m
df["Vp"] = 1 / df.dtc # m/s
df["Vs"] = 1 / df.dts # m/s

# Compute Sv
df["prev_dens"] = df.dens.shift().fillna(1870)
#                      kg/m3                        g[m/s2]   = $ Svgrad [Pa/m]
df["SvGrad"] = ( df.dens/2 + df.prev_dens/2 ) *    9.8
df['DeltaDepth'] = df.depth_ft.diff().shift(-1) * 0.3048
df['dSv'] = df.DeltaDepth * df.SvGrad
df['Sv'] = df.dSv.shift().cumsum().fillna(0)
df['Sv_MPa'] = df.Sv / 1e6

# Effective stresses
df["Sig_v"] = df.Sv - df.Pp

# Edyn, vdin
df["E_dyn"] = df.dens * ( df.Vs**2 ) * ( 3 * df.Vp**2 - 4 * df.Vs**2 ) / ( df.Vp**2 - df.Vs**2 )
df["poisson_dyn"] = ( df.Vp**2 - 2 * df.Vs**2 ) / 2 / ( df.Vp**2 - df.Vs**2 )

df["E"] = 0.65 * df.E_dyn
df["poisson"] = df.poisson_dyn

df["E_plane_strain"] = df.E / ( 1 - df.poisson**2 )
df["E_plane_strain_MPa"] = df.E_plane_strain / 1E6

# Shmin, no tectonic
df["Sigma_hmin_notect"] = df.poisson / ( 1 - df.poisson ) * df.Sig_v
df["Shmin_notect"] = df.Sigma_hmin_notect + df.Pp
df["Shmin_notect_MPa"] = df.Shmin_notect / 1e6

# Effective horizontal stresses
# Sigma_hmin, Sigma_hmax, tectonic stresses eps_hmax = 0.0015   eps_hmin=0
df["Sigma_hmin"] = df.poisson / ( 1 - df.poisson ) * df.Sig_v + df.E_plane_strain * 0.0015 * df.poisson
df["Sigma_hmax"] = df.poisson / ( 1 - df.poisson ) * df.Sig_v + df.E_plane_strain * 0.0015

df["Shmin"] = df.Sigma_hmin + df.Pp
df["Shmax"] = df.Sigma_hmax + df.Pp

# Units
df["Shmin_MPa"] = df.Shmin / 1e6
df["Shmax_MPa"] = df.Shmax / 1e6


fig, [ax1, ax2, ax3] = plt.subplots( 1, 3, sharey=True )
fig.set_size_inches(8,7)

## Plot Stressees
ax = ax1
ax.plot(df.Sv_MPa, df.depth_ft, label="$S_v$", c='k')
ax.plot(df.Shmin_notect_MPa, df.depth_ft, '--', label="$S_{hmin} (no tect)$", c='r')
ax.plot(df.Pp/1e6, df.depth_ft, '--', label="$P_p$", c='green')
ax.set_xlim(0,18)
ax.set_ylim(0,2500)

ax.set_xlabel("Stress (MPa)")
ax.set_ylabel("Depth (ft)")
ax.set_xticks( np.linspace(0, 15, 7) )
ax.set_yticks( np.linspace(0, 2600, 14) )
ax.set_title("Stresses")
from matplotlib.ticker import FormatStrFormatter
ax.xaxis.set_major_formatter(FormatStrFormatter('%.0f'))
ax.invert_yaxis()
ax.legend()

## Plot Young modulus
ax = ax2
ax.plot(df.E_plane_strain_MPa, df.depth_ft, label="$E_{plane\_strain} (static)$", c='k')
# ax.set_xlim(0,3)
ax.set_xlabel("E (MPa)")
# ax.set_xticks( np.linspace(0, 3, 5) )
ax.set_title("Young Modulus")
from matplotlib.ticker import FormatStrFormatter
ax.xaxis.set_major_formatter(FormatStrFormatter('%.0f'))
ax.invert_yaxis()
ax.legend()

## Plot stresses under tectonic strains
ax = ax3
ax.plot(df.Sv_MPa, df.depth_ft, label="$S_v$", c='k')
ax.plot(df.Shmin_MPa, df.depth_ft, '--', label="$S_{hmin}$", c='r')
ax.plot(df.Shmax_MPa, df.depth_ft, '--', label="$S_{Hmax}$", c='b')


ax.set_xlim(0,18)
ax.set_xlabel("Stress (MPa)")
ax.set_ylabel("Depth (m)")
ax.set_xticks( np.linspace(0, 18, 7) )
ax.set_title("Stresses")
from matplotlib.ticker import FormatStrFormatter
ax.xaxis.set_major_formatter(FormatStrFormatter('%.0f'))
ax.legend()

ax.invert_yaxis()
fig.tight_layout()
```



In [1]:

```
from IPython.display import display, Math, Latex
display(Latex(r"\newpage"))
```

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The pay-zone is between 2,100 ft and 2,450 ft. A hydraulic fracture is planned to be executed with a vertical well at a depth between 2,130 ft and 2,160 ft. What will be the height of this fracture? Will it reach out to the entire pay zone?

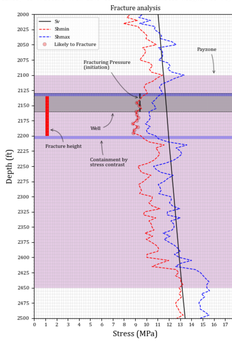
Likely to fracture from 2135 to 2200 ft (Estimated height: 65 ft).

The fracture starts at P_{inj} around 9.4 MPa (13,600 psi) and opens downwards, where stresses are lower.

In [3]:

```
Frac_press = 9.4

plt.style.use('default')   ## reset!
plt.style.use('paper.mplstyle')

# Estimate fracture height
df["Frac_MPa"] = df.Shmin_MPa

# Likely to fracture
mask2 = ( df.Shmin_MPa < Frac_press ) & ( df.depth_ft > 2100) & ( df.depth_ft < 2210)
dfm2 = df[mask2]

likely_to_frac_range = [ dfm2.depth_ft.min(), dfm2.depth_ft.max(), dfm2.depth_ft.max() - dfm2.depth_ft.min() ]

print(f"Likely to fracture from {likely_to_frac_range[0]} to {likely_to_frac_range[1]} ft (Estimated height: {likely_to

# Plot
fig, ax = plt.subplots( 1, 1, sharey=True )
fig.set_size_inches(5,7)

## Plot stresses under tectonic strains
ax.plot(df.Sv_MPa, df.depth_ft, label="Sv", c='k')
ax.plot(df.Shmin_MPa, df.depth_ft, '--', label="Shmin", c='r')
ax.plot(df.Shmax_MPa, df.depth_ft, '--', label="Shmax", c='b')
# ax.plot(df.Frac_MPa, df.depth_ft, 'o', label="Fracture", c='k', linewidth=1,  markersize=7)

# Likely to fracture
ax.plot(dfm2.Frac_MPa, dfm2.depth_ft, 'o', label="Likely to Fracture", c='red', markersize=5, markeredgewidth=.5, marke

ax.set_xlim(0,18)
ax.set_xlabel("Stress (MPa)")
ax.set_ylabel("Depth (ft)")
ax.set_xticks( np.linspace(0, 18, 19) )
ax.set_yticks( np.linspace(2000, 2500, 21) )
ax.set_ylim(2000,2500)
ax.set_title("Fracture analysis")
from matplotlib.ticker import FormatStrFormatter
ax.xaxis.set_major_formatter(FormatStrFormatter('%.0f'))
ax.legend( fontsize=8 )

# Add rectangle
import matplotlib.patches as mpatches
# Payzone
rect=mpatches.Rectangle((0,2100),18,350, fill=True, alpha=0.2, color="purple", linewidth=0)
fig.gca().add_patch(rect)

# Vertical well - fracture start
rect=mpatches.Rectangle((0,2130),18,30, fill=True, alpha=0.5, color="gray", linewidth=0)
fig.gca().add_patch(rect)
rect=mpatches.Rectangle((0,2130),18,30, fill=False, alpha=1.0, color="k", linewidth=.5)
fig.gca().add_patch(rect)

# Fracture containment
for fc in [ 2130, 2200 ] :
        rect=mpatches.Rectangle((0,fc),18,5, fill=True, alpha=0.3, color="blue", linewidth=0)
        fig.gca().add_patch(rect)

# Likely to fracture
rect=mpatches.Rectangle((1,2135),.3,65,fill=True, alpha=1, color="red", linewidth=0)
fig.gca().add_patch(rect)

ax.vlines(x = Frac_press, ymin = 2130, ymax = 2160, colors = 'k', label = 'Fracturing pressure', linewidth=2, linestyle
ax.annotate("Fracturing Pressure\n(initiation)", (Frac_press,2137), xytext=(Frac_press-5,2090), fontsize=8,
        arrowprops = dict(  arrowstyle="->", connectionstyle="angle3,angleA=-60,angleB=0", alpha=0.5))


ax.annotate("Containment by\nstress contrast", (6,2205), xytext=(5,2250), fontsize=8,
        arrowprops = dict(  arrowstyle="->", connectionstyle="angle3,angleA=0,angleB=-90", alpha=0.5))

ax.annotate("Payzone", (16,2100), xytext=(14.5,2060), fontsize=8,
        arrowprops = dict(  arrowstyle="->", connectionstyle="angle3,angleA=0,angleB=-90", alpha=0.5))

ax.annotate("Well", (7,2160), xytext=(5,2190), fontsize=8,
        arrowprops = dict(  arrowstyle="->", connectionstyle="angle3,angleA=0,angleB=-90", alpha=0.5))

ax.annotate("Fracture height", (1.3,2190), xytext=(1,2220), fontsize=8,
        arrowprops = dict(  arrowstyle="->", connectionstyle="angle3,angleA=90,angleB=180", alpha=0.5))



ax.invert_yaxis()
fig.tight_layout()
```

```
Likely to fracture from 2145 to 2195 ft (Estimated height: 50 ft).
```



In [ ]: