Interactive Fault Extraction in 3D Seismic Data Using the Hough Transform and Tracking Vectors

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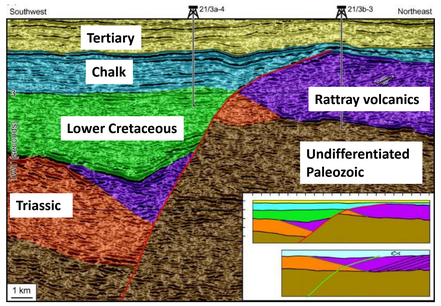
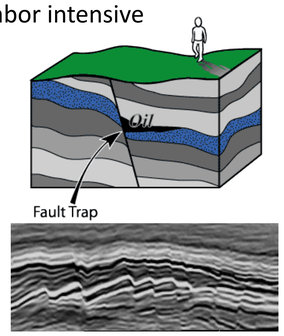
Faults and Its Geological Features

- Faults formed by the displacements of fractures in the subsurface
- Faults are closely related to the formation of petroleum reservoirs
- Manual fault labeling is time consuming and labor intensive

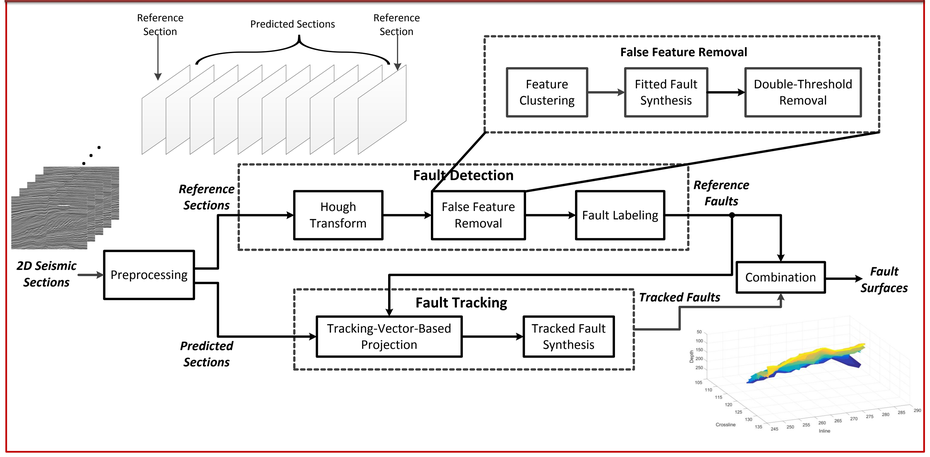




Figs ① ② ③

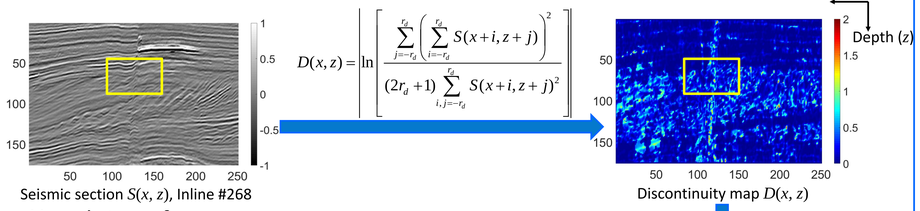
1. http://gsabulletin.gsapubs.org/content/112/9/1414/F5.large.jpg 2. http://www.priweb.org/ed/pgws/systems/traps/structural/structural.html
3. https://opendtect.org/osr/pmwiki.php/Main/NetherlandsOffshoreF3BlockComplete4GB

Proposed Method Overview



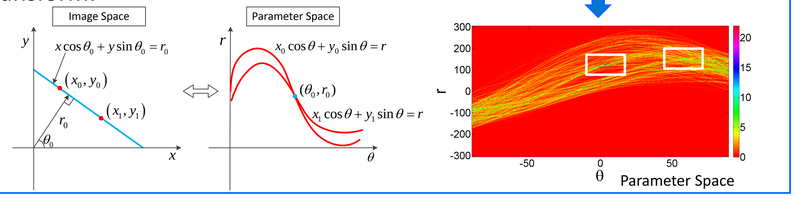
Fault Detection in Reference Sections

- Preprocessing: discontinuity map

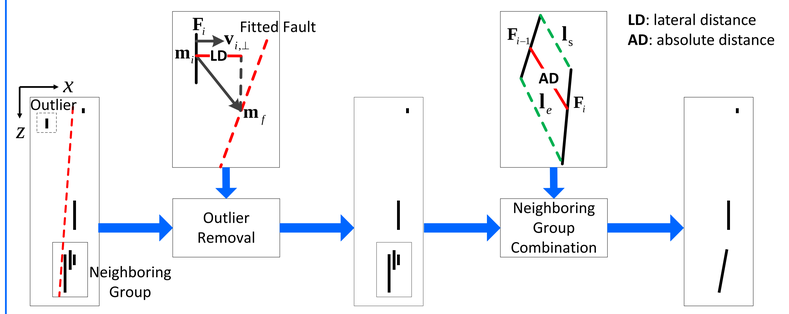


$$D(x,z)=\ln\left|\frac{\sum_{j=-r_d}^{r_d}\left(\sum_{i=-r_d}^{r_d}S(x+i,z+j)\right)^2}{(2r_d+1)\sum_{i,j=-r_d}^{r_d}S(x+i,z+j)^2}\right|$$

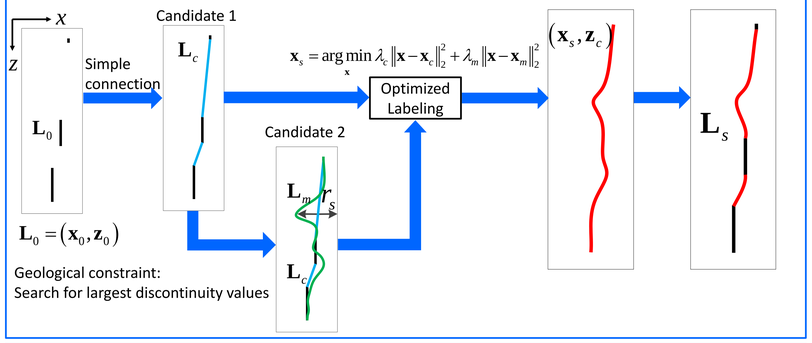
- Hough transform:



- False feature removal:

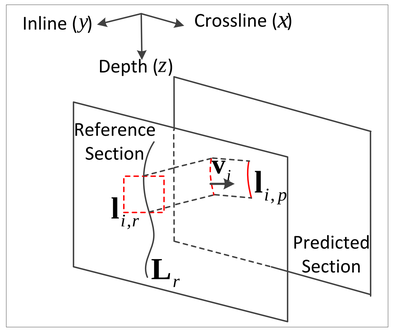


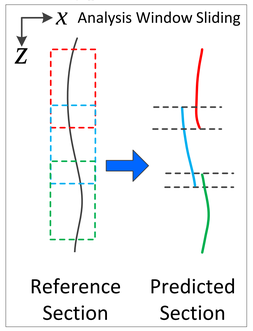
- Fault labeling:



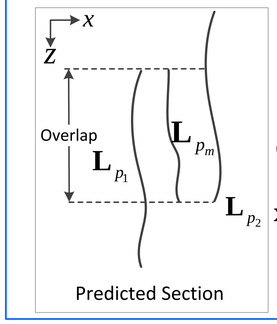
Fault Tracking in Predicted Sections

- Tracking-vector-based projection: $\mathbf{v}_i=\arg\max_{\mathbf{v}}\sum_{n=1}^{|\mathbf{l}_{i,r}|}D_p\left(\mathbf{l}_{i,r}(n)+\mathbf{v}\right)$





- Tracked fault synthesis



$$\mathbf{x}_{p_m}=\arg\max_{x\in[x_{p_1},x_{p_2}]}D_p\left(x,\mathbf{z}_{p_m}(n)\right),n=1,2,\cdots,\left|\mathbf{z}_{p_m}\right|$$

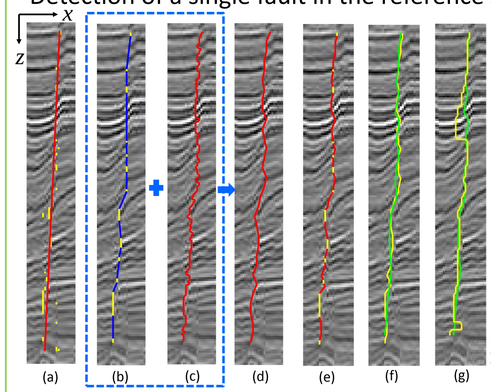
x_{p_1} and x_{p_2} are the x-coordinates of $\mathbf{z}_{p_m}$ in $\mathbf{L}_{p_1},\mathbf{L}_{p_2}$

Combing $\mathbf{L}_{p_1},\mathbf{L}_{p_2}$, and $\mathbf{L}_{p_m}$

$$\mathbf{x}=\arg\max_{\mathbf{x}}\mu_p\cdot\left(\lambda_{p_1}\cdot\left\|\mathbf{x}-\mathbf{x}_{p_1}\right\|^2+\lambda_{p_2}\cdot\left\|\mathbf{x}-\mathbf{x}_{p_2}\right\|^2\right)+\mu_m\left\|\mathbf{x}-\mathbf{x}_{p_m}\right\|^2+\delta\|\mathbf{x}\|^2$$

Experimental Results

- Detection of a single fault in the reference section:

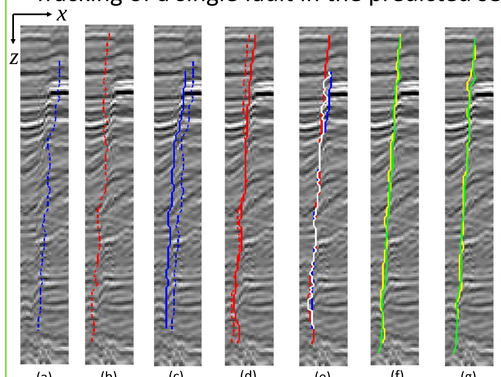


(a) Detected fault features (yellow) and fitted fault (red)
(b) Remaining fault features and simple connection (blue)
(c) Fault with the largest discontinuity values
(d) Combine fault candidates in (b) and (c)
(e) Connect remaining features using fault in (d)
(f) Compare detected fault by the proposed method with manually labeled fault
(g) Compare detected fault by Hale's method [4] with manually labeled fault

Manually Labeled Detected

[4]. D. Hale, "Methods to compute fault images, extract fault surfaces, and estimate fault throws from 3D seismic images," Geophysics, vol. 78, no. 2, pp. O33–O43, 2013.

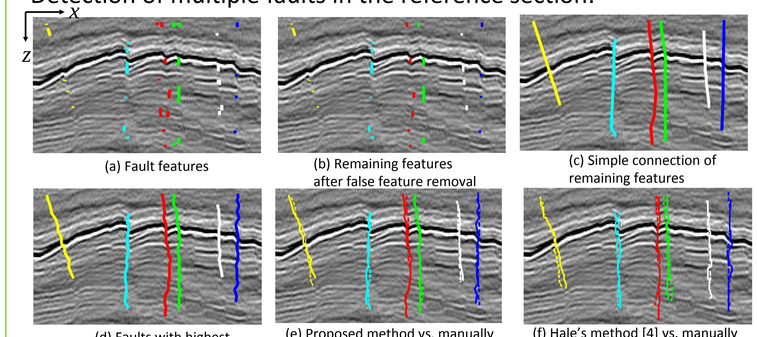
- Tracking of a single fault in the predicted section (Inline #258):



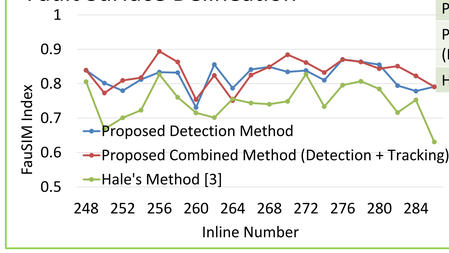
(a) the reference fault detected in Inline #248 (dashed blue)
(b) the reference fault detected in Inline #268 (dashed red)
(c) Reference fault in Inline #248 (dashed blue) and the projected fault, $\mathbf{L}_{p_1'}$ (solid blue)
(d) Reference fault in Inline #268 (dashed red) and the projected fault, $\mathbf{L}_{p_2'}$ (solid red)
(e) $\mathbf{L}_{p_1'}$, $\mathbf{L}_{p_2'}$, and $\mathbf{L}_{p_m}$ (white) for the synthesis of the tracked fault
(f) the comparison between the tracked fault (yellow) and the manually picked fault (green)
(g) the comparison between the detected fault (yellow) and the manually picked fault (green)

Manually Labeled Detected

- Detection of multiple faults in the reference section:



- Fault Surface Delineation



Methods	Mean	Std. Dev.
Proposed Detection Method	0.8197	0.0355
Proposed Combined Method (Detection + Tracking)	0.8308	0.0400
Hale's Method	0.7488	0.0512