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3D SEISMIC DATABASE AND METHODOLOGY

Quantification of channel morphology and architecture

The primary source of the database utilized in the current study is ca 500 km^2 km^2 of 3D seismic data, acquired by the China Petroleum and Chemical Corporation from the Lower Congo Basin, West African margin (Fig. 1). 3D seismic data have been migrated with a single pass 3D post-stack time migration, and have a bin size spacing of 12.5 m (in-line) by 12.5 m (cross-line) and a sampling interval of 4 ms. The frequency of the time-migrated volume varies with depth, but is approximately 50 Hz for the study interval of interest, yielding a vertical (λ/4) resolution of 7.5 m and a detection of 1.2 m (λ/25). They were displayed using "SEG (Society of Exploration Geophysics) reverse polarity", where a positive reflection coefficient corresponds to an increase in acoustic impedance, and is represented by a positive reflection event. They were displayed using a red-white-black color bar, on which a peak (a decrease in acoustic impedance) is represented by the black and a trough (an increase in acoustic impedance) is represented by the red.

3D seismic data were used to quantify morphologies and architecture of the studied channels, using "traditional" 2D stratigraphic analyses and 3D geomorphological approaches. The flattened horizontal seismic amplitude slices were produced by the Lower Congo 3D seismic volume flattened by the present-day seafloor (0 msec). Flattened horizontal seismic amplitude slices, together with with 2D seismic transects, were then used to delineate both plan-view and cross-sectional seismic manifestations of unidirectionally migrating deep-water channels as documented in this study. Our measurements of the morphometric properties of the studied channels were converted from time to depth, using an average velocity of 1500 m/s for seawater and 2003 m/s for the shallow siliciclastics (Gong et al., 2016).

Estimating bankfull turbidity current conditions from channel morphology

The Froude number approach developed by Sequeiros (2012) is applicable for both straight and sinuous deep-water channels, and is, thus, employed to estimate bankfull turbidity current conditions in the studied UCs (UC1 to UC3 on Figs. 2 and 3A). The predictive equation (Eq. 1) of this method returns the densimetric Froude number (Fr) of turbidity current as a function of: (i) the average bed slope (S); (ii) the combined friction factor $[C_f(1+\alpha)]$; and (iii) the ratio between the settling velocity of the suspended sediment (v_s) and the shear velocity of the current (u_*) (Sequeiros, 2012). Because $[C_f(1+\alpha)]$ depends on flow conditions as represented by Fr, the Froude number approach requires iteration. Six complementary equations (Eq. 2 to Eq. 7) were, thus, proposed to relate other key flow parameters to Fr.

$$Fr = [0.15 + \tanh(7.62S^{0.75})](1 + v_s/u_*)^{1.1}[C_f(1+\alpha)]^{-0.21} \quad \text{(Eq. 1)}$$

$$\alpha = 0.15Fr^{3.95} \quad \text{(Eq. 2)} \qquad \frac{z_p}{h} = 0.42Fr^{-0.58} \quad \text{(Eq. 3)}$$

$$\frac{u_p}{U_t} = 1.15 + 0.14Fr^{1.30} \quad \text{(Eq. 4)} \qquad \frac{z_c}{h} = 0.09Fr^{-2.80} \quad \text{(Eq. 5)}$$

$$\frac{c_c}{C} = 1.15 + 0.20Fr^{2.90} \quad \text{(Eq. 6)} \qquad \frac{h}{z_i} = 0.78Fr^{-0.21} \quad \text{(Eq. 7)}$$

where (i) z_p is the height of the maximum velocity point above the bottom; (ii) h and U_t are layer-averaged thickness and velocity of the turbidity current, respectively; (iii) u_p is the peak velocity; (iv) c_c and C denotes the maximum concentration and layer-averaged suspended sediment concentration, respectively; and (v) z_i signifies the distance from the channel bed to the interface between the current and ambient water. Eq. 1 to Eq. 7, together with the bed resistance relation for channel turbidity currents (Cz_p) (Eq. 8) and an equation for friction coefficient (Eq. 9), allow closing the loop of Eq. 1 to Eq. 9.

$$Cz_p = u_p/u_* = 1/\kappa \ln(30z_p/k_s) \qquad \text{(Eq. 8)}$$

$$C_f = (u_*/U_t)^2 \qquad \text{(Eq. 9)}$$

where: (i) κ is the von Karman constant, and is equal to 0.405; (ii) k_s refers to the bed roughness height; and (iii) C_f denotes friction coefficient.

To compute Fr, seven variables (i.e., C, $\overline{\Delta\rho/\rho}$, u_*/v_s, $C_f\,(1+\alpha)$, S, z_i and κ_s) need to be estimated. Firstly, turbidity currents are diluted flows with siliciclastic material, and generally have the layer-averaged volumetric concentration (C) of < 5% (Sequeiros, 2012). Secondly, a review and systematic analysis of 78 published works containing 1092 estimates of velocity and concentration of gravity flows from both field measurements and laboratory experiments dating as far back as the early 1950s suggests that the mean range of layer-averaged fractional excess density of turbidity flows ($\overline{\Delta\rho}/\overline{\rho}$) varies from 0.4% to 0.7% (0.25% < C < 0.45% with ρ_s = 2650 kg/m^3) (Sequeiros, 2012). Thirdly, laboratory experiments suggest that u_*/v_s varies from 5 to 50. Fourthly, previous studies suggest that laboratory-scale turbidity currents have C_f

($1+\alpha$) of 0.01 to 0.07, and that field-scale turbidity flows have C_f ($1+\alpha$) of 0.001 to 0.01. Fifthly, S and z_i were estimated from nine chosen channel cross-sections (UC1 to UC3 in Figs. 2 and on seismic line X on Fig. 3A), which have S of 0.011 to 0.020 (averaging 0.015) (Table DR1). z_i was assumed to be equal to bankfull depths of individual channel-complex sets (reported as H of 64 to 108 m, with mean value of H = 88 m). Sequeiros (2012) suggested that turbidity currents with relatively coarse suspended materials have κ_s of 0.01 to 1 m.

To start iterating, we assumed an arbitrary Fr to calculate α, C_f and other secondary variables. α was firstly calculated via Eq. 2, while Cz_p, z_p, and h were then computed by Eq. 8, Eq. 3, and Eq. 7, respectively. A bed resistance relation for turbidity flows (Eq. 10) was introduced to compute C_f.

$$\mathrm{C_f} = \left(\frac{u_*}{U_t}\right)^2 = \left(\frac{u_p}{Cz_p \times U_t}\right)^2 \qquad \text{(Eq. 10)}$$

where: (i) u_p/U_t and Cz_p come from Eq. 4 and Eq. 8, respectively. After such iterative processes, the loop of Eq. 1 to Eq. 9 was finally closed, resulting in values of Fr, α, h, z_p, Cz_p, u_p/U_t, and C_f as listed in Table DR1. Fr of turbidity currents in the studied channels was computed to range from 1.11 to 1.38 (averaging 1.24), thereby exhibiting supercritical flow regimes (Table DR1). After the computations of Fr, the layer-averaged velocity (U_t) was then calculated via Eq. 11.

$$U_t = Fr(g\overline{\Delta\rho}/\overline{\rho}h)^{1/2} \qquad \text{(Eq. 11)}$$

where: (i) g is the gravitational acceleration; (ii) $\overline{\Delta\rho}$ refers to the layer-averaged excess density of the current; (iii) $\overline{\rho}$ denotes the layer-averaged density of the turbidity flow; and (iv) $\overline{\Delta\rho}/\overline{\rho}$ signifies the layer-averaged fractional excess density of the flow with respect to that of the ambient fluid (ρ_a) (i.e., $\overline{\Delta\rho}/\overline{\rho}$ of < 0.7% for field-scale turbidity currents, as suggested by Sequeiros, 2012). Our results suggest that turbidity currents in the Lower Congo UCs had U_t of 1.72 to 2.59 m/s (averaging 2.22 m/s) and low heights of velocity maximum (i.e. 0.35 to 0.39 of the flow height) (Table DR1). Our results of *S* and *Fr* were, then, plotted together with 73 measurements of *S* and *Fr* of field- and laboratory-scale turbidity current (Sequeiros, 2012), resulting in a power law relationship of *Fr* to *S* (R^2 = 0.84; n=82) (Table DR1). Given geological and methodological uncertainties, the agreement between *Fr* as iteratively calculated via Eq. 1 to Eq. 10 and those in published source articles is surprisingly good, validating the accuracy of our computations.

In addition, a direct comparison between our results and measurements of 30 field-scale and 43 laboratory-scale submarine channel turbidity currents was conducted (Sequeiros 2012), in order to validate the accuracy of our computations. After the determination of turbidity current conditions in the studied channels, model of a stratified lake to wind stress and associated concept of Wedderburn number (W) and new Wedderburn number (W^{-1}) are used to answer the questions of how do turbidity flows interact with contour currents in unidirectionally migrating deep-water channels recognized in the Lower Cogon Basin (Stevens and Lawrence, 1997; Boegman et al., 2005).

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Table DR1. Tabulation of bankfull turbidity current conditions and parameters used to quantify the internal wave field along pycnoclines between turbidity and contour currents. Please refer to notation section for full details of parameters listed in this table.

Seismic lines	Channels	Estimating bankfull turbidity currents from channel morphology												Parameterizing internal wave field along pycnoclines between turbidity and contour currents															
		Input				Iterate	Output				C	Output		Input						Output									
		S	z_i	κ_s	v_s/u_*	Fr	α	C_f	h	z_p		U_t	U_p	g	ρ_2	C_d	U_{c1}	U_{c2}	B	W (-)		A (m)		W^{-1} (-)		v (m/s)		β (°)	
		-	m	m	-	-	-	-	m	m	-	m/s	m/s	m/s^2	kg/m^3	-	m/s	m/s	m	U_{c1}	U_{c2}	U_{c1}	U_{c2}	U_{c1}	U_{c2}	U_{c1}	U_{c2}	U_{c1}	U_{c2}
Figure 2A	UC1	0.020	80	1	0.002	1.38	0.531	0.0074	58.3	20.4	0.0032	2.33	3.16	9.80	1041	0.01	0.1	0.3	1612	0.77	0.26	0.65	1.94	1.30	3.89	1.17	1.20	4.9	14.4
	UC2	0.011	108	1	0.002	1.12	0.239	0.0060	81.9	32.1	0.0032	2.25	2.96	9.80	1041	0.01	0.1	0.3	2780	0.97	0.32	0.52	1.55	1.03	3.10	1.45	1.48	4.0	11.7
	UC3	0.015	86	1	0.002	1.26	0.369	0.0068	63.9	23.5	0.0032	2.22	2.97	9.80	1041	0.01	0.1	0.3	3817	0.33	0.11	1.54	4.61	3.07	9.21	1.12	1.15	5.1	15.1
Figure 2B	UC1	0.012	79	1	0.002	1.14	0.248	0.0066	60.3	23.5	0.0032	1.95	2.57	9.80	1041	0.01	0.1	0.3	1575	0.57	0.19	0.87	2.61	1.74	5.23	0.98	1.02	5.8	17.1
	UC2	0.017	103	1	0.002	1.32	0.445	0.0066	76.1	27.3	0.0032	2.54	3.44	9.80	1041	0.01	0.1	0.3	2402	0.81	0.27	0.62	1.86	1.24	3.72	1.28	1.31	4.5	13.3
	UC3	0.014	75	1	0.002	1.21	0.319	0.0070	56.1	21.1	0.0032	2.01	2.67	9.80	1041	0.01	0.1	0.3	2944	0.30	0.10	1.66	4.97	3.31	9.93	1.01	1.05	5.7	16.6
Line x on Figure 3A	UC1	0.015	96	1	0.002	1.27	0.382	0.0066	71.3	26.1	0.0032	2.37	3.18	9.80	1041	0.01	0.1	0.3	1506	1.04	0.35	0.48	1.44	0.96	2.87	1.19	1.22	4.8	14.2
	UC2	0.018	103	1	0.002	1.35	0.488	0.0068	75.2	26.6	0.0032	2.59	3.51	9.80	1041	0.01	0.1	0.3	2069	0.96	0.32	0.52	1.56	1.04	3.13	1.30	1.33	4.4	13.0
	UC3	0.011	64	1	0.002	1.11	0.230	0.0070	48.5	19.1	0.0032	1.72	2.25	9.80	1041	0.01	0.1	0.3	2650	0.21	0.07	2.36	7.07	4.71	14.13	0.87	0.91	6.6	19.2

NOTATION

A = amplitude of the deflections of pycnoclines between turbidity and contour currents;

B = bankfull channel width;

B_d = bottom drag coefficient;

B/H = aspect ratio;

C = layer-averaged suspended sediment concentration of the current;

C_d = drag coefficient;

C_f = friction coefficient [equal to $(u_*/U)^2$];

Cz_p = dimensionless Chezy friction (calculated via u_p divided by u_*);

c_c = maximum volume concentration

Fr = densimetric Froude number;

g = gravitational acceleration;

$g`$ = reduced density;

H = bankfull channel depth;

h = layer-averaged thickness of the turbidity flow;

h_1 = the upper layer thickness at rest condition;

$\grave{\mathrm{h}}_1$ = interface depth;

k_s = bed roughness height;

Ri = Richardson number;

S = average thalweg slope;

U_t = layer-averaged velocity of turbidity flow;

U_c = layer-averaged velocity of contour current;

UCs = unidirectionally migrating deep-water channels;

v_* = shear velocity of the current;

u_*/v_s = ratio of shear velocity to settling velocity;

u_p = peak velocity of the current;

V = velocity of nonlinear surges and solitary waves along pycnoclines;

β = paleocurrent direction of nonlinear surges and solitary waves along pycnoclines;

v_s = settling velocity of characteristic grain size (computed by a pondered average of all grain sizes in suspension);

v_* = turbulent velocity;

W = Wedderburn number;

W^{-1} = new Wedderburn number (equal to $\frac{\eta_0}{h_1}$)

z_c = distance above the bed to the point below which c is roughly equal to the maximum volume concentration (c_c);

z_i = distance from the bed to the current interface (equal to H);

z_p = height of the downstream velocity maximum;

α = ratio between bed shear stress ($\mathcal{T}_i$) and interface shear stress ($\mathcal{T}_b$);

ρ_1 = density of contour current;

ρ_2 = density of turbidity current;

ρ_i = density of the interstitial fluid;

ρ_s = density of the particles;

ρ_w = ambient water density;

$\overline{\Delta\rho}$ = layer-averaged excess density of the current;

$\overline{\rho}$ = layer-averaged density of the current;

$\overline{\Delta\rho}/\overline{\rho}$ = layer-averaged fractional excess density of the flow, the relation between layer-averaged concentration and excess density (*RC*) is equal to $\overline{\Delta\rho}/\overline{\rho}$.

η_0 = maximum interference displacement