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Earthquakes triggered by the subsurface undrained response to reservoir impoundment at Irapé, Brazil

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1 Content

This supplementary material contains three tables providing data of seismicity and information on sampling, sample preparation, measurement procedures with equipment details, including three figures and generated data in Tables S2 and S3.

2 Seismicity data

Table S1. Hypocentral location of the main earthquakes triggered during the first half of 2006.

No	Date	Hours (UTC)	Latitude	Longitude	EH (km)	Depth (km)	Magnitude	Q
1	07/01/2006	03:29:34	-16.73417	-42.59028	1.3	0.26	1.8	D1
2	10/01/2006	03:06:56	-16.72889	-42.60278	0.5	4.02	1.4	C1
3	10/01/2006	03:33:53	-16.73278	-42.60778	0.9	0.04	1.7	C1
4	12/01/2006	06:05:50	-16.73667	-42.60944	2.3	0.01	1.8	C1
5	13/01/2006	02:29:04	-16.72083	-42.61806	2.8	4.09	1.0	C1
6	14/01/2006	05:19:31	-16.73528	-42.60694	0.7	0.07	1.4	C1
7	15/01/2006	17:14:30	-16.73389	-42.60444	0.5	0.03	1.9	C1
8	19/01/2006	04:01:25	-16.73889	-42.54889	6.5	0.47	2.3	D1
9	19/01/2006	13:57:39	-16.71306	-42.58944	1.8	0.08	1.6	C1
10	23/01/2006	08:22:34	-16.75500	-42.61917	1.8	0.43	1.7	C1
11	23/01/2006	12:51:07	-16.75833	-42.60556	2.1	0.13	1.5	D1
12	02/03/2006	07:33:56	-16.75417	-42.61861	2.5	0.44	1.9	C1
13	02/03/2006	09:10:06	-16.73556	-42.55722	2.1	0.5	1.3	D1
14	12/03/2006	06:08:22	-16.69167	-42.60333	2.1	0.51	1.4	C1
15	13/03/2006	08:33:16	-16.75111	-42.60972	2.6	0.12	1.3	D1
16	16/03/2006	01:46:22	-16.70361	-42.62944	1.2	11.42	1.6	C1
17	17/03/2006	00:19:58	-16.73750	-42.62333	1.1	7.47	1.4	C1
18	19/03/2006	02:18:20	-16.77167	-42.62000	2.4	0.07	1.5	C1
19	28/04/2006	08:24:10	-16.77167	-42.61833	1.3	0.44	1.5	D1
20	28/04/2006	09:26:34	-16.76806	-42.64917	2.8	6.84	2.1	C1
21	28/04/2006	16:39:56	-16.75528	-42.60889	1.0	0.14	1.4	D1
22	03/05/2006	10:46:54	-16.77639	-42.65250	3.6	11.08	1.6	C1
23	03/05/2006	21:19:05	-16.77278	-42.62306	3.0	0.1	1.6	C1
24	07/05/2006	15:46:32	-16.71389	-42.58444	1.7	0.02	1.5	D1
25	08/05/2006	18:05:22	-16.73333	-42.61528	2.0	0.02	1.6	C1
26	12/05/2006	21:34:18	-16.75333	-42.61778	1.0	0.45	1.5	C1
27	14/05/2006	14:07:46	-16.73111	-42.57750	2.7	3.88	3.0	D1
28	14/05/2006	15:24:53	-16.72194	-42.57972	1.8	8.42	1.9	D1
29	15/05/2006	09:23:14	-16.72222	-42.56722	1.4	0.37	1.7	D1

(**UTC:** Coordinated Universal Time, **EH (km):** Horizontal location error, **Depth (km):** HYPO71 Program output hypocentral depth of events, **Q:** Quality of events, where C1 and D1 have two family groups which refer to the family-based events subsequently).

The quality of events has been classified based on Root mean square error. The earthquake quality of C1 is more accurate than D1, so these events are classified into two groups that show the class of events. Nevertheless, D1 has generally 0.1 of the root mean square residual in-depth errors, so these values of uncertainty are generally accepted. However, the analysis of seismograms went through a double-check routine (Silva et al., 2014). The uncertainty of earthquakes was generally less than 0.1 of the roots mean square residual in depth errors. In this work, we did not consider this factor as an influencing element.

3 Field sampling, sample preparation, and measurement procedures with equipment details

Rock samples in this study comprise core plugs from bulk samples of mica-schist rock collected around the reservoir by pitting of 0.10 m at different locations. Mica-schist is metamorphic rock, its colour is shiny, blackish to medium grey, and textures are foliated, fine to medium-grained.

All collected samples are close to the dam as well as to seismic stations since the epicenter of the main event was encountered about 1 km from the dam (Figure 3 in manuscript). We collected a total of seven sets of samples. Nonetheless, we could only test three sets, from which we could prepare a total of 11 cores of hard and intact samples (Figure 4 in manuscript). The rest of the samples were fragile and fractured during the coring from bulk samples. We extracted the core samples in shape of cylindrical plugs perpendicular to the bedding plane of rocks (Figure S1).

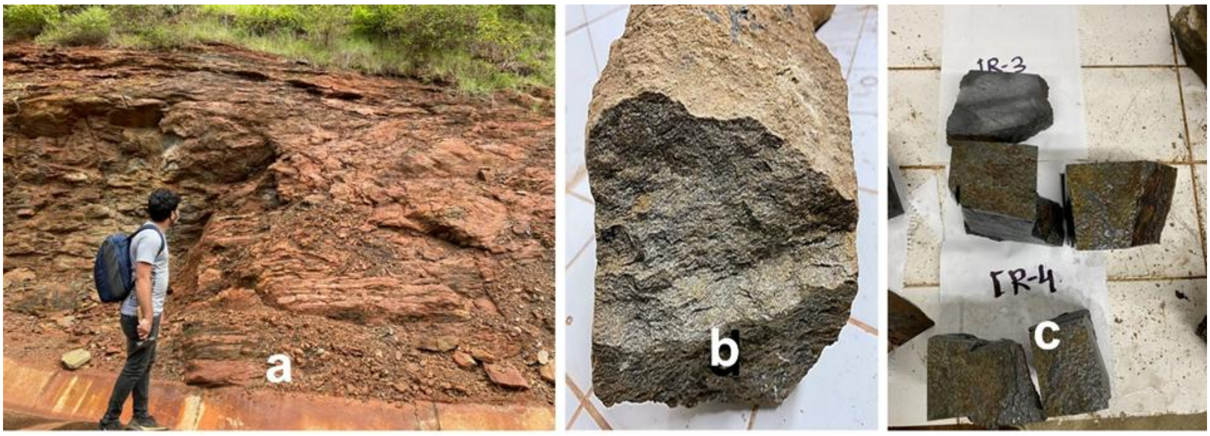

Figure S1. a. Outcrop of mica-schist near the Irapé dam (photos taken during the field trip) **b.** bulk sample extracted from the dam area **c.** cutting and washing of bulk samples to retrieve the core plugs.

All samples are in the form of cylindrical plugs that have length ranging from 3.8 to 5.0 cm and diameter is of 2.50 cm, which meets the standard criteria to test the core plugs samples by Ultra-Pore 300 and Ultra-Perm 610 (see the equipment descriptions).

Ultra-Perm 610 (Core Lab Instruments)

The permeability tests have been performed using UltraPerm-600 (Figure S2). UltraPerm-600 is a steady-state air permeameter, in which back pressure control allows constant rate or constant mean pressure. The instrument allows the determination of permeability up to 3.0 mD. Thus, the lowest permeability 0.002 mD is assigned (Table S2). The Ultra-Perm 610 Permeameter uses advanced precision mass flow meters and pressure transducers to measure absolute permeability of rock. The core plugs should be around 2.5 cm in diameter and around 4.0 cm in length. By combining automated data acquisition and real-time graphics with mass flow determinations, greater accuracy and precision of the data are obtained (Haskett et al.,1988). The operating software allows permeability data to be easily related to historical and current databases generated by different techniques.

Figure S2. Ultra-Perm 610 gas permeameter with pressure sample saturator (Core Lab Instruments).

Ultra-Pore 300 (Core Lab Instruments)

We have measured porosity values using Ultra-Pore 300 (Core Lab Instruments) (Figure S3 and Table S3). The models of the equipment are made by Core lab Instruments, in Texas, USA. UltraPore-300 is a gas expansion helium pycnometer for the determination of grain volume or pore volume of core plug and full diameter samples.

Figure S3. Ultra-Pore 300 Porosimeter with matrix cup and analysis plugs.

Matrix cups for the 2.5-3.8 cm diameter of samples with Setra 204 transducer rated for 0-1.72 MPa. The pore volume hypothesizes through the nitrogen gas (N_2) expansion technique. The system can be used in grain volume or pore volume measurement mode, depending on sample holder configuration. It has multiple volumes built into the system, which allow it to be used for small discs (cuttings), plugs and full diameter samples. More information about this equipment in accordance with international standards can be accessed at www.lpfr.igd.unb.br/infraestrutura/porosimetro and www.corelab.com/cli/routine-rock/ultrapore-porosimeter.

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Table S2. List of permeability data measured from cylindrical plug samples (Barometric pressure (PSI) atm, Upstream Pressure=psig, Gas viscosity=cp, *Q*= Gas flow rate at cc/sec)

No	Sample ID	Depth (m)	Length (cm)	Diameter (cm)	Temp (ºC)	Barometric Pressure (PSI)	Confining Pressure	Upstr Pres (psig)	P1 (atm)	P2 (atm)	Q (cc/sec)	K-air (md)	P mean (atm)	K-inf (md)	b (atm)	Beta	Visc (cP)	Q unadj (cc/s)
1	IR-1a	0.1	4.90	2.50	22	14.70	500	2.78	1.1894	1.0003	0.000	<0.002	1.0949	0	0	0	0.01756	0.0000
2	IR-1b	0.1	4.90	2.50	22	14.70	500	2.64	1.1799	1.0003	0.000	<0.002	1.0902	0	0	0	0.01756	0.0000
3	IR-1c	0.1	4.90	2.50	22	14.70	500	2.42	1.1649	1.0003	0.000	<0.002	1.0827	0	0	0	0.01756	0.0000
4	IR-1d	0.1	4.00	2.50	22	14.70	500	2.66	1.1813	1.0003	0.000	0.0098	1.0907	0	0	0	0.01756	0.0005
5	IR-2a	0.1	4.10	2.50	22	14.70	500	2.69	1.1833	1.0003	0.000	<0.002	1.0919	0	0	0	0.01756	0.0000
6	IR-2b	0.1	3.80	2.50	22	14.70	500	2.61	1.1779	1.0003	0.000	0.0038	1.0890	0	0	0	0.01756	0.0002
7	IR-2c	0.1	3.80	2.50	22	14.70	500	2.61	1.1779	1.0003	0.000	0.0038	1.0892	0	0	0	0.01756	0.0002
8	IR-3a	0.1	5.00	2.50	22	14.70	500	2.65	1.1806	1.0003	0.000	<0.002	1.0904	0	0	0	0.01756	0.0000
9	IR-3b	0.1	5.00	2.50	22	14.70	500	2.61	1.1779	1.0003	0.000	<0.002	1.0890	0	0	0	0.01756	0.0000
10	IR-3c	0.1	4.60	2.50	22	14.70	500	2.71	1.1847	1.0003	0.000	<0.002	1.0923	0	0	0	0.01756	0.0000
11	IR-3d	0.1	4.00	2.50	22	14.70	500	2.71	1.1847	1.0003	0.000	<0.002	1.0923	0	0	0	0.01756	0.0000

⊥ *Experiments loaded perpendicular to bedding plane*

Table S3. List of porosity data measured from cylindrical plug samples

NO.	Sample ID	Depth (m)	Dry Weight (g)	Grain Volume (cc)	Grain Density (g/cc)	Pore Volume (cc)	Porosity (%)	Hg Bulk Vol. (cc)	Length (cm)	Diam. (cm)	Calliper Bulk Vol (cc)
1	IR-1a	0.1	57.56	22.2416	2.588	1.811	7.5	0	4.90	2.50	24.053
2	IR-1b	0.1	58.03	22.4214	2.588	1.632	6.8	0	4.90	2.50	24.053
3	IR-1c	0.1	57.46	21.9409	2.619	2.112	8.8	0	4.90	2.50	24.053
4	IR-1d	0.1	47.62	18.3480	2.595	1.287	6.6	0	4.00	2.50	19.635
5	IR-2a	0.1	50.82	18.2157	2.790	1.910	9.5	0	4.10	2.50	20.126
6	IR-2b	0.1	45.86	16.7010	2.746	1.952	10.5	0	3.80	2.50	18.653
7	IR-2c	0.1	36.91	12.9748	2.845	2.242	14.7	0	3.80	2.50	15.217
8	IR-3a	0.1	60.30	22.8400	2.640	1.704	6.9	0	5.00	2.50	24.544
9	IR-3b	0.1	58.79	21.2745	2.763	3.270	13.3	0	5.00	2.50	24.544
10	IR-3c	0.1	55.48	20.9707	2.646	1.609	7.1	0	4.60	2.50	22.580
11	IR-3d	0.1	49.87	18.8501	2.646	1.276	6.3	0	4.10	2.50	20.126

⊥ Experiments loaded perpendicular to bedding plane

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