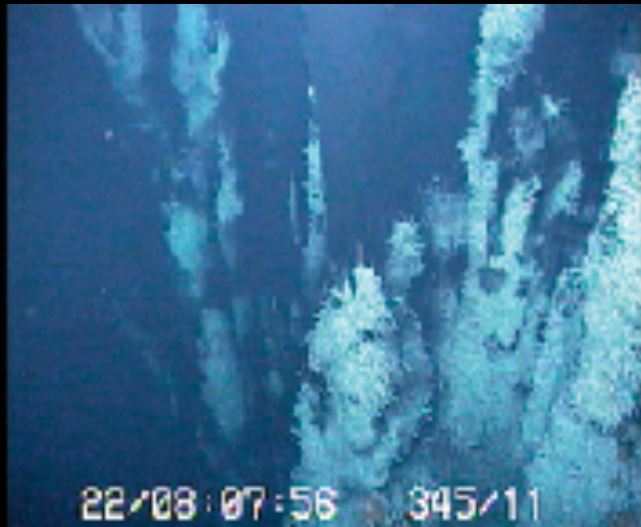


Hydrothermal Activity in the Indian Ocean



Susan E. Humphris
Woods Hole Oceanographic Institution

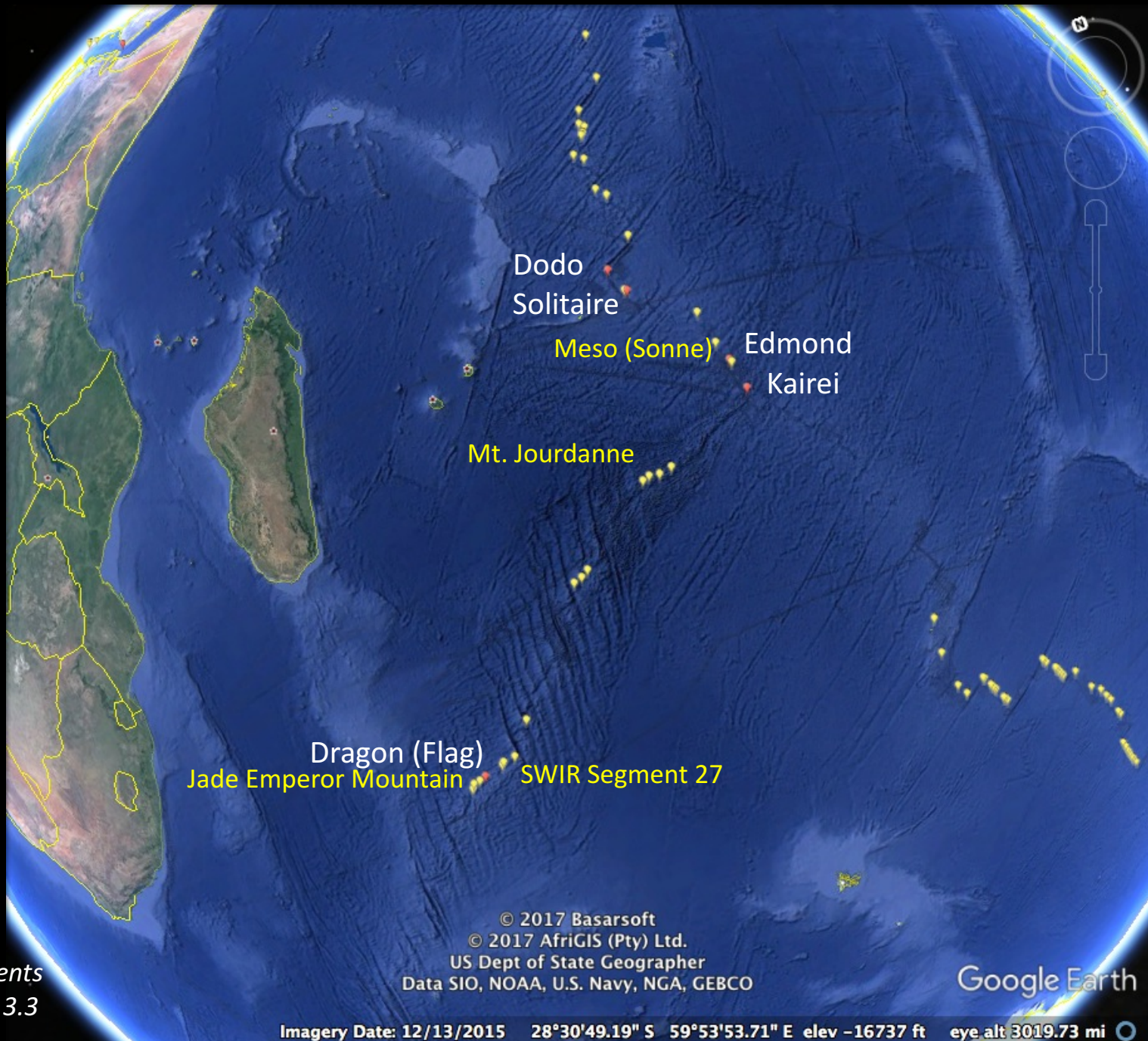


*InterRidge Vents
Database, v. 3.3
(2015)*

Image U.S. Geological Survey
Image Landsat / Copernicus
US Dept of State Geographer
Data SIO, NOAA, U.S. Navy, NGA, GEBCO

Google Earth

Imagery Date: 12/13/2015 43°00'05.54" S 53°23'40.10" E elev -12631 ft eye alt 4721.76 mi



Dodo
Solitaire

Meso (Sonne)

Edmond
Kairei

Mt. Jourdanne

Dragon (Flag)
Jade Emperor Mountain

SWIR Segment 27

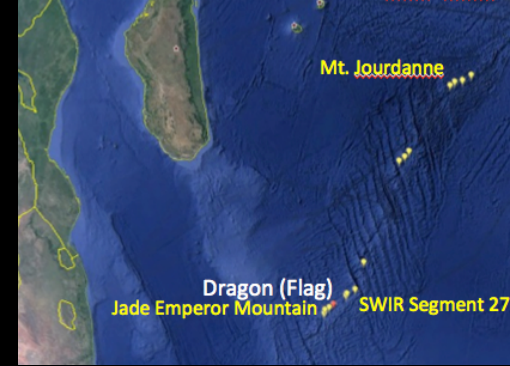
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US Dept of State Geographer
Data SIO, NOAA, U.S. Navy, NGA, GEBCO

Google Earth

Imagery Date: 12/13/2015 28°30'49.19" S 59°53'53.71" E elev -16737 ft eye.alt 3019.73 mi

InterRidge Vents
Database, v. 3.3
(2015)

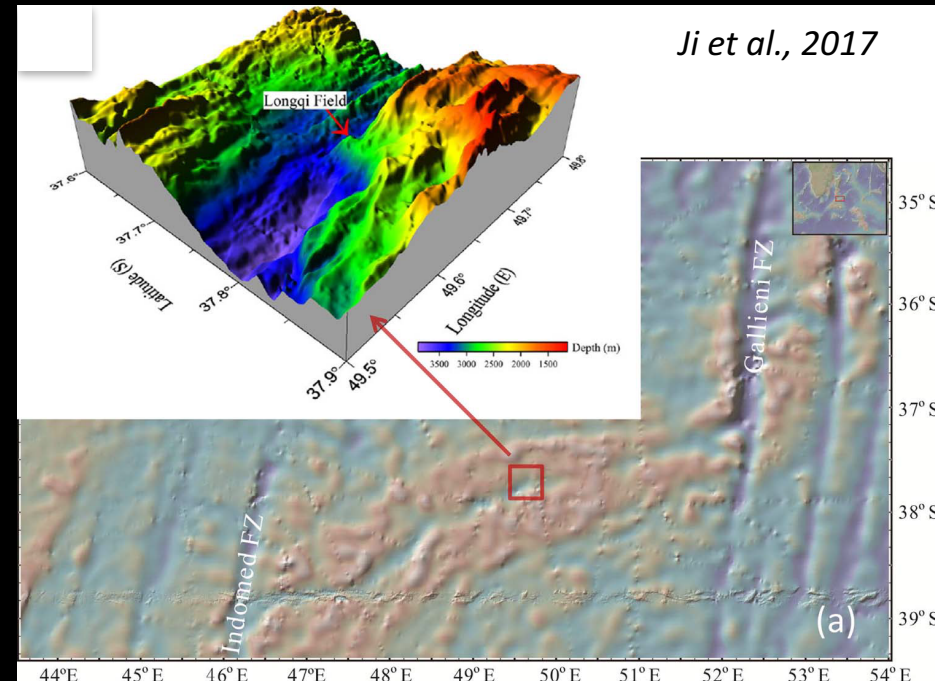
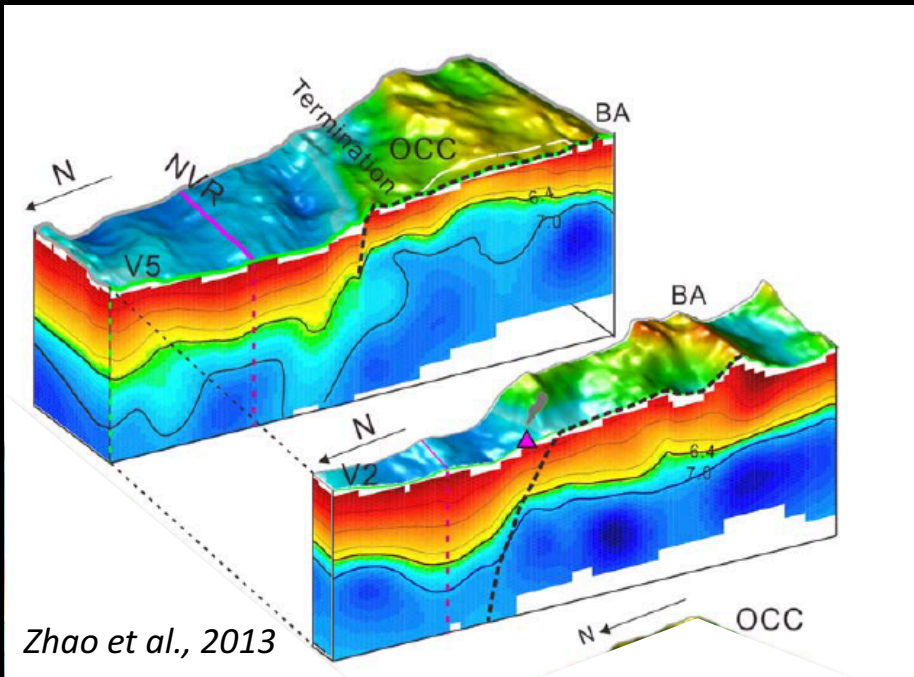
Inactive Hydrothermal Deposits on the Ultraslow-Spreading Southwest Indian Ridge



	<i>Depth (m)</i>	<i>Location</i>	<i>Size</i>	<i>Characteristics</i>
Mt. Jourdanne (27.85°S 63.93°E)	2940	Graben on top of axial volcanic ridge	0.5 km ²	Small chimneys & mounds; galena & Pb-As sulfosalts. Low Cu, high Zn, Pb, very high Au (11 ppm) and Ag (0.1 wt.%)
SWIR Unnamed, Segment 27 (37.66°S 50.47°E) (Break Bridge)	1739	Center of segment	200 x 125 m	Sulfide-silica chimneys, metalliferous sediments
Jade Emperor Mountain (37.94°S 49.26°E)	1400	?	?	Sphalerite, wurtzite, pyrite, chalcopyrite

Dragon Flag (Longqi) Hydrothermal Field (37.78°S 49.65°E)

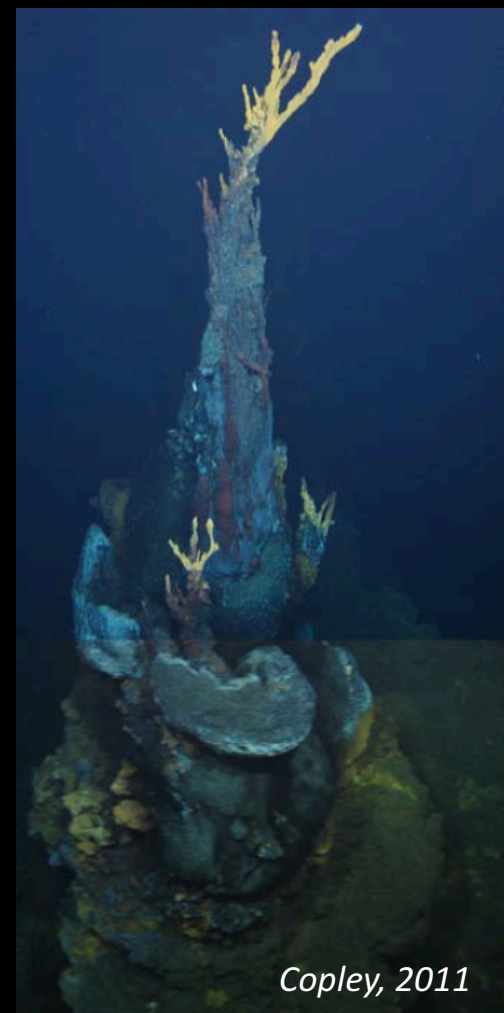
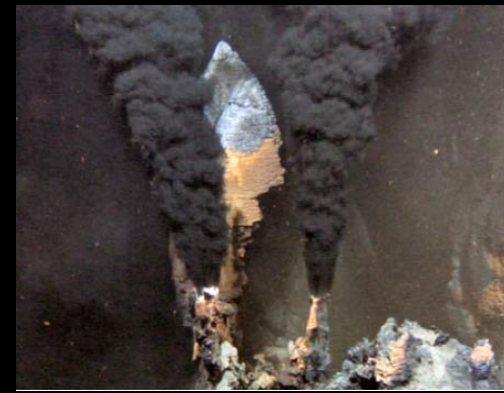
- At the termination of a detachment fault in Segment 28 at a depth of 2780 m
- Numerous active and inactive chimneys (up to 20 m), mounds and Fe-Si precipitates; also diffuse flow zones over large areas
- Chimneys of pyrite, marcasite, and sphalerite with conduits lined with chalcopyrite



End-Member Fluid Compositions from Longqi Hydrothermal Field, SWIR

	Vent DFF6	Vent DFF20	Seawater
Depth (m)	2765	2768	—
T _{MAX} (°C)	379	365	—
pH	3.68	3.58	7.8
Cl (mM)	615	616	542
K (mM)	11.1	11.4	10.1
Ca (mM)	40.6	42.9	10.2
Si (mM)	2.9	8.7	0.1
Fe (mM)	11.6	12.0	0.001
Mn (μM)	1345	1431	<0.001
Cu (μM)	14.2	53.7	0.004
Zn (μM)	47.0	90.5	0.006
H ₂ (mM)	0.21	0.17	<0.001

(Ji et al., 2017)



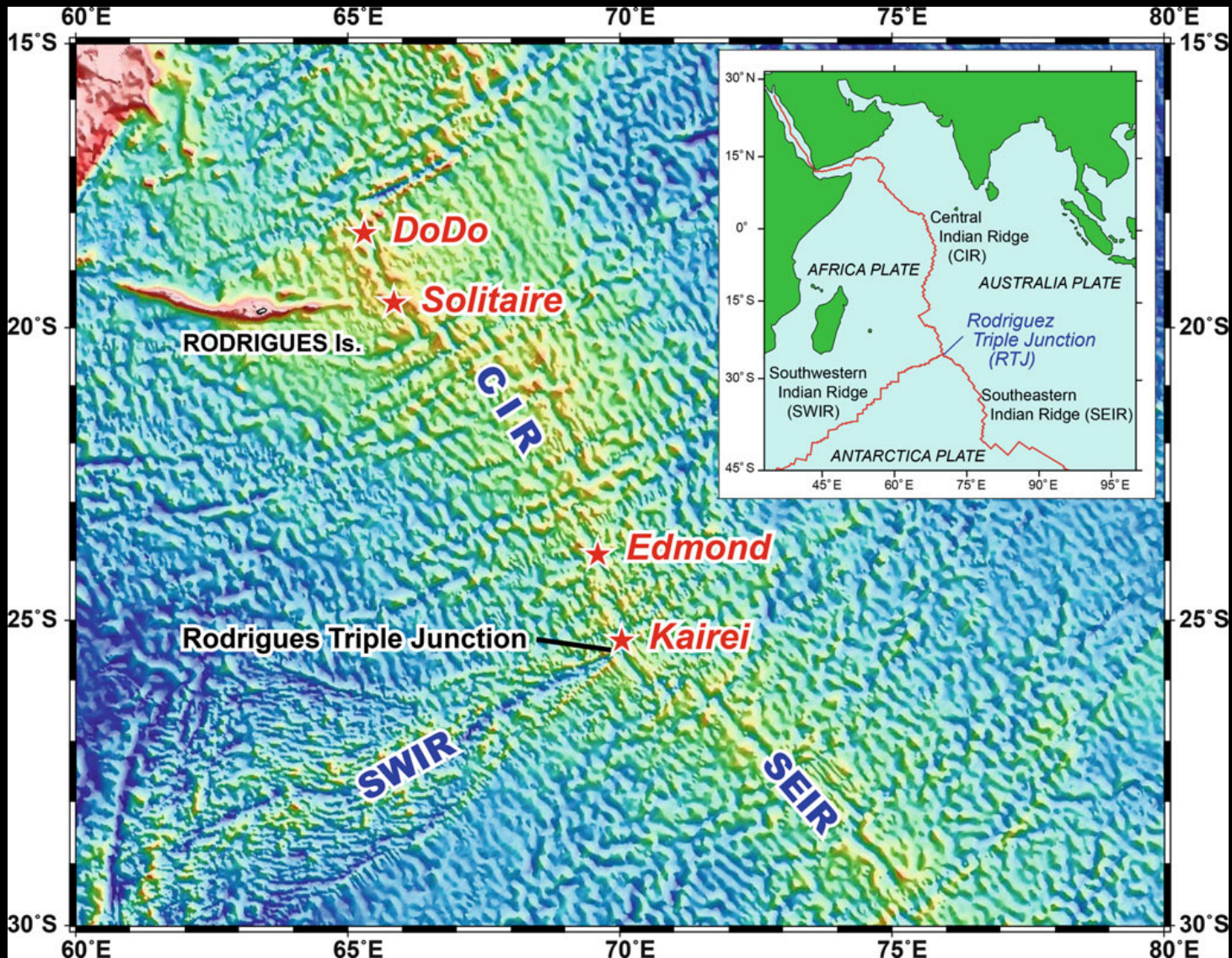
Copley, 2011

Inactive Hydrothermal Field on the Intermediate-Spreading Central Indian Ridge



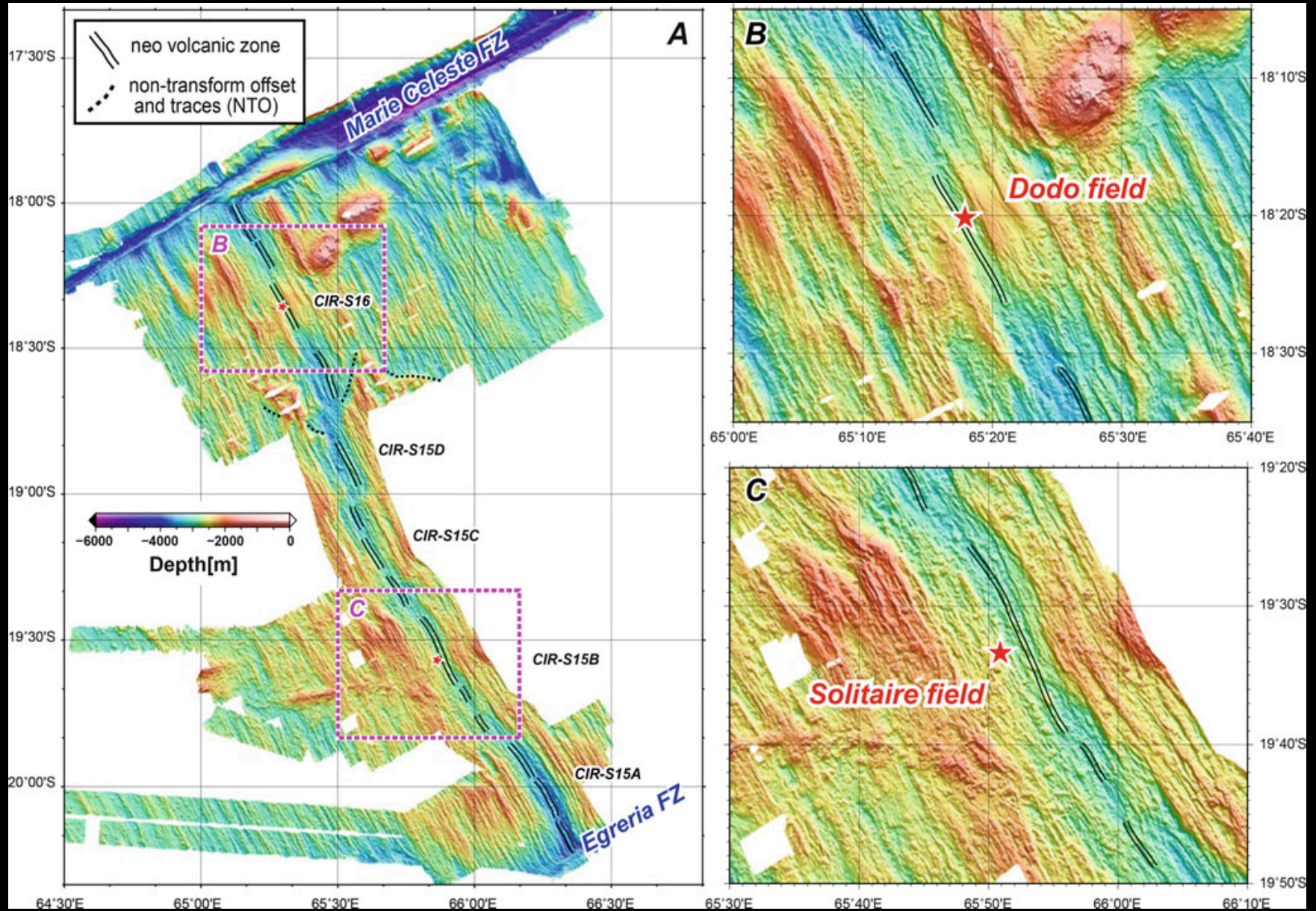
	<i>Depth (m)</i>	<i>Location</i>	<i>Size</i>	<i>Characteristics</i>
MESO Zone (23.39°S 69.24°E)	2850	Mid-segment , on top of axial volcanic ridge	0.6 km ²	Three different sites (one is Sonne field) in a state of disintegration. Mound that is topped with chimney stumps (1.5 m high) that have been oxidized to secondary Cu-minerals. Fe-oxhydroxide muds around the periphery.

Active Hydrothermal Fields on the Intermediate-Spreading Central Indian Ridge



(Nakamura and Takai, 2015)

Geotectonic Settings of Dodo & Solitaire Hydrothermal Fields



(Okino et al., 2015)

Dodo



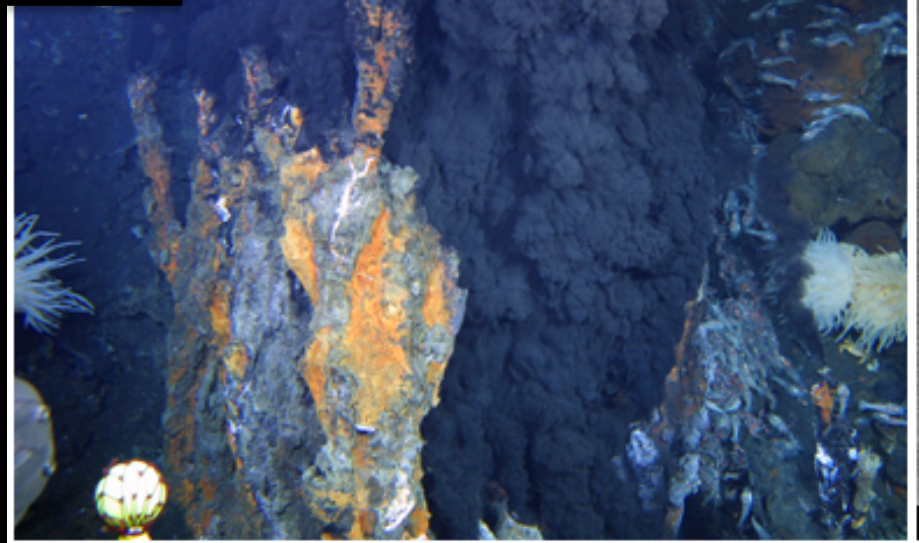
Edmond



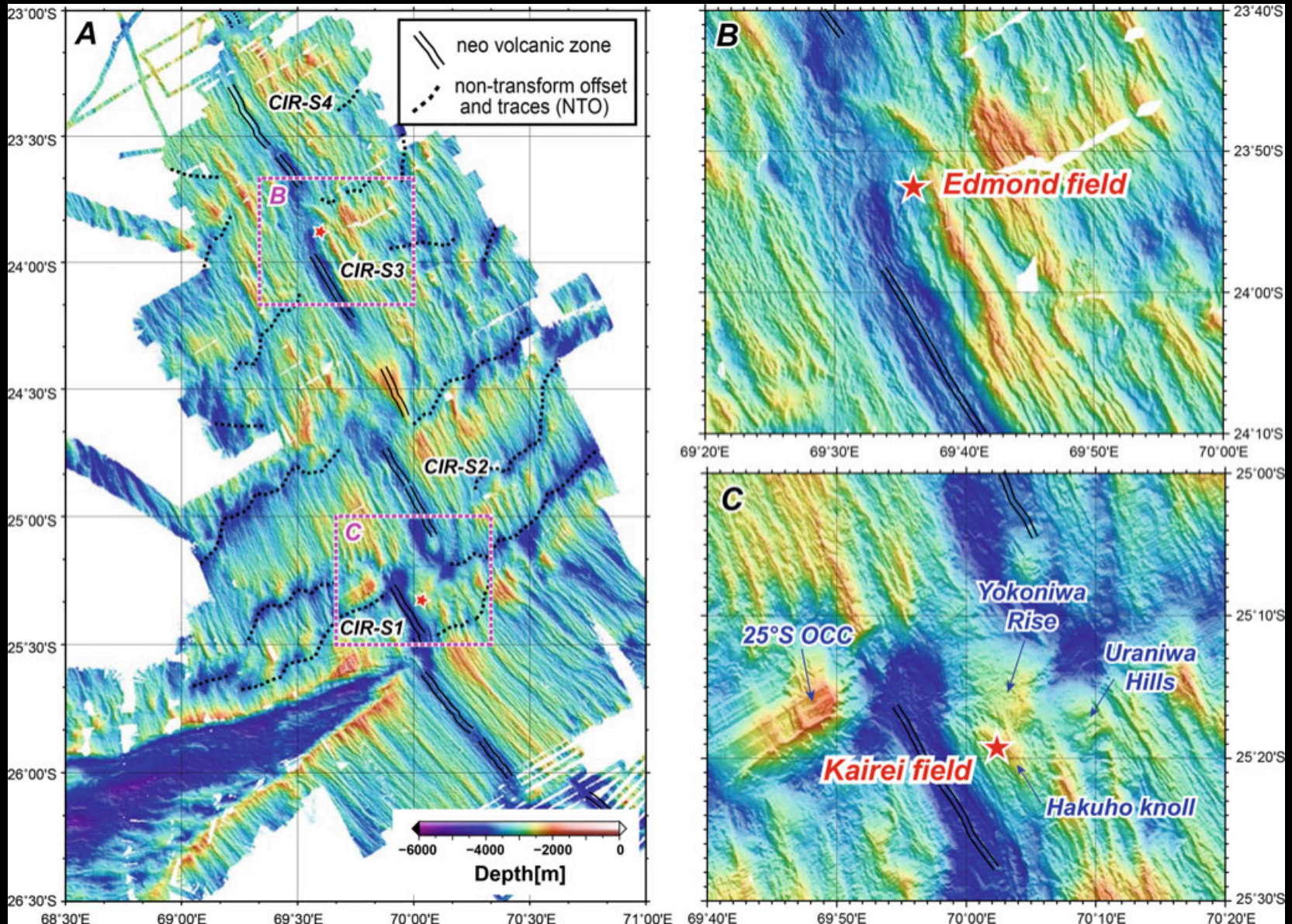
Solitaire



Kairei



Geotectonic Settings of Edmond & Kairei Hydrothermal Fields

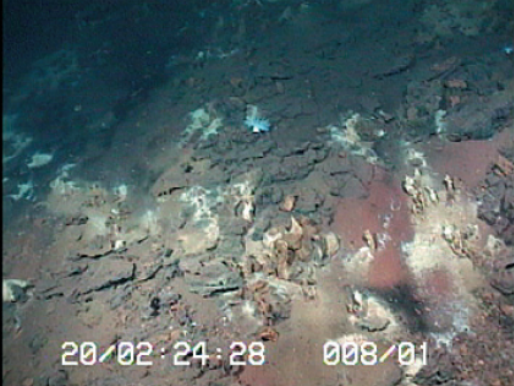


(Okino et al., 2015)

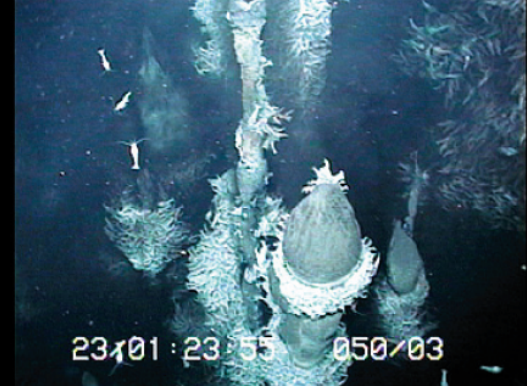
End-Member Fluid Compositions from CIR Hydrothermal Fields

	Dodo	Solitaire	Edmond	Kairei	<u>Seawater</u>
Host rock	Basalt	Basalt	Basalt	<u>Basalt/</u> <u>Peridotite (?)</u>	
Depth (m)	2745	2606	3300	2422	--
T _{MAX} (°C)	356	307	382	359	--
<u>pH</u>	3.27	4.40	3.13	3.36	7.8
<u>Cl (mM)</u>	684	489	950	637	542
<u>Na (mM)</u>	566	409	717	534	475
<u>K (mM)</u>	38	32	43	15	10.1
<u>Ca (mM)</u>	22	21	64	31	10.2
<u>Si (mM)</u>	17.3	15.2	20	17	0.1
<u>Fe (μM)</u>	5408	60	13,900	5400	0.001
<u>Mn (μM)</u>	917	78	1430	840	<0.001
<u>CO₂ (mM)</u>	4.6	16.2	5.0	3.94	2.3
<u>CH₄ (mM)</u>	0.025	0.043	--	0.104	0
<u>H₂ (mM)</u>	2.70	0.43	0.12	3.8-8.5	0
<u>H₂S (mM)</u>	2.80	4.75	4.81	4.0	0

(Kawagucci et al., 2016)



Summary



- Hydrothermal activity is widespread in the Indian Ocean
 - 90-100 sites of inferred hydrothermal activity reported to date
- There is considerable diversity in the tectonic settings among the five known active sites
 - on-axis, on rift valley wall, associated with a detachment fault
- There is variation in the substrate host rock
 - N-MORB, hotspot influenced MORB, ultramafic
- Vent fluid chemistries are similar to those seen at other MOR systems with the fundamental regulating processes being fluid-mineral equilibria and phase separation

Outstanding Questions for Consideration by IIOE-2



- What is the abundance and geological, chemical, and biological diversity of seafloor hydrothermal systems on the mid-ocean ridges of the Indian Ocean?
- What is the contribution of elemental exchange during water-rock reactions in Indian Ocean hydrothermal systems to local and global biogeochemical cycles?
- How do fluids link subseafloor and water column biogeochemical processes?
- What is the resource potential of both active and inactive mineral deposits at Indian Ocean spreading centers?