經濟部幕僚單位及行政機關人員從事兩岸交流活動報告書

「參訪中國大陸自然資源部第二海洋研究所及參加第1屆國際海脊協會之中洋脊海床塊狀硫化礦資源國際研討會」

報　告　書

研提人單位　：經濟部中央地質調查所

職 稱：科長

姓名　：陳松春

參 訪 期 間：108 年 9 月 16 日至 108 年 9 月 22 日

報 告 日 期：108 年 10 月 7 日

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政府機關（構）人員從事兩岸交流活動（參訪及參加會議）報告

壹、 交流活動基本資料

一、活動名稱:「參訪中國大陸自然資源部第二海洋研究所及參加第1屆國際海脊協會之中洋脊海床塊狀硫化礦資源國際研討會」

二、活動日期：108年9月16日至108年9月22日

三、主辦單位：杭州第二海洋研究所

四、報告撰寫人服務單位：經濟部中央地質調查所

貳、 活動重點

一、 活動性質

「國際海脊協會(InterRidge Working Group)」是國際非營利組織，主要是以推動海洋海床之研究、利用及保護等為目的，由於海洋無國界，為順利進行全球海洋海床之相關研究，必須以國際合作方式來推動，目前國際海脊協會有3個主要會員國(中國大陸、法國及挪威)，7個一般會員國(加拿大、德國、義大利、印度、日本、韓國及英國等)及8個共同會員國(澳洲、智利、紐西蘭、菲律賓、波蘭、俄羅斯、南非及美國等)，總部辦公室設置於法國巴黎，每個會員國每年繳付會費美金5,000至25,000元，提供協會運作所需之經費來源。海洋蘊藏豐富的金屬礦產資源，為人類未來所需礦產的主要來源之一，為了解在中洋脊海底塊狀硫化礦形成及分布之熱液

循環機制及地質條件特性等科學問題，該協會訂於 2019 年 9 月 19 日至 21 日在中國大陸杭州舉辦「第 1 屆國際海脊協會之中洋脊海床塊狀硫化礦資源國際研討會 (1st workshop of the IR WG on Seafloor Massive Sulfides Resource along MOR)」【註: MOR 為 Mid-ocean Ridge (中洋脊)之縮寫】, 會議主題是「熱液礦形成過程及海床塊狀硫化礦在慢速及超慢速中洋脊擴張的命運 (Hydrothermal ore-forming processes and the fate of SMS deposits along slow and ultraslow spreading MOR) 」，主辦單位是中國大陸自然資源部第二海洋研究所。

本所從 105 年起開始執行「臺灣東北海域礦產資源潛能調查」四年期科施政計畫，計畫執行 3 年多以來，在調查區(南沖繩海槽)海床發現有活躍的熱液噴泉活動、廣泛的熱液換質和金屬礦化現象（煙囪石柱、礦物隆堆），從海底影像發現被稱為金屬噴泉的「黑煙囪」，並採獲超過 80 公斤的礦石，經分析平均金屬含量至少 50%以上（部分高達 60~65%）；另於今(108)年 4 月及 7 月使用我國勵進研究船(隸屬於國家實驗研究院台灣海洋科技研究中心)之線控無人載具(ROV)設備，在棉花火山首度完整拍攝記錄到熱液礦物隆堆、黑煙囪及活躍的熱液生物群聚(貽貝、潛鎧蝦及深海魚類等)，並採集到多金屬礦石及完整黑煙囪石柱，初步分析富含磁黃鐵礦、閃鋅礦、

輝銻礦、重晶石及方鉛礦等礦石。從採取的沉積物及礦石分析結果，富含金、銀、銅、鉛、鋅、銻、鉍等多金屬資源，顯示南沖繩海槽區具有多金屬礦產賦存潛能。惟國內深海採樣設備及經驗均不足，無法順利採得礦化礦石，面臨「看得到卻採不到」的困境，有待提升國內深海採樣技術或借助國外深海精密探測設備來突破困境。

參與此國際研討會，可了解國際海底礦產資源調查研究的最新概況及探測方法、技術能力等資訊，另外職及委辦計畫研究團隊臺灣大學海洋研究所將在會中各發表 1 篇我國海域礦產資源調查成果「Hydrothermal fields in the southern Okinawa Trough off northeastern Taiwan」及「3D seismic imaging and potential massive sulfide deposits of Geolin Mounds hydrothermal field in the southern Okinawa Trough」,讓國際了解我國海底礦產調查研究成果，希望可吸引及促成國際合作的契機，加速我國海底礦產調查的進展。約 2 年前德國及日本透過學界傳達有意和本所國際合作進行海底礦產資源的調查研究，惟當時我國海底礦產資源調查剛起步，尚無明顯進展，未能進一步洽談國際合作事宜，時至今日我國已有突破性進展，希望能有機會洽談國際合作，借助國外專業的深海探測設備及技術能力，加速我國海底礦產資源調查研

究的腳步。

中國大陸為進行海洋調查研究，在各地設置了 4 個海洋研究所，分別位於山東青島、浙江杭州、福建廈門及廣西北海等地，各海洋研究所都有不同的主要任務執掌，位於杭州的第二海洋研究所(簡稱為海洋二所) (本研討會的主辦單位)的主要任務執掌為有關海洋礦產資源調查研究，該所從 2001~2013 年已在東太平洋、西北太平洋、西南印度洋等國際海域進行海底礦產調查研究，至今已在全球大洋之中洋脊發現 30 多處熱液活動區及許多不同類型的熱液硫化礦床(資料來源：海洋二所網站)。海洋二所擁有配備高精密探測設備 4,500 噸級的「向陽紅 10 號」海洋綜合研究船(該船於 2014 年建造完成)(比我國目前最大的研究船 2,600 噸的勵進研究船還大的多)，為目前海洋二所大洋探測的主力研究船。臺灣大學海洋中心劉家瑄教授及海洋研究所蘇志杰、許鶴瀚教授等人也將參加此國際研討會，劉教授規劃在研討會前 9 月 17 日至 18 日順道參訪海洋二所，職也將隨同參訪，了解海洋二所在海洋調查研究(含海底礦產資源)現況，提供我國未來海底礦產資源調查研究發展的參考。

參訪中國大陸自然資源部第二海洋研究所，可了解中國大陸在海洋及海底礦產資源之探測設備、技術能力及調查研

究成果等現況；參加第 1 屆國際海脊協會之中洋脊海床塊狀硫化礦資源國際研討會，除可了解各國在海底礦產資源的調查研究概況及調查技術的進展外，並經由發表我國海底礦產調查研究成果，和各國學者專家交流，吸取相關調查技術與經驗。

預期效益為了解中國大陸海洋調查研究及各國在海底礦產資源的調查研究概況、技術與經驗，作為我國未來在海洋調查研究及海底礦產資源探勘之研發策略研擬的參考。如能吸引先進國家促成和我國進行海底礦產調查的國際合作，可加速我國海底礦產資源調查研究進展，迎頭趕上國際調查研究的腳步。

二、 活動內容

（一）行程

本次赴杭州「參訪中國大陸自然資源部第二海洋研究所及參加第 1 屆國際海脊協會之中洋脊海床塊狀硫化礦資源國際研討會」的行程詳如表 1，赴陸期間自 108 年 9 月 16 日至 9 月 22 日。行程分為二部分，9 月 17 日至 18 日為參訪中國大陸自然資源部第二海洋研究所；9 月 19 日至 21 日為參加第 1 屆國際海脊協會之中洋脊海床塊狀硫化礦資

源國際研討會，主辦單位第二海洋研究所。詳細行程安排如表 1。

表 1、行程安排與活動內容

日期	星期	活動內容	往返地點	夜宿地點
9 月 16 日	一	去程（桃園機場搭機至杭州）	臺北-杭州	杭州
9 月 17 日	二	參訪第二海洋研究所	杭州	杭州
9 月 18 日	三		杭州	杭州
9 月 19 日	四	研討會報到	杭州	杭州
9 月 20 日	五	參加研討會及發表調查研究成果	杭州	杭州
9 月 21 日	六	參加研討會及發表調查研究成果	杭州	杭州
9 月 22 日	日	回程（杭州搭機回桃園機場）	杭州−臺北	

（二）9 月 17 日至 18 日參訪中國大陸自然資源部第二海洋研究所

中國大陸自然資源部第二海洋研究所(簡稱海洋二所)，目前專業技術人員有 400 餘人，包含中國科學院士 2 人(蘇紀蘭院士及金翔龍院士)，海洋二所本部在杭州市，另在舟山市設有「舟山海洋科技研發基地」及臨安市設有「臨安青山湖科創基地」。海洋二所的主要任務是近海洋水文及洋流調查、海洋生態環境監測調查(長江出海口)、海洋地

質調查、大洋公海海底礦產調查及極地科學調查等，其中東海海域 200 浬以外之大陸礁層劃界調查、國際海底礦區調查申請(東太平洋、中太平洋、西北太平洋及西南印度洋等區)等是該所業務職掌。

本拜訪行程由丁巍偉副主任接待，9 月 17 日拜訪了該所二位院士，蘇紀蘭院士及金翔龍院士(圖 1 及圖 2)。18 日並和海洋二所及韓國學者舉行了小型討論會議。

9 月 17 日到第二海洋研究所，拜訪了蘇紀蘭院士及金翔龍院士，蘇院士是物理海洋專家，早期是在台灣大學土木系畢業後，赴美國攻讀碩博士後轉赴中國大陸，蘇院士是海峽兩岸海洋科研合作的主要推手，海峽兩岸海洋研討會就是蘇院士大力促成的，臺灣才能逐漸瞭解中國大陸在海洋科學調查研究的成果與進展，至今海峽兩岸海洋研討會仍固定每年在中國大陸及台灣兩地輪流主辦，今 (108) 年在臺灣台北南港展覽館舉行，明年規劃於大陸杭州市舉行，主辦單位即為第二海洋研究所。

金翔龍院士已高齡 86 歲，仍致力於海洋科研工作，中國大陸的載人潛水艇(HOV)蛟龍號為目前世界上唯一可達深度 7,000 公尺以上的深海探測設備，就是金院士一手

推動建造的。另外中國大陸自主式水下載具(AUV)潛龍號、線控無人載具(ROV)海龍號系列深海探測設備等，也都是金院士協助推動建造的。經和金院士的瞭解，中國大陸從 1980 年代就致力於海洋探測設備之研發，並且已逐漸建立海洋產業鏈，目前中國大陸的海洋探測設備(海底淺鑽機、AUV、ROV、 HOV、震測纜線、重力儀等)都是中國大陸廠商自己建造的，但對於內部的儀器設備之感應元件(Sensor)，還是還沒完全自主，這是大陸當局正在加強的部分。中國大陸也積極進行南、北極的極地科研工作，展現海洋強國的姿態，從金院士口述了解到，中國大陸在海洋調查方面有 3 項目標，(1)海洋資源開發，開發海底石油及金屬礦產資源 ，並同時提升及建立海洋產業經濟；(2)海洋環境生態保護；(3)維護國家海洋權益，著眼在軍事安全、公海太平洋及印度洋海底礦區調查研究，並申請國際公海礦區。

圖 1、9 月 17 日拜訪蘇紀蘭院士合影。由左至右分別為台大海研所陳姿婷博士候選人、職陳松春、台大海研所劉家瑄教授、蘇紀蘭院士、台大海研所蘇志杰教授及許鶴瀚教授。

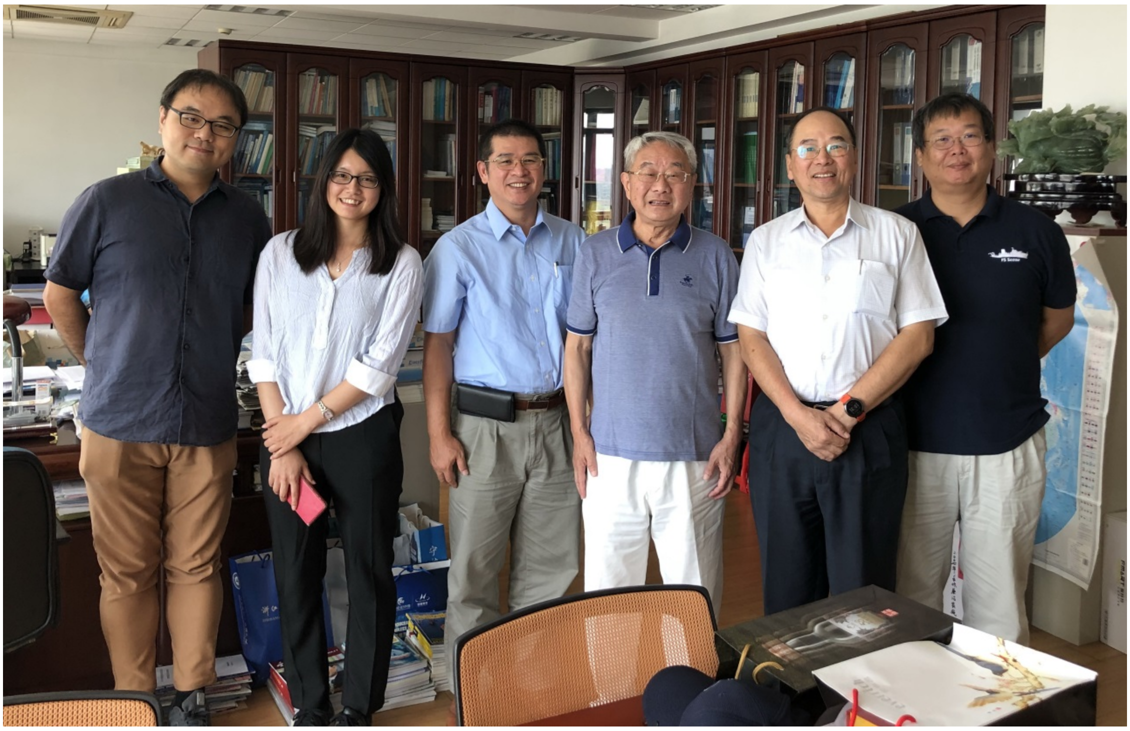


圖 2、9 月 17 日拜訪金翔龍院士合影。由左至右分別為台大海研所許鶴瀚教授、陳姿婷博士候選人、職陳松春、金翔龍院士、台大海研所劉家瑄教授及蘇志杰教授。

圖 3、參訪海洋二所時在門口留影。由左至右分別為台大海研所蘇志杰教授、職陳松春、台大海研所許鶴瀚教授及劉家瑄教授。

由於韓國首爾大學的 Sang-Mook Lee 教授在參加研討會前也規劃前往海洋二所參訪，因此海洋二所就順勢舉辦臺、中、韓等國的小型的研討會交流「海底縱橫論壇」，議程如圖 4，共有 7 個演講交流，韓國 Sang-Mook Lee、台大海洋研究所蘇志杰、許鶴瀚教授及陳姿婷博士候選人也在會中發表我國在西南海域、東部海域及東北海域的海洋地質調查概況、海洋二所也有 3 個演講。會議開始由丁巍偉副主任介紹本研討會及海洋二所業務介紹，其餘 7 項演講如下:

1. 9:30-10:00 Sang-Mook Lee (韓國首爾大學) Different Styles of Basin Opening in the East Sea/Japan Sea and Their Significances.

2. 10:00-10:20 Weiwei Ding (丁巍偉，海洋二所) South China Sea: Transition from rifting to drifting.

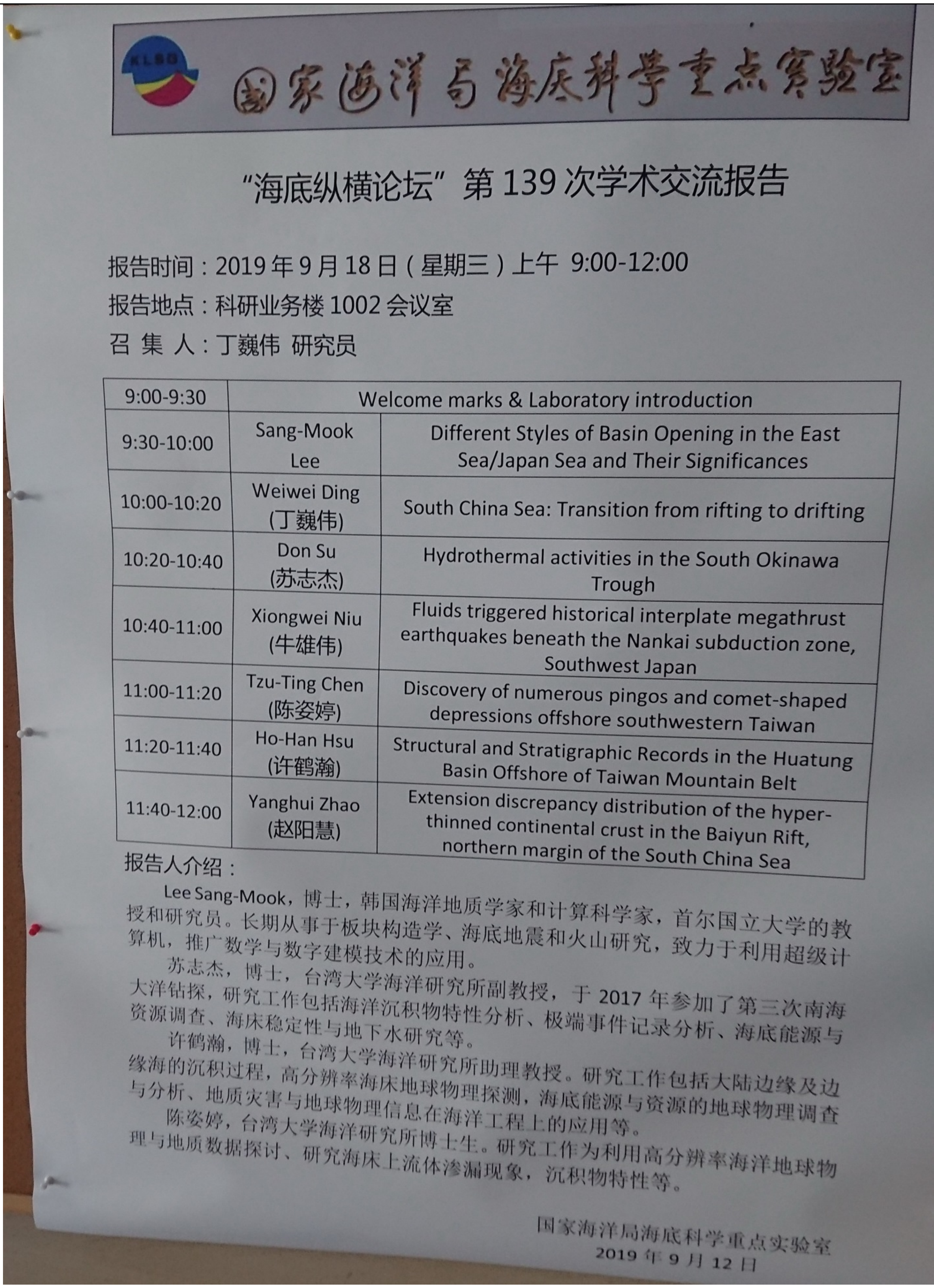
3. 10:20-10:40 Don Su (蘇志杰，台大海研所) Hydrothermal activities in the South Okinawa Trough.

4. 10:40-11:00 Xiongwei Niu (牛雄偉，海洋二所) Fluids triggered historical interplate megathrust earthquakes beneath the Nankai subduction zone, Southwest Japan.

5. 11:00-11:20 Tzu-Ting Chen (陳姿婷，台大海研所) Discovery of numerous pingos and comet-shaped depressions offshore southwestern Taiwan.

6. 11:20-11:40 Ho-Han Hsu (許鶴瀚，台大海研所) Structural and Stratigraphic Records in the Huatung Basin Offshore of Taiwan Mountain Belt.

7. 11:40-12:00 Yanghui Zhao (趙陽慧，海洋二所) Extension discrepancy distribution of the hyper-thinned continental crust in the Baiyun Rift, northern margin of the South China Sea.



国家海洋局海底科学重点实验室

“海底纵横论坛”第 139 次学术交流报告

报告时间：2019 年 9 月 18 日（星期三）上午 9:00-12:00

报告地点：科研业务楼 1002 会议室

召 集 人：丁巍伟 研究员

9:00-9:30	Welcome marks & Laboratory introduction	
9:30-10:00	Sang-Mook Lee	Different Styles of Basin Opening in the East Sea/Japan Sea and Their Significances
10:00-10:20	Weiwei Ding (丁巍伟)	South China Sea: Transition from rifting to drifting
10:20-10:40	Don Su (苏志杰)	Hydrothermal activities in the South Okinawa Trough
10:40-11:00	Xiongwei Niu (牛雄伟)	Fluids triggered historical interplate megathrust earthquakes beneath the Nankai subduction zone, Southwest Japan
11:00-11:20	Tzu-Ting Chen (陈姿婷)	Discovery of numerous pingos and comet-shaped depressions offshore southwestern Taiwan
11:20-11:40	Ho-Han Hsu (许鹤瀚)	Structural and Stratigraphic Records in the Huatung Basin Offshore of Taiwan Mountain Belt
11:40-12:00	Yanghui Zhao (赵阳慧)	Extension discrepancy distribution of the hyper-thinned continental crust in the Baiyun Rift, northern margin of the South China Sea

报告人介绍：

Lee Sang-Mook，博士，韩国海洋地质学家和计算科学家，首尔国立大学的教授和研究员。长期从事于板块构造学、海底地震和火山研究，致力于利用超级计算机，推广数学与数字建模技术的应用。

苏志杰，博士，台湾大学海洋研究所副教授，于 2017 年参加了第三次南海大洋钻探，研究工作包括海洋沉积物特性分析、极端事件记录分析、海底能源与资源调查、海床稳定性与地下水研究等。

许鹤瀚，博士，台湾大学海洋研究所助理教授。研究工作包括大陆边缘及边缘海的沉积过程，高分辨率海床地球物理探测，海底能源与资源的地球物理调查与分析、地质灾害与地球物理信息在海洋工程上的应用等。

陈姿婷，台湾大学海洋研究所博士生。研究工作为利用高分辨率海洋地球物理与地质数据探讨、研究海床上流体渗漏现象，沉积物特性等。

国家海洋局海底科学重点实验室

2019 年 9 月 12 日

圖 4、9 月 18 日在海洋二所舉行的臺、中、韓小型研討交流會「海底縱橫論壇」議程。

圖 5、9 月 18 日在海洋二所舉辦的「海底縱橫論壇」研討會照片。

從參訪行程中了解到中國大陸的海洋探測設備相當精良，4,500 噸級的「向陽紅 10 號」海洋綜合研究船是探測主力(圖 6),另在 2108 年新建於 2019 年 7 月下水的 4,600 噸級的「大洋號」調查船(圖 7)，這 2 艘探測船是海洋二所未來大洋海底礦產調查的主力研究船。探測儀器設備部分有自己建造的自主式水下載具載人潛水艇(HOV)蛟龍號(圖

8)為目前世界上唯一可達深度 7,000 公尺以上的深海探測設備；另外中國大陸自主式水下載具(AUV)潛龍號系列(圖 9)，探測深度從 4,500~6,000 m；線控無人載具(ROV)海龍號系列(圖 10)，最大探測深度可達 6,000；m，另外還有自行研發製造的海底淺鑽岩心鑽機設備(圖 11)，最深可鑽取岩心長度 20 m，以及深海視訊抓斗(圖 12)，最大探測深度可達 6,000 m，是海底礦產採樣的最佳利器。所謂工欲善其事，必先利其器，中國大陸在海域調查已完整建立載具、精密探測設備、採樣設備等器具，全部設備都自己製造，並已完整建立海洋經濟產業鏈。

圖 6、中國大陸 4,500 噸級的「向陽紅 10 號」海洋綜合研究船(該船於 2014 年建造完成)，總長 93 m，寬 17.4 m，為中國大陸現今大洋海底礦產調查的主力船。圖片來源: 中國大陸自然資源部第二海洋研究所網站。

圖 7、中國大陸新建造於 2019 年 7 月下水的 4,600 噸級「大洋號」大洋綜合資源調查船，總長 98.5 m，寬 17.4 m，為中國大陸未來大洋海底礦產調查的主力船。圖片來源: https://udn.com/news/story/7332/3955690。

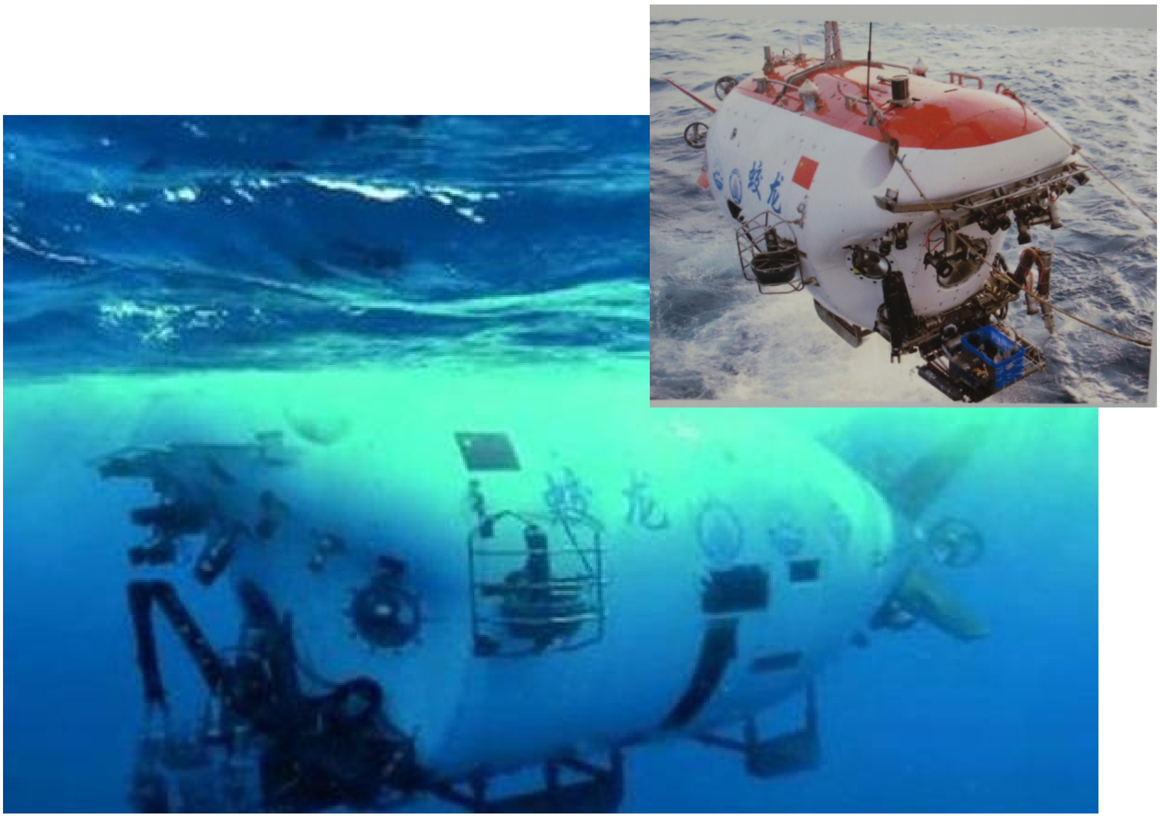


圖 8、中國大陸自行研發製造的蛟龍號載人潛艇(HOV)，可下潛水深深達 7,000 m。圖片來源: https://kknews.cc/zh-tw/science/za5xy5p.html。


跨入了国际先进行列。

"潜龙"系列AUV

系列编号	主要任务	调查能力	作业水深
潜龙一号	多金属结核调查	近海底地形地貌、浅地层地质结构、海底流场、海洋环境参数等综合精细调查能力	6000米
潜龙二号	多金属硫化物资源调查	具有热液异常探测、微地形地貌探测、海底照相和磁力探测等调查能力	4500米
潜龙三号	多金属硫化物资源调查	具有微地形地貌测量，海底照相，磁参数测量，CTD、浊度、氧化还原电位、甲烷等水体参数测量等调查能力	4500米

圖 9、中國大陸自行研發製造的 AUV 潛龍系列，探測深度從 4,500~6,000 m。

圖 10、中國大陸自行研發製造的 ROV 海龍系列，最大探測深度為 6,000 m。

圖 11、中國大陸自行研發製造的海底沉積物岩心淺鑽機，最大可鑽取岩心長度為 20 m。

深海电视抓斗

深海电视抓斗又称深海可视取样系统，经铠装缆吊装下放至海底进行拖曳式近底观察，有甲板监视系统操作控制设备对海底目标进行抓取采样。设备操作简便，可靠耐用，经过10多年的实践与应用，已成为深海科考调查装备主力。可搭载多种传感器、配备推进器、搭载工具、准确投放等不同功能的衍生型号。在大洋资源勘查、深海热液区域探测方面发挥了重要作用。

系统组成

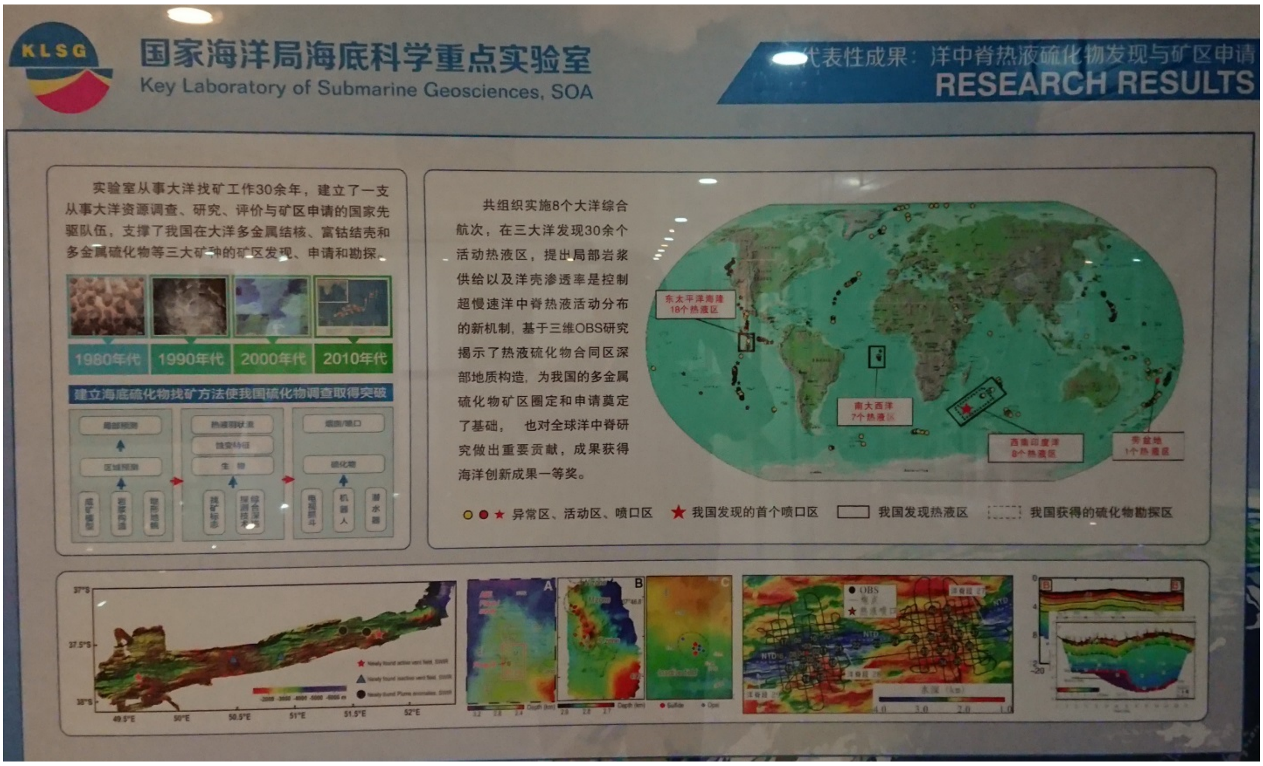
甲板单元：通讯机、供电电源和工控机
水下本体：控制装置、液压动力装置、抓取采样机构、推进器和投放回收机构等

主要型号及参数

序号	参数	型号	
		XQ-GTV6001G/T	XQ-MGTV6001G-Ⅰ
1	工作水深	≤6000 m	≤6000 m
2	工作海况	≤4级	≤4级
3	抓样重量	≤500 kg	≤300 kg
4	外形尺寸长×宽×高	2.0 m×1.5 m×1.8 m	2.0 m×1.5 m×1.8 m
5	质量	2400 kg	1500 kg

圖 12、中國大陸自行研發製造的深海視訊抓斗，最大探測深度可達 6,000 m。是海底礦產採樣的最佳利器。

由於本所正在進行東北海域多金屬礦產調查研究，因此本次參訪海洋二所主要目的是瞭解該所在海底金屬調查的狀況及進展。中國大陸致力於各大洋中洋脊之海底礦產調查，目前已在東太平洋發現18個熱液礦區、在南大西洋發現7個熱液礦區、在西南印度洋發現8個熱液礦區及在澳洲東部之勞盆地發現1個熱液礦區，合計目前在三大洋的中洋脊已發現34個熱液礦區(圖13及14)，並正在申請國際礦區作業中。由於中國大陸的海底礦產調查都以國際海域為主，有關大陸海域內之礦產調查目前僅局部進行調查，未詳細調查。除了在中洋脊海底礦產調查外，中國大陸也積極在深海鈷結核及錳結核的調查研究，這些鈷結核或錳結核一般生成的水深都在3,000 m以上，錳或鈷核中富含多種金屬，其中以鈷、鎳、銅三者最為重要；這些金屬都是鋼鐵精密工業、電子工業、資訊工業的重要材料。中國大陸在各大洋採取的海底熱液黑煙囪硫化多金屬礦及鈷結核及錳核如圖15所示。我國的研究船亦曾在臺灣東部外海採到大量錳核標本，經分析具有鐵、錳、鎳、銅、鈷等多金屬，我國缺乏自然金屬資源，海域蘊藏豐富的金屬礦資源，不論是以資源或戰略安全角度，建議我國日後必須加強海底金屬礦產資源的調查研究。



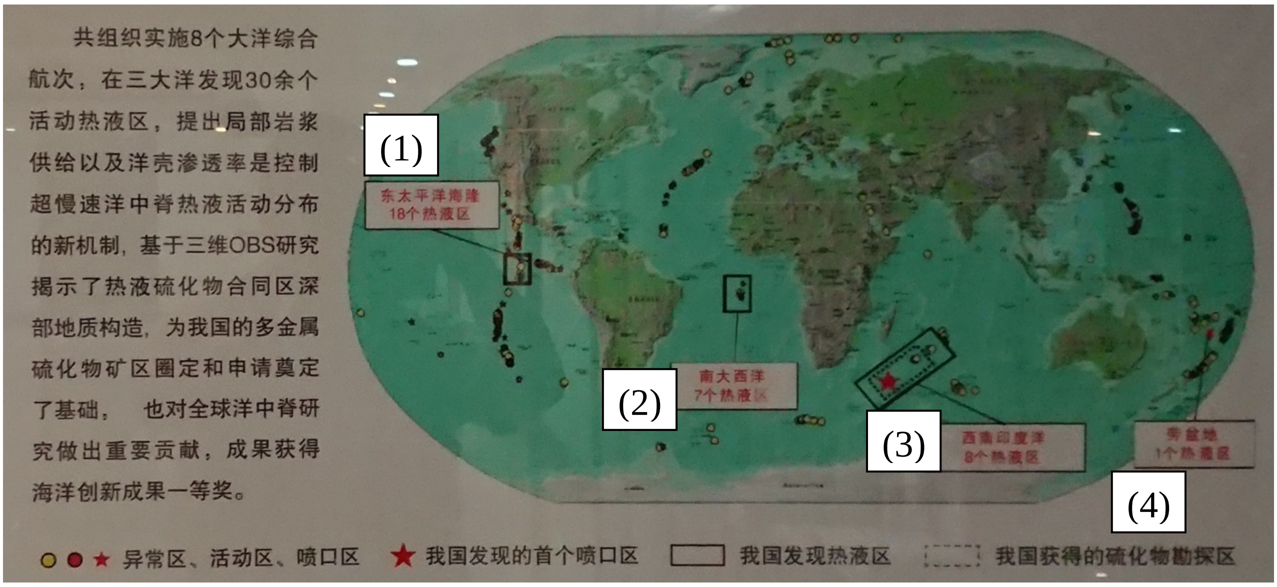


圖 13、中國大陸致力於各大洋中洋脊之海底礦產調查。目前在三大洋已發現 34 個熱液礦區，並正在申請國際礦區作業中。圖中(1)東太平洋 18 個熱礦區；(2)南大西洋 7 個熱礦區；(3)西南印度洋 8 個熱礦區；(4)澳洲東部之勞盆地 1 個熱礦區。

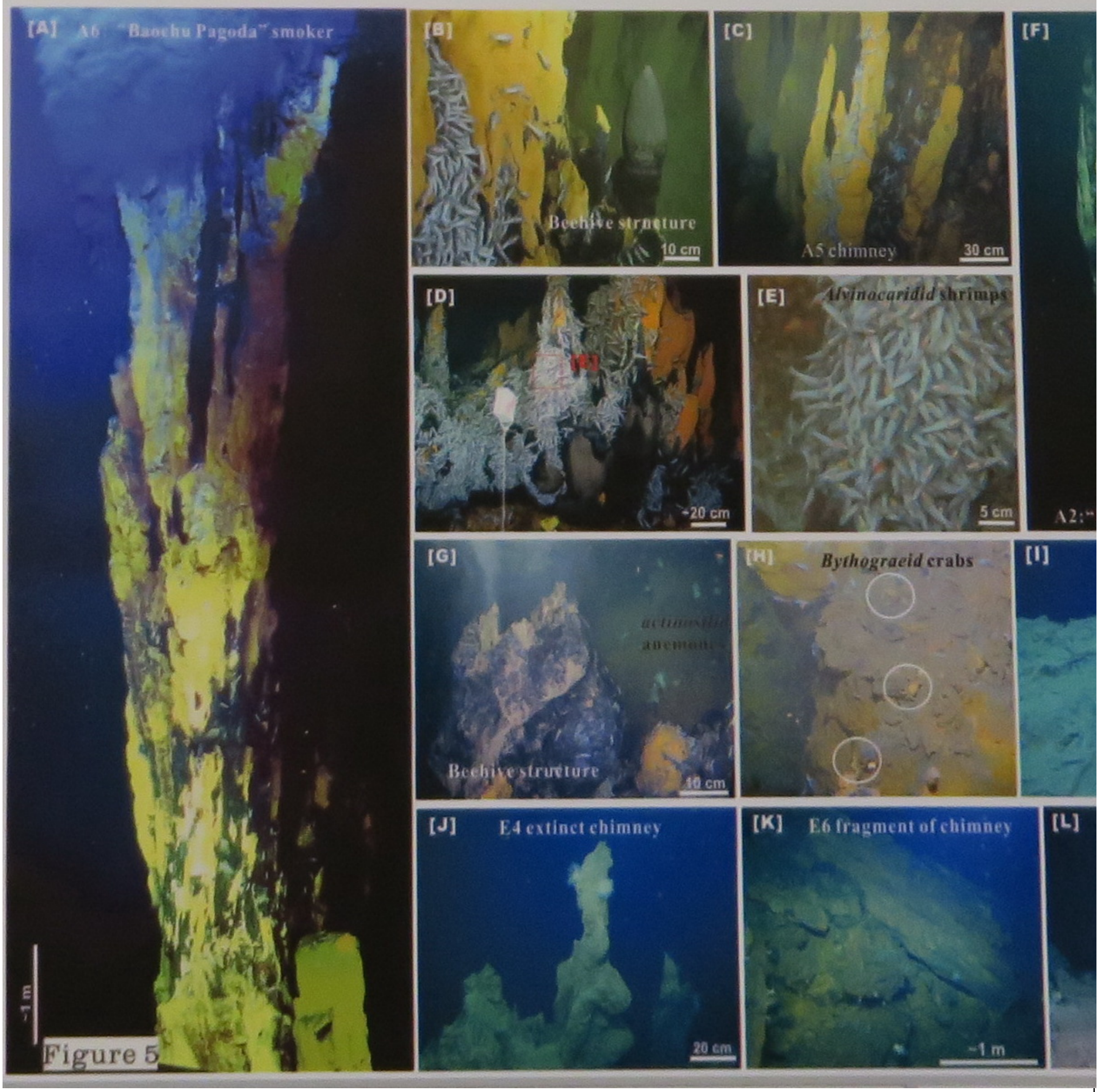


圖 14、中國大陸在北大西洋中洋脊水深約 3,480 m 發現的海底黑煙囪及生物群群落。

圖 15、中國大陸在各大洋採取的海底多金屬礦產礦石。黃棕色的是熱液黑煙囪，為硫化多金屬礦石。其餘黑色圓球狀及塊狀的是鈷結核及錳核。

（三）研討會議

第 1 屆國際海脊協會之中洋脊海床塊狀硫化礦資源國際研討會於 108 年 9 月 19 日至 9 月 21 日在杭州百瑞運河大飯店內舉行(圖 16)，主辦單位是中國大陸自然資源部第二海洋研究所(簡稱海洋二所)，會議議程如附件 1。每天議程除了口頭報告外，在休息時間都是海報展示發表報告及討論，各國都針對在中洋脊的硫化礦發表調查成果，惟有我國發表的 2 篇調查成果(1 篇口頭及 1 篇海報發表)是在南沖繩海槽的弧後盆地，國際海脊協會主席法國 Florian Besson 對我國發表的 2 篇成果也甚表讚賞，也歡迎我國以後能持續參加國際海脊協會舉辦的海底礦產調查相關研討會議，為了解大洋的海底礦產及生態保護共同努力。在下午時段另有分組討論(圖 17)，針對未來在大洋中洋脊硫化礦產需要再進行了解的議題，以及該如何去完成這些議題，經過 2 天的討論，大家都認為對中洋脊的硫化礦產的了解還是相當有限，惟有持續進行深海海水取樣、岩心鑽探，採取到海水及岩心沉積物樣本才能進一步研究。

本研討會共計 108 人參加，其中臺灣 5 人參加，佔與會人數的 5%，佔居第 2。由於中國大陸是主辦單位，共有 81 人參加會議，佔與會人數的 75% (如表 2 及圖 18)。

圖 16、本研討會議在杭州市百瑞運河大飯店之 3 樓會議室舉行。

圖 17、研討會中每天下午都有分組討論情形。

表 2、參加會議國家人數及發表論文數量統計表

國家	參加人數	百分比 (%)	口頭發表篇數	海報發表篇數	合計發表數量	百分比 (%)
中國	**81**	75	7	19	**26**	62
臺灣	**5**	**4**	**1**	**1**	**2**	**5**
美國	4	4	1	0	1	2
俄羅斯	3	3	2	1	3	7
法國	4	3	1	0	1	2
英國	2	2	2	0	2	5
韓國	2	2	1	1	2	5
葡萄牙	2	2	2	0	2	5
波蘭	2	2	0	1	1	2
德國	1	1	1	0	1	3
加拿大	1	1	1	0	1	2
挪威	1	1	0	0	0	0
Total	108		19	23	42	

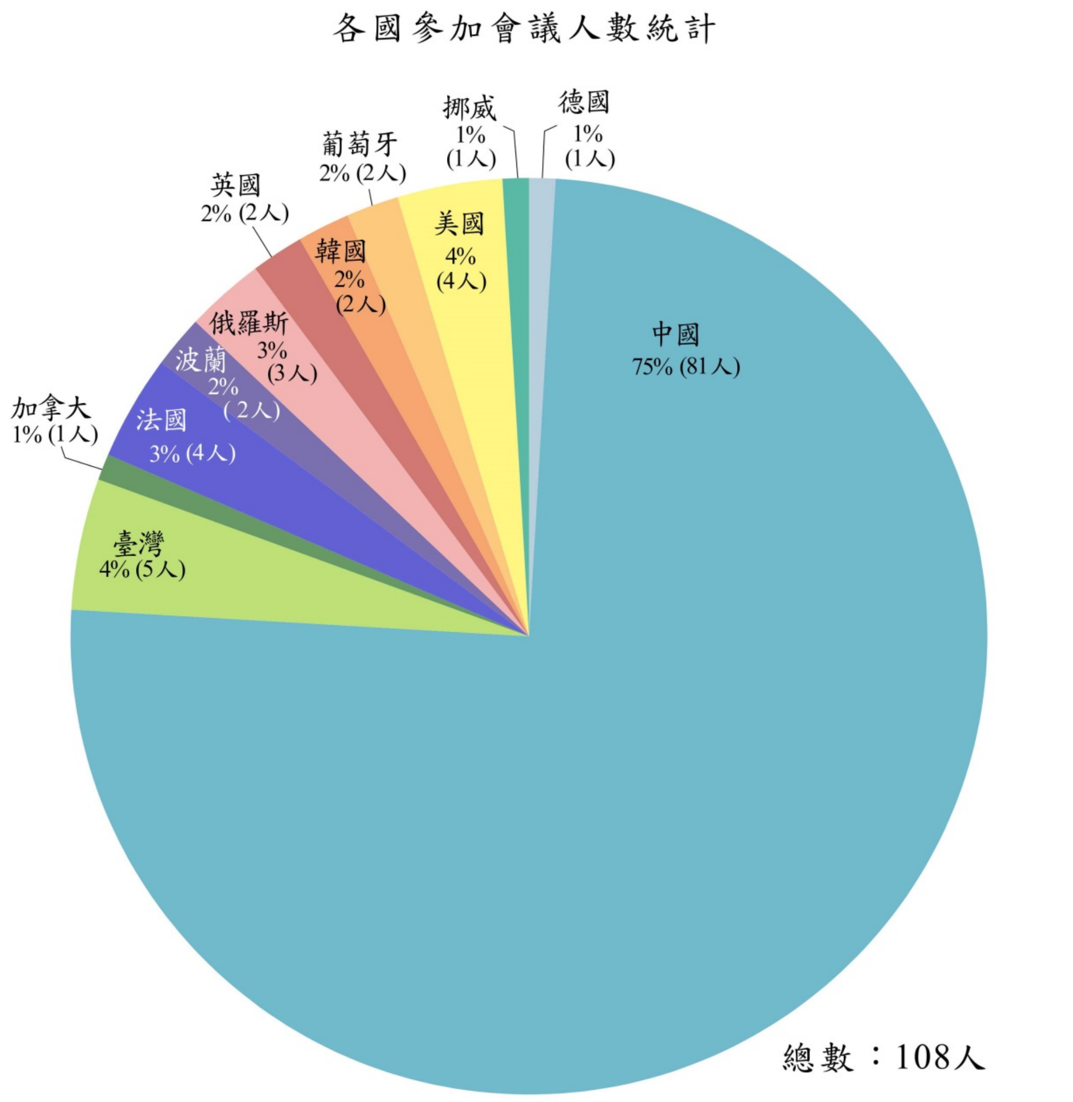


圖 18、各國參加人數統計表。共有 108 人參加，其中臺灣 5 人參加，佔與會人數的 5%，由於中國大陸是主辦單位，共有 81 人參加會議，佔與會人數的 75%。

（四）論文發表

本會議共有 42 篇論文發表，其中口頭發表有 19 篇，海報發表有 23 篇，我國共發表口頭及海報各 1 篇，佔發表數量 5%，排序為第 3，中國大陸發表論述數量共 62 篇(口頭發表 7 篇，海報發表 19 篇)，佔發表數量 62%，排序為第 1(表 2 及圖 19)。各國發表論文，都是在各大洋中洋脊的硫化礦的調查研究成果，惟有我國發表的 2 篇調查成果(1 篇口頭及 1 篇海報發表)是在南沖繩海槽的弧後盆地。職陳松春以海報表 1 篇臺灣東北海域礦產資源調查成果，題目為「Hydrothermal fields in the southern Okinawa Trough off northeastern Taiwan」,另 1 篇為台大海洋研究所許鶴瀚教授以口頭發表 1 篇，題目為「3D seismic imaging and potential massive sulfide deposits of Geolin Mounds hydrothermal field in the southern Okinawa Troug」。在海報發表時間，與各國學者專家說明東北海域南沖繩海槽區多金屬礦產調查成果，其中中國大陸學者對本海報特別感興趣，多次詢問瞭解相關調查概況及分析結果，與中國大陸相關學者在海報前討論及合影照片如圖 20。

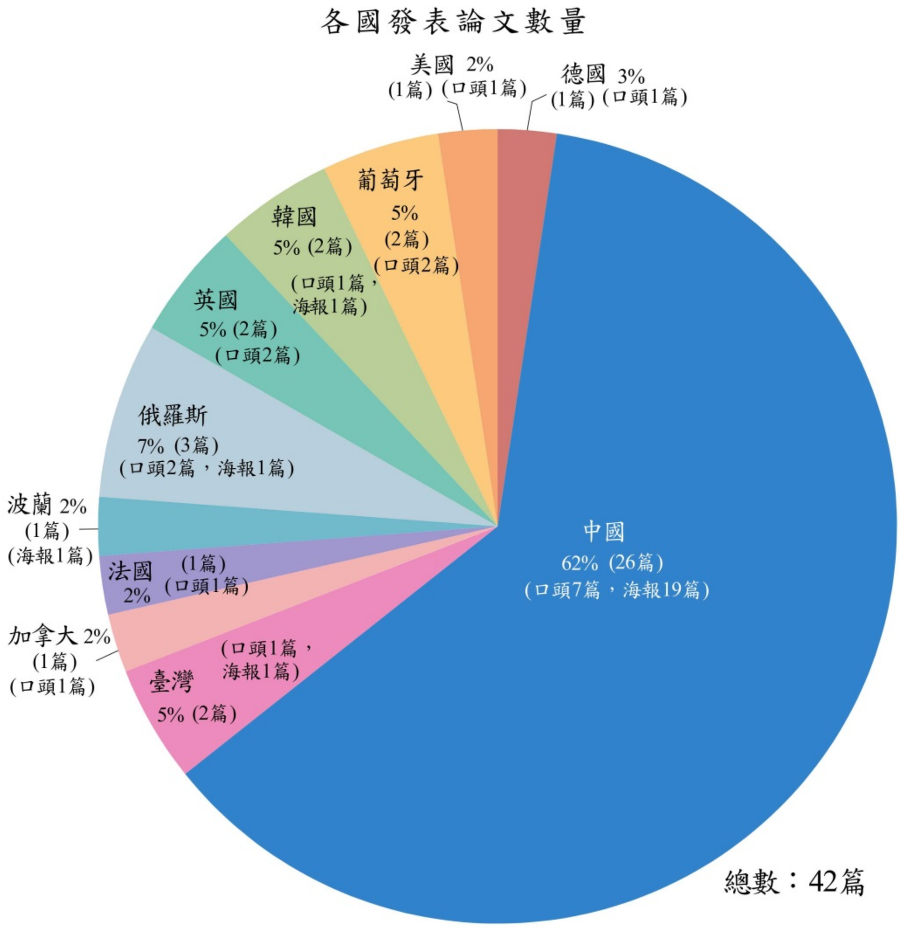


圖 19、會議發表論文統計分析圖。

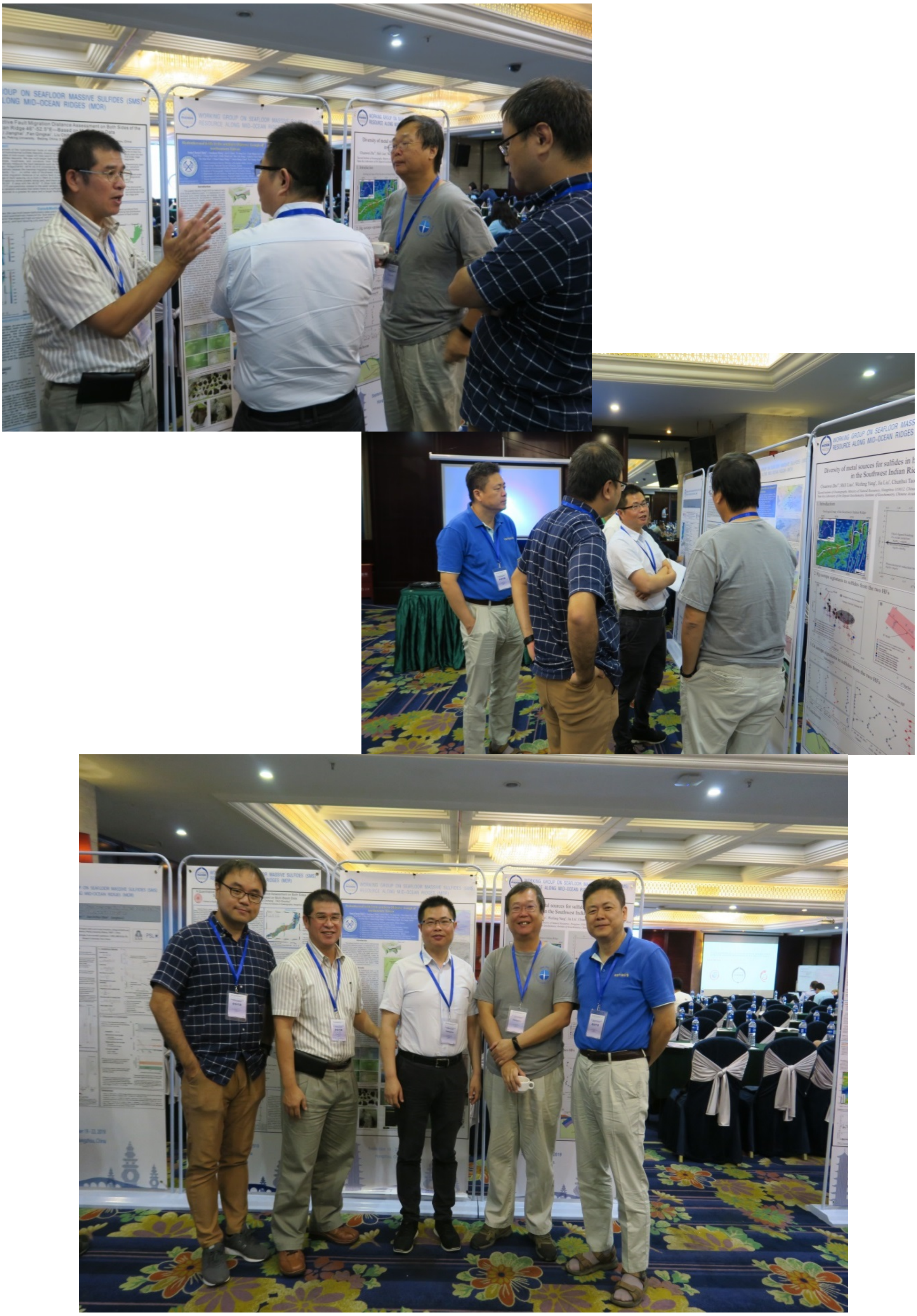


圖 20、職(陳松春)(左上圖左 1)在海報區發表調查研究成果，及和中國大陸學者專家合影。下圖由左至右分別是台大海研所許鶴瀚教授、職陳松春、中國科學院海洋研究所曾志剛教授、台大海研所蘇志杰教授、海洋二所重點實驗室陶春輝主任。

職海報發表重要成果說明：位於臺灣東北海域南沖繩海槽區，有活躍的火成活動，有利於海底金屬礦產的型行，為了解南沖繩海槽區的金屬礦產賦存潛能，本所於 105 年起執行「臺灣東北海域礦產資源潛能調查研究」四年期施政計畫，經 3 年多的調查研究，已圈繪出 6 處礦產潛能區(圖 21)，於石林隆堆採獲超過 80 公斤的礦石(圖 22)，經分析平均金屬含量至少 50%以上（部分高達 60~65%）；在棉花火山及石林隆堆之海床發現被稱為金屬噴泉的「黑煙囪」(圖 23)；從海底攝影機影像接合圖可清楚了解礦物隆堆的分布(圖 24)，另於 108 年 4 月及 7 月利用國內勵進研究船之線控無人載具(ROV)，在棉花火山也首度拍攝記錄到熱液礦物隆堆及黑煙囪，並採取到多金屬礦石及黑煙囪碎片，這次臺灣首次以 ROV 清晰紀錄到熱液礦弄物隆堆及黑煙囪，本研究分別命名為「巫婆隆堆(Witch Mound)」及「魔王煙囪(Devil Chimney)」(圖 25 及 26)，經分析礦石種類有磁黃鐵礦、閃鋅礦、輝銻礦、重晶石及方鉛礦等，綜整從採取的沉積物及礦石分析結果，顯示富含金、銀、銅、鉛、鋅、銻、鉍等多金屬資源，顯示南沖繩海槽區具有多金屬礦產賦存潛能。

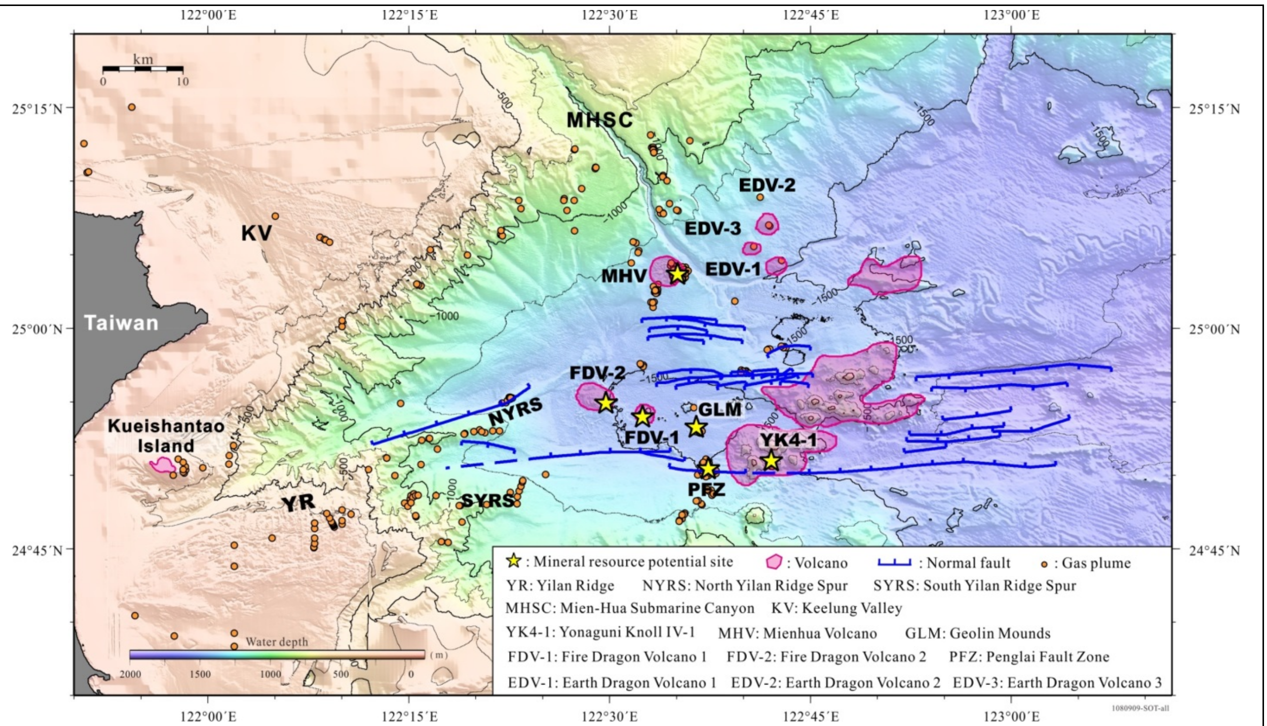


圖 21、南沖繩海槽斷層、火山及 6 處礦產潛能區(黃色星號)分布圖。

圖 22、在石林隆堆採取到超過 80 公斤的礦石，經分析平均金屬含量至少 50%以上（部分高達 60~65%）。

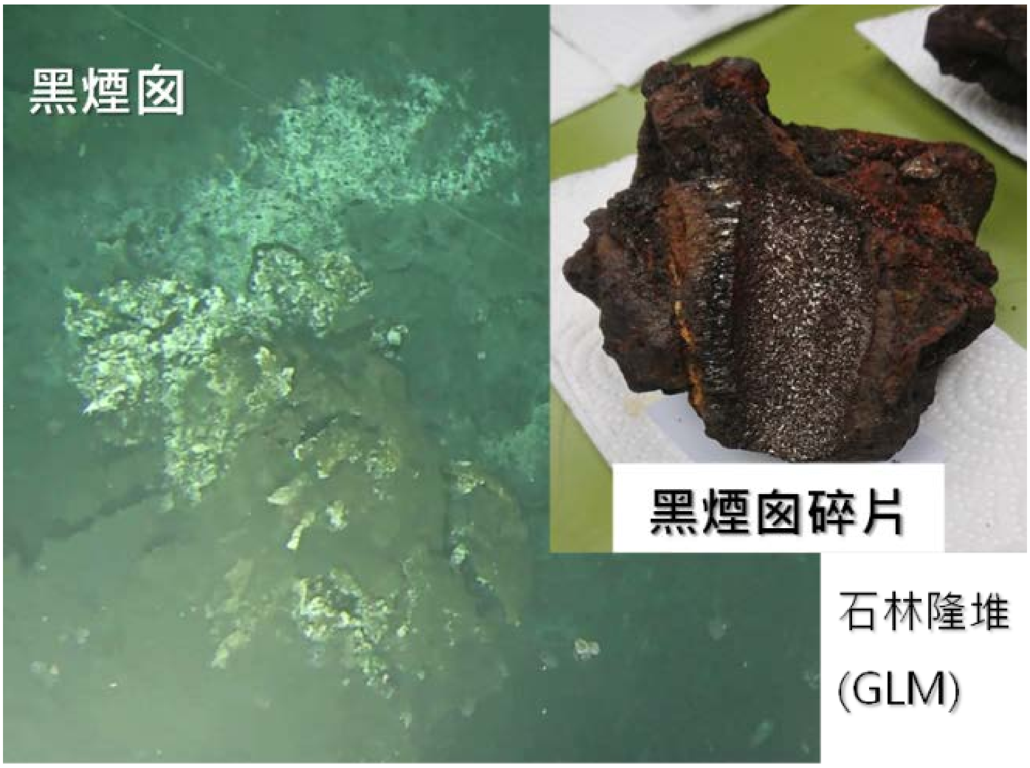


圖 23、在石林隆堆拍攝到的黑煙囪，及採取到的黑煙囪碎片，經分析有閃鋅礦及磁黃鐵礦。

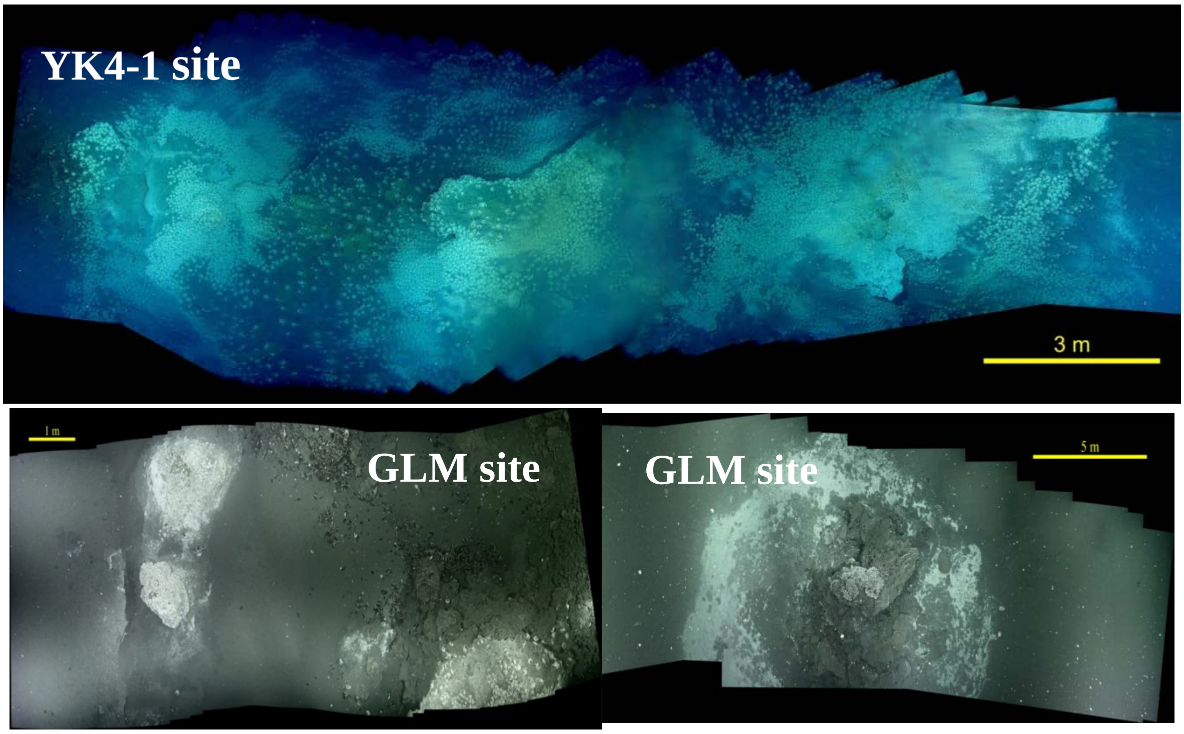


圖 24、在第四與那國海丘(YK4-1)石林隆堆(GLM)拍攝到的礦物隆堆分布(海底影像相拼接圖)。

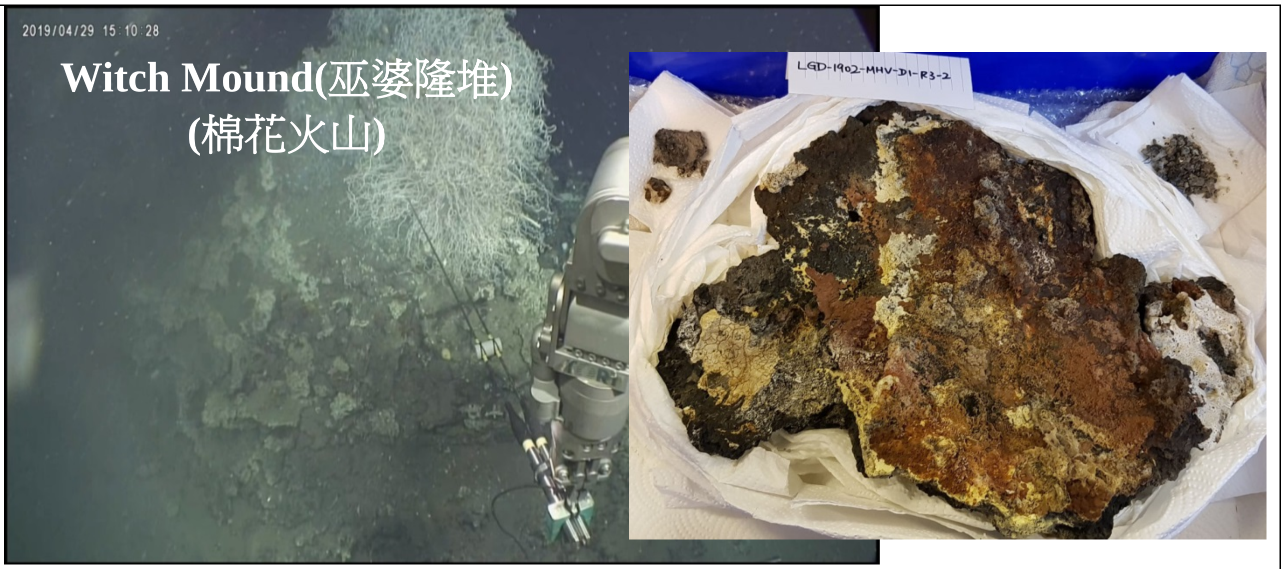


圖 25、108 年 4 月使用國內勵進研究船之線控無人載具(ROV)在棉花火山拍攝到的熱液礦物隆堆，命名為「巫婆隆堆(Witch Mound)」，右圖為採取到的熱液礦石。

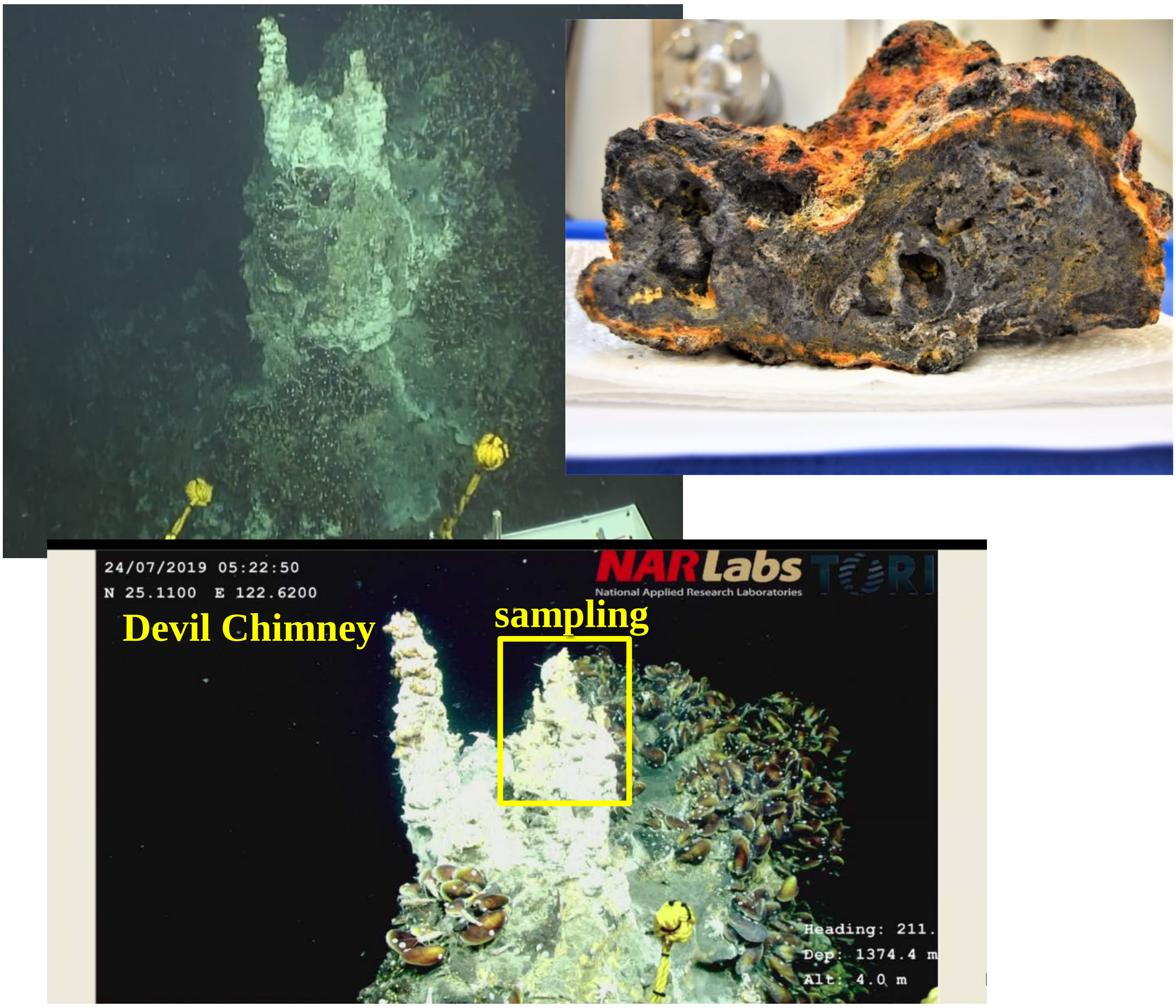


圖 26、108 年 7 月使用國內勵進研究船之線控無人載具(ROV)在棉花火山拍攝到的黑煙囪，命名為「魔王煙囪(Devil Chimney)」，右上圖為採取到的煙囪碎片礦石，初步分析磁黃鐵礦、閃鋅礦、輝銻礦、重晶石及方鉛礦等。

三、 遭遇之問題

本次「參訪中國大陸自然資源部第二海洋研究所及參加第 1 屆國際海脊協會之中洋脊海床塊狀硫化礦資源國際研討會」,均未遭遇到任何問題。

四、 我方因應方法及效果：無

五、 心得及建議

（一）中國大陸自然資源部第二海洋研究所(簡稱海洋二所)是專職海底礦產調查研究的單位，目前其在各大洋中洋脊都有調查區，目前在三大洋已發現 34 個熱液礦區(圖 13),其中在西南印度洋有更密集的探勘,目前已著手申請國際礦區。為進行海底礦產及海洋地質調查在海洋二所有 2 艘大噸位的多功能探測船，分別為 4,500 噸級的「向陽紅 10 號」海洋綜合研究船及於 2019 年 7 月下水的 4,600 噸級的「大洋號」調查船，以及有高精密深海型(4,500~7,000 m)的探測設備，例如自主式水下載具載人潛水艇(HOV)蛟龍號、自主式水下載具(AUV)潛龍號系列、線控無人載具(ROV)海龍號系列、海底淺鑽岩心鑽機以及深海視訊抓斗設備等。相對於我國雖有 2,600 噸的勵進研究船及深海型 ROV,但 ROV 探測及操作才剛

起步，也沒有其他精密水下探測設備，臺灣是海島國家，但缺乏海洋探測設備，在海域的調查研究的經費投入相當有限，在海域調查研究人才的培育也不足，因此對我們週遭海域地質狀況仍不清楚，尤其目前離岸風機正如火如荼建置中，海底地質安全將直接影響風機的安全，海陸域斷層也將直接威脅人民生命財產安全，建議我國應全面檢視海域調查研究政策，加強海域地質安全調查及海底礦產資源等調查研究。

（二）橫跨全球三大洋(太平洋、印度洋及大西洋)的中洋脊有高溫岩漿及熱源，造就了許多海底熱液多金屬礦床，各國家除了進行以資源角度進行調查研究外，也著力於環境生態的保護，唯有進一步了解，才能永續利用海底金屬礦產及保護環境生態，讓人類和海底礦產能永續共存，另中國大陸也致力於大洋深海錳核及鈷結核的調查研究。建議我國應持續參與海底礦產調查相關研討會議，掌握國際上調查研究進展，提供我國海底礦產調查規劃參考。

（三）從本所 3 年多的調查研究結果，顯示臺灣東北部南沖繩海槽具有熱液多金屬硫化礦產賦存潛能，本所 105-108

年海底礦產調查計畫經費每年約 4,000~5,000 萬元，但 109 年之後經費大幅刪減，只剩約 2,300 多萬元，加上 109 年新研究船(新海研一~三號)及勵進研究船租金大幅調漲，本所已無經費繼續到南沖繩海槽之礦產潛能區進一步調查研究，109-112 年只能規劃在東北海域近岸區進行火成活動及礦產地質調查。另外在東部深海(水深大於 3,000 m)也有錳核礦石(註 1)，我國缺乏自然金屬礦資源，不論以資源或戰略安全角度，都應加速海底礦產調查研究腳步，建議政府應強化海洋調查研究能量，以了解我國海域地質狀況及海底金屬礦產資源潛能，提供藍色國土永續利用、開發及環境生態保護的基本資料。

註 1: 1970 年代台大海洋研究所陳汝勤教授曾利用研究船在**臺灣東部海域採取到錳核**，經分析錳核中富含鐵、錳、鎳、銅及鈷，此等錳核之形成可能由錳及其他過渡元素受到催化性之氧化而被吸附於適當之深海面上，上覆之海水及底下沉積物中錳之上移，均可加速錳核之成長，此等鐵錳沉積可能**成為鈷、銅、鎳及錳之礦源**，在洋底上**有數以百萬噸計**的**錳核，**在不久的將來將值得我們去開採(陳汝勤，1976)。

陳汝勤(1976) 台灣東部深海沉積物之礦物學與地球化學研究，國科會會刊，第 9 期，Part 1，第 127-145 頁。

參、謹檢附參加本次活動（會議）相關資料如附件，報請 備查。

職 經濟部中央地質調查所

科長 陳松春 謹陳

108 年 10 月 8 日

附件 1、會議議程

Agenda 日程安排

September 19 Thursday 9 月 19 日 周四	1st floor lobby of Hangzhou Braim Canal Hotel. 百瑞运河大饭店 1 楼接待大厅
06:00-24:00	Register full day | 全天注册
17:00-18:00	WG Steering Committee Meeting at Hebei Conference Room, 3rd floor 工作组委员会会议（3 楼河北厅）
18:00-20:00	Dinner | 晚餐

Note：The WG Steering Committee Meeting is valid for the InterRidge officer and WG Steering Committee Members only. 工作组委员会会议仅限于 InterRidge 官员及工作组成员参加。

September 20 (Day 1) Friday 9 月 20 日 （第一天）周五	Area B, International Hall, 3rd floor at Braim Canal Hotel 百瑞运河大饭店 3 楼国际厅 B 区（主会场） Shandong and Hebei Conference Rooms, 3rd floor of the hotel (for break-out sessions only) 酒店 3 楼山东和河北厅会议室（供专题讨论使用）
09:00-09:15	Opening remarks | 开幕式
Primary Session | 主题报告	Session Chair | 主席: **Maurice Tivey**
09:15-09:35 (20 min)	Geological mapping of mid-ocean ridges and its implications and use for the prediction of SMS occurrences **Sven Petersen** GEOMAR, Germany（德国亥姆霍兹基尔海洋研究中心）
09:35-09:55 (20 min)	An integrated assessment extinct Seafloor Massive Sulphide deposits at the TAG hydrothermal Field **Bramley Murton** National Oceanography Center, UK（英国国家海洋中心）
09:55-10:15 (20 min)	Oceanic Core Complexes and the substrate for formation seafloor hydrothermal sulphide deposits **Henry J.B. Dick** Woods Hole Oceanographic Institution, USA.（美国伍兹霍尔海洋研究所）
10:15-11:00	Group Photo, Poster and Coffee/Tea Break 拍摄集体照片，海报展示及休息
11:00-11:20 (20 min)	The inactive hydrothermal vent fields in the Central Indian Ridge between 8°S and 18°S, Indian Ocean **Sang-Joon Pak** Korea Institute of Ocean Science and Technology, South Korea（韩国海洋科学技术研究所）
11:20-11:40 (20 min)	Hull-mounted multibeam echosounder (MBSE): a cost and time-effective tool for detection of extinct seafloor massive sulfide deposits

	Ewan Pelleter Ifremer, Unité Géosciences Marines - Marine Geosciences Department, France （法国海洋开发研究院海底地球科学部）
11:40-12:00 (20 min)	Diversity of hydrothermal systems on Southwest Indian Ridge **Chunhui Tao（陶春辉）** KLSG, MNR, China.（自然资源部第二海洋研究所海底科学重点实验室）
12:00-14:00	Lunch & Break | 午餐
14:00-14:20 (20 min)	All SMS deposits are hydrothermal deposits, but not all hydrothermal deposits are SMS deposits **John Jamieson** Memorial University, Canada（加拿大纽芬兰纪念大学）
14:20-14:40 (20 min)	Extreme hydrothermal activity on Carlsberg Ridge during the last glacial stage: evidence from an off-axis sediment core **Xiqiu Han（韩喜球）** Key Laboratory of Submarine Geosciences,Second Institute of Oceanography, MNR, Hangzhou, China.（自然资源部海底科学重点实验室）
14:40-15:00 (20 min)	Finding, mapping and evaluating seafloor mining prospects **Isobel Yeo** Kingston University London, UK（英国伦敦金斯顿大学）
15:00-15:20 (20 min)	Can submarine massive sulphide deposits be recycled? **Fernando Barriga** University of Lisbon, Portugal（葡萄牙里斯本大学）
15:20-15:40 (20 min)	Morphology and formation of SMS deposits in different geological settings **Georgy Cherkashov** Institute for Geology and Mineral Resources of the Ocean, Russia（俄罗斯海洋地质矿产研究所）
15:40-16:00	Coffee/Tea Break and Poster | 休息及海报展示
16:00-16:30	Big question breakout sessions – 1^{st} round 分组讨论
16:30-17:00	Big question breakout sessions – 2^{nd} round 分组讨论
17:00-17:30	Plenary report from breakout group leaders | 小组总结汇报
17:45-20:00	Dinner | 晚餐

September 21 (Day 2) Saturday　Area B, International Hall, 3rd floor at Braim Canal Hotel 9 月 21 日 （第二天）周六　百瑞运河大饭店 3 楼国际厅 B 区
Early Career Scientist Session | 年轻科学家报告

Session Chair|主席: **Georgy Cherkashov**	
09:00-09:15 (15 min)	Lucky Strike: is it a TAG (Trans-Atlantic Geotraverse) precursory hydrothermal system? **Isabel Costa** Center for Innovation in Science and Technology (INCITE), Instituto Politécnico Setúbal, Escola Superior Tecnologia Barreiro, Barreiro, Portugal(葡萄牙巴雷罗高等技术学院塞图巴尔理工学院科技创新中心)
09:15-09:30 (15 min)	3D Seismic Imaging and Potential Massive Sulfides Deposits of Geolin Mounds Hydrothermal Field in the Southern Okinawa Trough **Ho Han Hsu （许鹤瀚）** Institute of Oceanography, Taiwan University, Taiwan, China（台湾大学海洋研究所）
09:30-09:45 (15 min)	Sulfide mineralization of the Saldanha hydrothermal field (MAR): constraints from sulfur isotope in-situ microanalysis **Wenhong Johnson Qiu （邱文洪）** Institute of Science and Environment (ISE), University of Saint Joseph, Macao SAR, China （澳门圣约瑟大学科学与环境研究所）
09:45-10:00 (15 min)	Ultramafic rocks hosting sulfide mineralization along SWIR: insights from the sulfide sulfur isotopic and LA-ICP-MS trace-element compositions **Teng Ding（丁腾）** Institute of Marine Geology, College of Oceanography, Hohai University, China（河海大学海洋学院海洋地质研究所）
10:00-10:45	Coffee/Tea Break & Poster | 休息及海报展示
10:45-11:00 (15 min)	Au and Te Minerals in Seafloor Massive Sulphides from Semyenov-2 Hydrothermal Field, Mid-Atlantic Ridge **Anna Firstova** Institute for Geology and Mineral Resources of the Ocean, Russia（俄罗斯海洋地质矿产研究所）
11:00-11:15 (15 min)	Difference in hydrothermal activity between slow and fast spreading centers **Duo Zhou（周多）** Zhejiang University, China（浙江大学）
11:15-11:30 (15 min)	Multi-stage detachment faulting controls hydrothermal activity in the Dragon Horn area (49.7°E, SWIR): Insight from magnetic studies **Tao Wu（吴涛）** Key Laboratory of Submarine Geosciences,Second Institute of Oceanography, MNR, Hangzhou, China.（自然资源部第二海洋研究所海底科学重点实验室）
11:30-11:45 (15 min)	Numerical simulation of hydrothermal plumes in stratified crossflows **Yingzhong Lou （楼映中）** Institute of Port, Coastal, and Offshore Engineering, Ocean College, Zhejiang University, China(浙江大学海洋学院港口海岸与近海工程研究

	所）
12:00-14:00	Lunch & Break｜ 午餐
14:00-14:30 (30 min)	Letter of WG appointment issuing｜ 工作组成员聘书颁发 Best oral/poster presentation awarding｜ 最佳口头及海报展示奖
14:30-15:30 (60 min)	Brainstorm the way to go for big questions and international cooperation 集体讨论及国际合作
15:30-15:50	Coffee/Tea Break｜ 休息
15:50-16:50 (60 min)	Workshop output summary｜ 研讨会成果总结
16:50-17:00 (10 min)	Closing remarks｜ 闭幕式
17:00-17:40 (40 min)	Working Group internal round-table conference｜ 工作组圆桌会议
17:45-20:00	Dinner｜ 晚餐

September 22 (Day 3) Sunday 9 月 22 日（第三天） 周天	Geological investigation around Hangzhou (optional). 杭州周边地质调查（可选）。
07:00-21:00	Geological field trip around Hangzhou 杭州周边地质考察

Notes|注意：

1. For the oral reporters (primary and early career), please hand in your prepared PPT to volunteers no later than 08:00 am, Sept. 20th, who will help to copy it to the computer in the meeting room. Please double check it runs well.
   请口头（大会主题及年轻科学家）报告作者最晚于 20 号上午 08:00 之前将准备好的 PPT 交由会务志愿者统一拷贝到会议室电脑上，请务必检查内容是否播放正常。
2. The group photo will be taken at the Canal Square (tentatively) in front of the hotel. Please go directly to the Square after Henry's talk.
   集体照片暂定在酒店前方的运河广场拍摄，由于时间紧张，请在 Henry 报告结束后即刻前往。
3. Shandong and Hebei Conference Rooms will be available for the Break-out sessions as well, please go to the corresponding room according to the Chair's guidance.
   山东和河北厅会在分专题讨论时开放，请根据会议主席指示前往相应会议室进行讨论。

附件 2、職陳松春在會中發表 1 篇論文之摘要

Hydrothermal fields in the southern Okinawa Trough off northeastern Taiwan

Song-Chuen Chen[1,*], Yunshuen Wang[1], Jui-E Chen[1], Yi-Jung Lin[1], Char-Shine Liu[2], Shu-Kun Hsu[3], Chih-Chieh Su[4], Wei-Teh Jiang[5], Andrew Tien-Shun Lin[6], Ho-Han Hsu[4], Chau-Chang Wang[7,8], Hsin-Hung Chen[8], Yu-Cheng Chou[8], Ching-Hui Tsai[3]

1 Central Geological Survey, Ministry of Economic Affair, New Taipei City, Taiwan
2 Ocean Center, Taiwan University, Taipei City, Taiwan
3 Center for Environmental Studies, Central University, Taoyuan City, Taiwan
4 Institute of Oceanography, Taiwan University, Taipei City, Taiwan
5 Department of Earth Sciences, Cheng Kung University, Tainan City, Taiwan
6 Department of Earth Sciences, Central University, Taoyuan City, Taiwan
7 Taiwan Ocean Research Institute, Applied Research Laboratories, Kaohsiung City, Taiwan
8 Institute of Undersea Technology, Sun Yat-sen University, Kaohsiung City, Taiwan

Abstract

The southern Okinawa Trough (SOT) is a back-arc basin of the Ryukyu subduction system. It is characterized by well-developed active normal faulting and volcanism, favorable geological conditions for the formation of Seafloor Massive Sulfide (SMS) deposits. In order to investigate and evaluate the mineral resources potential in the SOT, Central Geological Survey (CGS), Ministry of Economic Affairs, Taiwan (R.O.C.) has initiated a 4-years program since 2016. In that program, intensive geophysical, geochemical and seafloor image investigations have been conducted in the SOT. We have identified six hydrothermal fields in the investigation area including Yonaguni Knoll IV-1 (YK4-1), Penglai Fault Zone (PFZ), Geolin Mounds (GLM), Mienhwa Volcano (MHV), Fire Dragon Volcano 1 (FDV-1) and Fire Dragon Volcano 2 (FDV-2). These hydrothermal fields were discovered mostly by the CGS program except that YK4-1 has been reported previously by Japan (Nunoura, 2004; Inagaki et al., 2006; Hongo et al., 2007; Suzuki et al., 2008; Gena et al., 2013; Ishibashi et al., 2015).
Based on geophysical data, volcanic activities, normal fault zones, and gas plumes are commonly observed in the central rift zone. Widely distributed mineral mounds are mapped by the deep-towed sidescan sonar images in the PFZ and GLM sites, and mineral mounds are confirmed by seafloor images taken by deep-towed video systems of ATIS and FITS. As shown on the real-time seafloor images, vapor-rich vent fluids and chimney-mound structures are widely distributed on the seafloor in the active hydrothermal fields. Water column and cored sediment samples collected at the hydrothermal sites show notably geochemical anomalies resulted from the intense hydrothermal activities. Relatively high concentrations of CH4, CO2, DIC and 3He/4He ratios have been found in the near bottom seawater samples at the FDV-1, PFZ and GLM sites. In addition, the cored sediments show relatively high concentrations of Ag, Cu, As, Sb, Bi, Cd, Pb and Zn. Mineralogical analyses of the chimney-mound fragments indicate that the GLM site mineralization is characterized by low sulfidation deposits of pyrrhotite, isocubanite, galena, bismuth, and other minerals, whereas the ore specimens collected from the MHV site contain mainly sphalerite, galena, and chalcopyrite, implying intermediate sulfidation mineralization. Recently, several hydrothermal mounds and black smokers were recorded and sampled by remotely operated vehicle (ROV) in the MHV site onboard R/V LEGEND in 2019. The black smoker fragments taken in the MHV site contain mainly pyrrhotite, sphalerite, stibnite, barite and galena. The results signify the potential existence of rich metals resources in the hydrothermal fields in SOT off northeastern Taiwan.

Keywords

Hydrothermal Field; Seafloor Massive Sulfide Deposits; Mienhwa Volcano; Geolin Mounds; Southern Okinawa Trough; Off northeastern Taiwan

附件 3、臺灣研究團隊在會中發表 1 篇論文之摘要

3D Seismic Imaging and Potential Massive Sulfides Deposits of Geolin Mounds Hydrothermal Field in the Southern Okinawa Trough

Ho-Han Hsu*[,1, 2], Chih-Chieh Su[1,2], Char-Shine Liu[2], Tzu-Ting Chen[1], Liang-Fu Lin[1], Jyun-Nai Wu[2], Wei-Zhi Liao[2], Song-Chuen Chen[3]

[1]Center for Innol Institute of Oceanography, Taiwan University, Taipei, Taiwan
2 Ocean Center, Taiwan University, Taipei, Taiwan
3 Central Geological Survey, Ministry of Economic Affair, Taipei, Taiwan

Abstract

Multi-scale geophysical and geochemical investigation including single-beam and multi-beam echo sounder, side-scan sonar, sub-bottom profiler, multi-channel seismic, heat flow measurement as well as multi-core, near-bottom water column, CTD mooring, gravity core and dredge sampling works have been conducted in a newly discovered hydrothermal field named as Geolin Mounds in the Southern Okinawa Trough. Vigorous flare features in water column and "rock grove" morphological characteristics above seafloor were observed in echo sounder and side-scan sonar data. Widely high heat flow anomalies (> 10,000 mW/m2) also exist in the survey area. Due to strong Kuroshio Current during multi-channel seismic data acquisition, serious streamer feathering effect (5-40°) happened. To take advantage of swath distributed CDPs caused by streamer feathering, we developed a pseudo-3D technique and produced a 3D seismic cube. In addition to specific features above seafloor, widely-distributed anomalies such as blanking zone and high-amplitude reflectors are observed around the Geolin Mounds hydrothermal field on our sub-bottom and multi-channel seismic profiles. Furthermore, 3D seismic cube provides estimation of the areas of blanking zone on selected time slice and better characterizes fault structures in the hydrothermal field. The geochemical analysis results present relatively high concentration of methane, rare earth elements and 3He/4He ratio in near bottom seawater samples. High Ag, Au, As, Bi, Cd, Cu, Fe, Pb, Sb, and Zn concentrations have been found in our sediment and rock samples. The time-series data of CTD mooring at Geolin Mounds revealed that temperature and methane concentration were simultaneously varied with time.

Based on the geophysical and geochemical investigation results, we believe that the Geolin Mounds hydrothermal field is without underlying submarine volcanos and hydrothermal fluid migration could be related to fault development. We suggest that the Geolin Mounds is in its embryo stage of evolution and is constantly supported by active hydrothermal circulation. Consequently, seafloor massive sulfides deposits can keep developing with hydrothermal fluid circulation along migration conduits which is probably created by fault structures nearby the field. We suggest that the Geolin Mounds hydrothermal field may grow sustainably and could provide high potential massive sulfides resources in the Southern Okinawa Trough in the near future. Furthermore, the Geolin Mounds hydrothermal field can serve as a good observatory for development of the seafloor edifice and ore mineralization associated with hydrothermal circulation activities in a back-arc spreading basin.

Keywords

Hydrothermal Field; 3D seismic; Seafloor Massive Sulfides Deposit; Geolin Mounds; Southern Okinawa Trough

volcanic intrusion, sandwave migration and liquefaction process are proposed to be causal mechanisms for seafloor instability in Taiwan Strait nowadays.

Keyword: seafloor instability, reflection seismic, foreland basin, fault, sandwave.

附件 4、「第 1 屆國際海脊協會之中洋脊海床塊狀硫化礦資源國際研討會–慢速至超慢速擴張洋中脊熱液成礦過程及多金屬硫化物命運研討會」

會議手冊及摘要手冊

Working Group on Seafloor Massive Sulfides (SMS)
Resource along Mid Ocean Ridges (MOR)

Workshop on Hydrothermal ore-forming processes and the fate of SMS deposits along slow and ultraslow spreading MOR

慢速-超慢速扩张洋中脊热液成矿过程及多金属硫化物命运研讨会

Conference Brochure | 会议手册

Hangzhou, China
September 19th – 22nd, 2019

中国 • 杭州
2019 年 9 月 19 - 22 日

Contents|目录

PREFACE

Over the past decades, seafloor hydrothermal systems have increasingly attracted the attention of geologists, marine biologists and ocean and planetary scientists because of the extreme environment, unique life forms, and mineral deposits that provide modern-day analogs to ancient deposits now mined on land. Recent surveys suggest that slow and ultraslow spreading ridges have an excess of high temperature venting relative to their predicted magmatic and mid-ocean ridge (MOR) spreading heat budgets. Hydrothermal deposits in these spreading environments have high concentrations of Cu and Au that are potentially large in tonnage and may reach 86% of the total MOR sulfide mineral resource. Despite these recent discoveries, the occurrence, distribution pattern, formation mechanism, and resource potential of hydrothermal systems on a global scale remains poorly documented and defined.

The InterRidge Workshop on hydrothermal ore-forming processes is organized by the InterRidge Working Group (WG) on Seafloor Massive Sulfides Resource (SMS) along Mid-Ocean Ridges (MOR) and hosted by the Second Institute of Oceanography (SIO), Ministry of Natural Resources (MNR) of the People's Republic of China.

The overall theme of the Workshop is **"Hydrothermal ore-forming processes and the fate of SMS deposits along slow and ultraslow spreading MOR"**. This Workshop aims to understand several key scientific questions related to hydrothermal circulation mechanisms and the geological factors that contribute to the formation, distribution and preservation of SMS deposits along different spreading MOR. The WG hopes to capture the known/unknown BIG questions on SMS formation and preservation in the geologic record and identify future ways to address them through this Workshop.

About the Working Group

The InterRidge Working Group on Seafloor Massive Sulfides Resource along Mid-Ocean Ridges was established on December 2018 with aims to enhance the cooperation among researchers working in this specific field, and collectively addresses challenges in understanding the nature of Seafloor Massive Sulfides. Find more about the WG at http://interridge.org/WG_SMS_MOR.

About the Second Institute of Oceanography

Directly affiliated to the Ministry of Natural Resources (MNR), the Second Institute of Oceanography (SIO) was established in 1966 and has developed into a non-profit oceanographic research institute with comprehensive disciplines, strong scientific and technological capabilities and advanced equipment support. It is mainly engaged in marine scientific researches on China seas, Oceans and Polar Regions as well as Research and Development and the application of high technology for marine environmental protection and resource exploration.

The research areas of SIO cover 5 research fields, including dynamic processes and numerical simulation, satellite oceanography and marine remote sensing, marine ecosystems, as well as engineering oceanography. These five research fields have derived into 19 research directions which have basically formed our own scientific innovation system and scientific research group that can meet our country's great demands and help us gain a foothold in the world marine scientific and technological development.

The 4500-tonne marine scientific research vessel "Xiang Yanghong No. 10", co-built by SIO and Zhejiang Taihe Shipping Co, Ltd, was listed in the National Oceanographic Research Fleet in 2014 and then undertook Chinas Ocean mineral resources investigation task in the Ocean in 2015, thus satisfying multidisciplinary research needs for deep-sea marine sciences. The newly built 4000-tonne "Dayang" Ocean integrated resources survey ship was successfully delivered to the MNR this July and will be managed by SIO after the delivery.

At present, there are more than 400 staff in SIO, including 2 academicians of Chinese Academy Of Science (CAS), 3 academicians of Chinese Academy of Engineering (CAE), 3 senior specialists at Zhejiang Provincial level, 94 senior professional technicians, 107 associate professional technicians and a group of influential academic leaders, thus forming a team of high-quality, high-level and high-skilled talents for marine science and technology.

前言

在过去的几十年里，海底热液系统凭借其特有的极端环境、独特的生命形式和可为现代陆地上正在开采的古老矿床提供可借鉴的海底矿床，越来越受到地质学家、海洋生物学家以及海洋和行星科学家们的关注。最近的研究调查表明，与预测的岩浆和沿洋中脊传播的热量分布相比，慢速和超慢速扩张洋中脊具有更多的高温喷口。在这种扩散环境下，热液矿床中铜和金富集的浓度较高且含量巨大，可能达到洋中脊硫化物资源总量的 86%。尽管已有众多发现，但全球范围内的热液系统的产生、形成机制、分布格局和资源潜力仍然缺乏文献记载和明确的定义。

为了了解与热液循环机制有关的几个关键科学问题，以及不同展布下洋中脊多金属硫化物矿床形成、分布和赋存的地质因素，洋中脊海底多金属硫化物资源工作组决定举办“热液成矿过程”研讨会，会议主题为“**慢速-超慢速扩张洋中脊热液成矿过程及多金属硫化物命运**”。工作组希望在地质记录中发现关于多金属硫化物形成和赋存的已知/未知的重大问题，并通过本次研讨会明确今后解决这些问题的方法。此次会议将由自然资源部第二海洋研究所承办。

洋中脊海底硫化物资源工作组简介

洋中脊海底多金属硫化物资源工作组成立于 2018 年 12 月，工作组致力于提高全球科学家在洋中脊硫化物资源研究领域的国际合作，共同解决在洋中脊尤其是慢速和超慢速扩张洋中脊海底硫化物的成因、机理和特性研究等方面所面临的科学难题。工作组的成立对于加强我国洋中脊硫化物资源领域的科学家与国外同行间的交流、促进我国在西南印度洋海底多金属硫化物勘探合同区及其它洋中脊区域的研究具有重要意义。

更多信息请访问工作组官方网站 http://interridge.org/WG_SMS_MOR。

自然资源部第二海洋研究所简介

自然资源部第二海洋研究所创建于 1966 年，是一座学科齐全、科技力量雄厚、设备先进的综合型公益性海洋研究机构，隶属于国家自然资源部。主要从事中国海、大洋和极地海洋科学研究，海洋环境保护与资源勘探高新技术研发与应用。

全所现有海底科学与深海勘测技术、海洋动力过程与数值模拟技术、卫星海洋学与海洋遥感、海洋生态系统与生物地球化学、工程海洋学 5 个重大研究领域和 19 个重点研究方向，基本形成了适应国家需求和立足海洋科技发展前沿的科技创新体系和科研群体。

海洋二所共建有一条 4500 吨级的海洋综合科考船—向阳红 10，该船满足深海海洋科学多学科交叉研究需求，于 2014 年 3 月入列国家海洋调查船队，2015 年首航西南印度洋承担中国大洋矿产资源调查任务。2019 年 7 月，我国自主研制的 4000 吨级大洋综合资源调查船—“大洋号”在广州建成并顺利交付至自然资

源部，该船由我所配建，交付后将由我所运行管理。同时，二所在浙江舟山长峙岛建有具备服务深海大洋勘探开发能力的装备研发基地。

全所现有在职职工 400 余人，其中中国科学院院士 2 人，中国工程院院士 3 人，浙江省特级专家 3 人，正高级专业技术人员 94 人，副高级专业技术人员 107 人，拥有一批在国内外有影响的学术带头人，形成了一支高素质、高水平、高技能的科技人才队伍。

主办单位 Organizers

InterRidge

InterRidge Working Group on SMS Resource along MOR

China Ocean Mineral Resources R & D Association (COMRA)

Second Institute of Oceanography (SIO), Ministry of Natural Resources of the People's Republic of China (MNR)

Key Laboratory of Submarine Geosciences (KLSG), SIO, MNR, China

Penetrating the hydrothermal circulation system along ultra-slow spreading Mid-Ocean Ridges project

国际大洋中脊协会

国际大洋中脊协会海底多金属硫化物资源工作组

中国大洋矿产资源研究开发协会

自然资源部第二海洋研究所

自然资源部海底科学重点实验室

国家重点研发计划"透视超慢速扩张洋脊热液循环系统"

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Jerome Dyment, Institut de Physique du Globe de Paris (IPGP), France （法国巴黎地球物理学院）

Jiabiao Li（李家彪）, SIO, MNR, China（自然资源部第二海洋研究所）

Feng Liu（刘峰）, COMRA（中国大洋矿产资源研究开发协会）

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Chunhui Tao (陶春辉), KLSG, SIO, MNR, China（自然资源部第二海洋研究所）

Georgy Cherkashov, Institute for Geology and Mineral Resources of the Ocean (VNIIO), Russia（俄罗斯地质和海洋矿产资源研究所）

Maurice Tivey, Woods Hole Oceanographic Institution (WHOI), USA（美国伍兹霍尔海洋研究所）

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Sang-Joon Pak, Korea Institute of Ocean Science and Technology, South Korea（韩国海洋科学技术研究所）
Sven Petersen, GEOMAR, Germany（德国亥姆霍兹基尔海洋研究中心）
Desiree Roerdink, University of Bergen, Norway（挪威卑尔根大学）
Isobel Yeo, National Oceanography Center, UK（英国伦敦金斯顿大学）

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SMS Investigation Group along SWIR
（西南印度洋硫化物调查工作组）
https://www.deepseavents.org/

Agenda 日程安排

September 19 Thursday 9 月 19 日 周四	1st floor lobby of Hangzhou Braim Canal Hotel. 百瑞运河大饭店 1 楼接待大厅
06:00-24:00	Register full day | 全天注册
17:00-18:00	WG Steering Committee Meeting at Hebei Conference Room, 3rd floor 工作组委员会会议（3 楼河北厅）
18:00-20:00	Dinner | 晚餐

Note：The WG Steering Committee Meeting is valid for the InterRidge officer and WG Steering Committee Members only. 工作组委员会会议仅限于 InterRidge 官员及工作组成员参加。

September 20 (Day 1) Friday 9 月 20 日 （第一天）周五	Area B, International Hall, 3rd floor at Braim Canal Hotel 百瑞运河大饭店 3 楼国际厅 B 区（主会场） Shandong and Hebei Conference Rooms, 3rd floor of the hotel (for break-out sessions only) 酒店 3 楼山东和河北厅会议室（供专题讨论使用）
09:00-09:15	Opening remarks | 开幕式
Primary Session | 主题报告	Session Chair | 主席: **Maurice Tivey**
09:15-09:35 (20 min)	Geological mapping of mid-ocean ridges and its implications and use for the prediction of SMS occurrences **Sven Petersen** GEOMAR, Germany（德国亥姆霍兹基尔海洋研究中心）
09:35-09:55 (20 min)	An integrated assessment extinct Seafloor Massive Sulphide deposits at the TAG hydrothermal Field **Bramley Murton** National Oceanography Center, UK（英国国家海洋中心）
09:55-10:15 (20 min)	Oceanic Core Complexes and the substrate for formation seafloor hydrothermal sulphide deposits **Henry J.B. Dick** Woods Hole Oceanographic Institution, USA.(美国伍兹霍尔海洋研究所)
10:15-11:00	Group Photo, Poster and Coffee/Tea Break 拍摄集体照片，海报展示及休息
11:00-11:20 (20 min)	The inactive hydrothermal vent fields in the Central Indian Ridge between 8°S and 18°S, Indian Ocean **Sang-Joon Pak** Korea Institute of Ocean Science and Technology, South Korea（韩国海洋科学技术研究所）
11:20-11:40 (20 min)	Hull-mounted multibeam echosounder (MBSE): a cost and time-effective tool for detection of extinct seafloor massive sulfide deposits

	Ewan Pelleter Ifremer, Unité Géosciences Marines - Marine Geosciences Department, France （法国海洋开发研究院海底地球科学部）
11:40-12:00 (20 min)	Diversity of hydrothermal systems on Southwest Indian Ridge **Chunhui Tao（陶春辉）** KLSG, MNR, China.（自然资源部第二海洋研究所海底科学重点实验室）
12:00-14:00	Lunch & Break | 午餐
14:00-14:20 (20 min)	All SMS deposits are hydrothermal deposits, but not all hydrothermal deposits are SMS deposits **John Jamieson** Memorial University, Canada（加拿大纽芬兰纪念大学）
14:20-14:40 (20 min)	Extreme hydrothermal activity on Carlsberg Ridge during the last glacial stage: evidence from an off-axis sediment core **Xiqiu Han（韩喜球）** Key Laboratory of Submarine Geosciences,Second Institute of Oceanography, MNR, Hangzhou, China.（自然资源部海底科学重点实验室）
14:40-15:00 (20 min)	Finding, mapping and evaluating seafloor mining prospects **Isobel Yeo** Kingston University London, UK（英国伦敦金斯顿大学）
15:00-15:20 (20 min)	Can submarine massive sulphide deposits be recycled? **Fernando Barriga** University of Lisbon, Portugal（葡萄牙里斯本大学）
15:20-15:40 (20 min)	Morphology and formation of SMS deposits in different geological settings **Georgy Cherkashov** Institute for Geology and Mineral Resources of the Ocean, Russia（俄罗斯海洋地质矿产研究所）
15:40-16:00	Coffee/Tea Break and Poster | 休息及海报展示
16:00-16:30	Big question breakout sessions – 1st round 分组讨论
16:30-17:00	Big question breakout sessions – 2nd round 分组讨论
17:00-17:30	Plenary report from breakout group leaders | 小组总结汇报
17:45-20:00	Dinner | 晚餐

September 21 (Day 2) Saturday Area B, International Hall, 3rd floor at Braim Canal Hotel 9 月 21 日 （第二天）周六 百瑞运河大饭店 3 楼国际厅 B 区
Early Career Scientist Session | 年轻科学家报告

Session Chair|主席: **Georgy Cherkashov**	
09:00-09:15 (15 min)	Lucky Strike: is it a TAG (Trans-Atlantic Geotraverse) precursory hydrothermal system? **Isabel Costa** Center for Innovation in Science and Technology (INCITE), Instituto Politécnico Setúbal, Escola Superior Tecnologia Barreiro, Barreiro, Portugal（葡萄牙巴雷罗高等技术学院塞图巴尔理工学院科技创新中心）
09:15-09:30 (15 min)	3D Seismic Imaging and Potential Massive Sulfides Deposits of Geolin Mounds Hydrothermal Field in the Southern Okinawa Trough **Ho Han Hsu （许鹤瀚）** Institute of Oceanography, Taiwan University, Taiwan, China（台湾大学海洋研究所）
09:30-09:45 (15 min)	Sulfide mineralization of the Saldanha hydrothermal field (MAR): constraints from sulfur isotope in-situ microanalysis **Wenhong Johnson Qiu （邱文洪）** Institute of Science and Environment (ISE), University of Saint Joseph, Macao SAR, China （澳门圣约瑟大学科学与环境研究所）
09:45-10:00 (15 min)	Ultramafic rocks hosting sulfide mineralization along SWIR: insights from the sulfide sulfur isotopic and LA-ICP-MS trace-element compositions **Teng Ding（丁腾）** Institute of Marine Geology, College of Oceanography, Hohai University, China（河海大学海洋学院海洋地质研究所）
10:00-10:45	Coffee/Tea Break & Poster | 休息及海报展示
10:45-11:00 (15 min)	Au and Te Minerals in Seafloor Massive Sulphides from Semyenov-2 Hydrothermal Field, Mid-Atlantic Ridge **Anna Firstova** Institute for Geology and Mineral Resources of the Ocean, Russia（俄罗斯海洋地质矿产研究所）
11:00-11:15 (15 min)	Difference in hydrothermal activity between slow and fast spreading centers **Duo Zhou（周多）** Zhejiang University, China（浙江大学）
11:15-11:30 (15 min)	Multi-stage detachment faulting controls hydrothermal activity in the Dragon Horn area (49.7°E, SWIR): Insight from magnetic studies **Tao Wu（吴涛）** Key Laboratory of Submarine Geosciences,Second Institute of Oceanography, MNR, Hangzhou, China.（自然资源部第二海洋研究所海底科学重点实验室）
11:30-11:45 (15 min)	Numerical simulation of hydrothermal plumes in stratified crossflows **Yingzhong Lou （楼映中）** Institute of Port, Coastal, and Offshore Engineering, Ocean College, Zhejiang University, China（浙江大学海洋学院港口海岸与近海工程研究

	所）
12:00-14:00	Lunch & Break | 午餐
14:00-14:30 (30 min)	Letter of WG appointment issuing | 工作组成员聘书颁发 Best oral/poster presentation awarding | 最佳口头及海报展示奖
14:30-15:30 (60 min)	Brainstorm the way to go for big questions and international cooperation 集体讨论及国际合作
15:30-15:50	Coffee/Tea Break | 休息
15:50-16:50 (60 min)	Workshop output summary | 研讨会成果总结
16:50-17:00 (10 min)	Closing remarks | 闭幕式
17:00-17:40 (40 min)	Working Group internal round-table conference | 工作组圆桌会议
17:45-20:00	Dinner | 晚餐

September 22 (Day 3) Sunday 9 月 22 日（第三天） 周天	Geological investigation around Hangzhou (optional). 杭州周边地质调查（可选）。
07:00-21:00	Geological field trip around Hangzhou 杭州周边地质考察

Notes|注意：

1. For the oral reporters (primary and early career), please hand in your prepared PPT to volunteers no later than 08:00 am, Sept. 20th, who will help to copy it to the computer in the meeting room. Please double check it runs well.
   请口头（大会主题及年轻科学家）报告作者最晚于 20 号上午 08:00 之前将准备好的 PPT 交由会务志愿者统一拷贝到会议室电脑上，请务必检查内容是否播放正常。
2. The group photo will be taken at the Canal Square (tentatively) in front of the hotel. Please go directly to the Square after Henry's talk.
   集体照片暂定在酒店前方的运河广场拍摄，由于时间紧张，请在 Henry 报告结束后即刻前往。
3. Shandong and Hebei Conference Rooms will be available for the Break-out sessions as well, please go to the corresponding room according to the Chair's guidance.
   山东和河北厅会在分专题讨论时开放，请根据会议主席指示前往相应会议室进行讨论。

Poster Presentations | 海报展示

No.	Title and author's info
1	Uranium in seafloor massive sulfides at the Mid-Atlantic Ridge (MAR) **Anna Sukhanova** Institute for Geology and Mineral Resources of the Ocean, Russia（俄罗斯地质和矿产资源研究所）
2	The Daxi Vent Field on the Slow-Spreading Carlsberg Ridge: An Active Hydrothermal System at a Non-transform Offset **Yejian Wang (王叶剑)** KLSG, MNR, China.（自然资源部第二海洋研究所海底科学重点实验室）
3	Hydrothermal Fe-Mn deposits from low-temperature systems of the Mid-Atlantic Ridge **Pedro Costa** Institute of Science and Environment (ISE), University of Saint Joseph, Macao SAR, China（澳门圣约瑟大学）
4	The characteristic of the Mid-Atlantic Ridge between Hayes and Kane Fracture Zone **Michal Tomczak** Polish Geological Institute - National Research Institute, Poland （波兰地质研究所）
5	Stepwise hydrothermal dissolution of titanomagnetite dramatically reduces magnetization in basaltic ocean crust: direct evidence from the Southwest Indian Ridge **Shishun Wang（汪诗舜）** School of Earth and Space Sciences, Peking University, Beijing, China（北京大学地球与空间科学学院）
6	1. Surface sediment geochemistry and hydrothermal activity indicators in the Dragon Horn area on the Southwest Indian Ridge 2. Bulk geochemistry, sulfur isotope characteristics of the Yuhuang-1 hydrothermal field on the ultraslow-spreading Southwest Indian Ridge 3. Surface sediment composition and distribution of hydrothermal derived elements at the Duanqiao-1 field, Southwest Indian Ridge **Shili Liao（廖时理）** Key Laboratory of Submarine Geosciences,Second Institute of Oceanography, MNR, Hangzhou, China.（自然资源部第二海洋研究所海底科学重点实验室）
7	Seismic observations of an active detachment faulting system beneath the Longqi hydrothermal field at the ultraslow spreading Southwest Indian Ridge **Yunlong Liu（柳云龙）** Key Laboratory of Submarine Geosciences,Second Institute of Oceanography, MNR, Hangzhou, China.（自然资源部第二海洋研究所海底科学重点实验室）
8	Diversity of metal sources for sulfides in hydrothermal fields in the Southwest Indian Ridge

	Chuanwei Zhu（朱传威） Guiyang Institute of Geochemistry, Chinese Academy of Sciences（中科院贵阳地化所）
9	Hydrothermal fields in the southern Okinawa Trough off northeastern Taiwan **Song-Chuen Chen（陈松春）** Central Geological Survey, Ministry of Economic Affair, Taipei, Taiwan，China（台湾台北经济部中央地质调查局）
10	Can Magnetites Provide New Information about the Physical and Chemical Conditions inside Hydrothermal Vents? **Sang-Mook Lee** School of Earth and Environmental Sciences, Seoul National University, Republic of Korea（韩国首尔国立大学地球与环境科学学院）
11	Highly siderophile elements and Osmium isotopes in abyssal peridotites from the Southwest Indian Ridge: Implications for evolution of the oceanic upper mantle **Wei Li（李伟）** Key Laboratory of Submarine Geosciences,Second Institute of Oceanography, MNR, Hangzhou, China.（自然资源部第二海洋研究所海底科学重点实验室）
12	A Quantitative Method for Active Fault Migration Distance Assessment on Both Sides of the Southwest Indian Ridge 46°～52.5°E—Based on Multi-Beam Data **Bo Feng（冯博）** Peking University, China（北京大学）
13	Crustal Thickness Anomalies Across the Carlsberg Ridge in the Northwest Indian Ocean Basin From Gravity Analysis **Juechen Song（宋珏琛）** Peking University, Beijing, China（北京大学）
14	Geological mapping at Southwest Indian Ridge Qiaoyue Seamount (~52°10′E）：Implication for prediction of hydrothermal field **Yongjin Huang（黄永金）** Key Laboratory of Submarine Geosciences,Second Institute of Oceanography, MNR, Hangzhou, China.（自然资源部第二海洋研究所海底科学重点实验室）
15	Synthetical anomaly characteristics of the 26th segment of Southwest Indian Ridge and implications for submarine hydrothermal activity **Zhen Dong （董振）** Ocean University of China , China（中国海洋大学）
16	Mineralogy and sulfur isotope characteristics of chimneys from Wocan-1 hydrothermal field, Carlsberg Ridge **Yiyang Cai （蔡翌旸）** Key Laboratory of Submarine Geosciences,Second Institute of Oceanography, MNR, Hangzhou, China.（自然资源部第二海洋研究所海底科学重点实验室）
17	Mineralogical in mafic and ultramafic rocks from the substrate of the Tianxiu Hydrothermal Field, Carlsberg Ridge **Peng Zhou（周鹏）** Key Laboratory of Submarine Geosciences,Second Institute of Oceanography, MNR, Hangzhou, China.（自然资源部第二海洋研究所海底科学重点实验室）

18	Sedimentary Records of Hydrothermal Activities at Tianxiu Hydrothermal Field, Carlsberg Ridge **Mou Li（李谋）** Zhejiang University, China（浙江大学）
19	Exploring the role of microorganisms in sulfur deposition in hydrothermal environment via metagenomic data mining **Baowei Huang（黄宝威）** Institute of Deep-sea Science and Engineering，Chinese Academy of Sciences, China. (中国科学院深海科学与工程研究所)
20	Geochemistry of hydrothermal fluids from Carlsberg Ridge **XuetingWu (吴雪停)** Key Laboratory of Submarine Geosciences,Second Institute of Oceanography, MNR, Hangzhou, China(自然资源部第二海洋研究所海底科学重点实验室)
21	Metal stable isotopes as tracers to constrain hydrothermal ore-forming processes **Yunchao Shu（舒云超）** University of Science and Technology of China,China（中国科学技术大学）
22	Geological characteristics and delineation of hydrothermal anomalies around 55°20′E of Southwest Indian Ridge **Liang Huang（黄亮）** China University of Geosciences (Wuhan) , China（中国地质大学（武汉））
23	Traceability Analysis of Seafloor Sediments Based on ArcGIS and Its Application in the Longqi Hydrothermal Field on the Southwest Indian Ridge **Donglei Pan（潘东雷）** Key Laboratory of Submarine Geosciences,Second Institute of Oceanography, MNR, Hangzhou, China 自然资源部第二海洋研究所海底科学重点实验室

Guidelines for Participants

会议指南

Part One: Important Information|重要信息

Conference venue: Hangzhou Braim Canal Hotel

Address: No. 58 Jinhua Road, Gongshu District, Hangzhou, China

1. Registration

Time: September 19th, full day.
Venue: First floor lobby of Hangzhou Braim Canal Hotel.

2. Meeting Venue

Area B, International Hall, 3rd floor at Hangzhou Braim Caval Hotel.

3. Dinner Venue

Western restaurant on the 2nd floor at Hangzhou Braim Canal Hotel.

会议地点：杭州百瑞运河大饭店

地址：浙江省杭州市拱墅区金华路 58 号

1. 会议注册

时间：2019 年 9 月 19 日全天
地点：杭州百瑞运河大饭店一楼大厅

2. 会议地点

杭州百瑞运河大饭店三楼国际厅 B 区。

3. 用餐地点

杭州百瑞运河大饭店二楼西餐厅。

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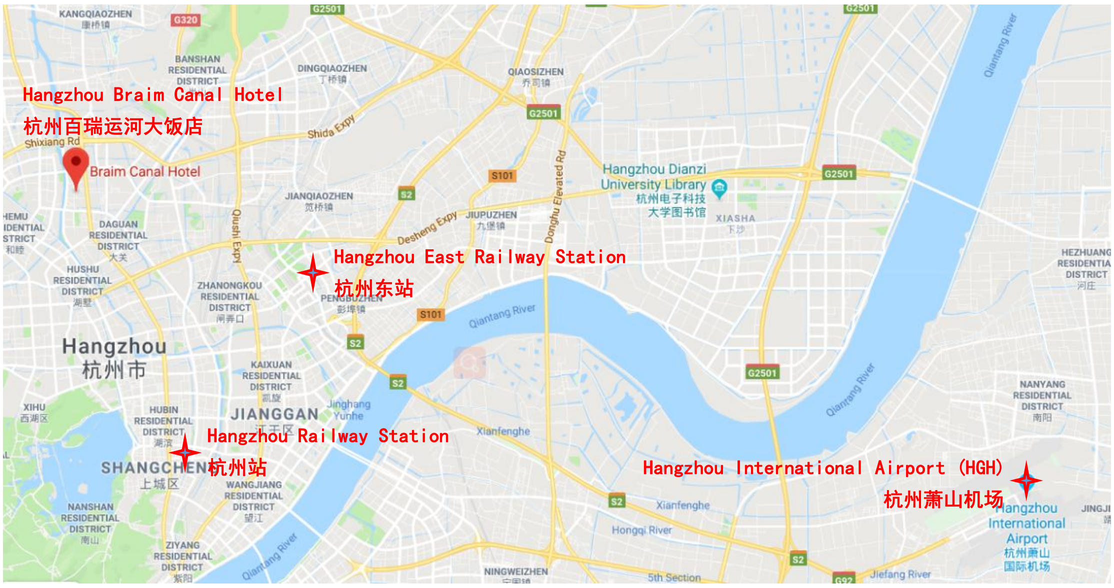

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Working Group on Seafloor Massive Sulfides (SMS)
Resource along Mid Ocean Ridges (MOR)

Workshop on Hydrothermal ore-forming processes and the fate of SMS deposits along slow and ultraslow spreading MOR

慢速-超慢速扩张洋中脊热液成矿过程及多金属硫化物命运研讨会

Abstract Brochure | 摘要手册

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InterRidge Workshop on Hydrothermal Ore-forming Processes
19-22 September 2019
Hangzhou, China

Primary Session

Geological mapping of mid-ocean ridges and its implications and use for the prediction of SMS occurrences

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Abstract
Seafloor hydrothermal systems or seafloor massive sulphides (SMS) have become a target of increased global exploration activity due to their presumed resource potential. Recent investigations have shown that these occurrences are more variable than previously thought and that this variability is not necessarily reflected in analogous volcanogenic massive sulphide deposits preserved in the ancient rock record. To date, over 400 hydrothermal occurrences hosting massive sulphides or of sufficiently high vent fluid temperature to carry sulphides to the near-subseafloor are known. Most of these occurrences are, however, hydrothermally active and tend to be in an early stage of development and are therefore commonly quite small. Additionally, they commonly host chemosynthetic faunal communities. Hence, inactive sites, that have gone through a full life-cycle of metal deposition, where hydrothermal activity has ceased, and where associated high-temperature vent communities have disappeared, are seen as the more reasonable mining target. These inactive systems, however, lack the prominent water column signature and might be difficult to locate. Many inactive sites are also considered to be located at some distance to the neovolcanic zone increasing the areas that needs to be explored to several million km^2. Therefore, we need new methodologies and procedures to narrow down the search areas to permissive tracts, which are likely to host large and economically interesting SMS occurrences. This contribution discusses how geological mapping and interpretation of topographic data could lead to more effective exploration for SMS occurrences.

Keywords
geological mapping, exploration

An integrated assessment of hydrothermally extinct seafloor massive sulphide deposits at the TAG hydrothermal field

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Abstract

One of the outstanding questions about seafloor massive sulphide deposits is the extent to which they are present on and below the seafloor, and to what extent they preserve their base metal contents after hydrothermal fluid circulation has ceased. The societal importance of this subject lies in determining whether extinct seafloor massive sulphide provide any kind of metal resource potential of significance, or are barren and offer no economic potential. Although many seafloor hydrothermally systems have been studied, extinct seafloor massive sulphide deposits are likely more accessible to future mining and far more abundant, but are often obscured by pelagic sediment and hence difficult to locate. Furthermore, SMS deposits are three dimensional. Yet, to date, very few have been explored or sampled below the seafloor. Here, we describe the most comprehensive study to date of hydrothermally extinct seafloor massive sulphide deposits formed at a slow spreading ridge. Our approach involved two research cruises in the summer of 2016 to the Trans-Atlantic Geotraverse (TAG) hydrothermal field at 26 °N on the Mid-Atlantic Ridge. These expeditions mapped a number of hydrothermally extinct SMS deposits using an autonomous underwater vehicle and re- motely operated vehicle, acquired a combination of geophysical data including sub-seafloor seismic reflection and refraction data from 25 ocean bottom instruments, and recovered core using a robotic lander-type seafloor drilling rig. Together, these results that have allowed us to construct a new generic model for extinct seafloor massive sulphide deposits indicate the presence of up to five times more massive sulphide at and below the seafloor than was previously thought. Despite

this, we are still uncertain about the metal tenor of these deposits at depth and hence their economic significance.

Keywords

Extinct SMS, preservation, metal tenor, structure, resource po

Seafloor Sulfides: What About The Source Region? Thoughts from Core Complexes

Henry JB Dick

Woods Hole Oceanographic Institution, Woods Hole MA 02536 USA and the Blue Mining project team[5].

Abstract

Oceanic core complexes host the largest massive sulfide deposits found to date at ocean ridges. Their composition should logically reflect that of their source rocks, presumably the underlying basement lithologies found there: diabase, mantle peridotite, and a wide variety of gabbroic rocks. Also to be considered is their state of alteration, whether it be granulite, amphibolite, greenschist or low temperature seafloor weathering. Even the state of deformation plays a role as some have undergone extensive brittle faulting, cataclasis, or even mylonitization and crystal-plastic deformation. Localization of fluid flow by faulting, both brittle and crystal-plastic is the major factor in focusing hydrothermal fluids. Also critical is the interplay between lithologies, where the contact between and intrusive gabbro and fresh or serpentinized peridotite can localize mineralization, or extraction of key elements.

Thus, in considering the nature of the fluids, minerals deposited, and their critical trace element concentrations all the above factors should be considered in any program designed to locate a potentially economically viable deposit. Reviewing what is exposed at oceanic core complexes, we find that they range from large peridotite massifs to gabbro plutons of enormous size. The Atlantis Bank gabbro massif, where drilled to 1.5 km, consists of massive upwardly differentiated accumulations of small intrusions that have undergone intense local crystal plastic deformation, where melt migrated up through a column of crystal mush over a kilometer scale; enriching the uppermost gabbro in iron, titanium and incompatible elements, and the composition of the bulk hole most closely resembles a highly evolved MORB magma – far from the composition of a primary magma. Alternatively at Hole U1309D, the section consists of numerous small intrusions, with interceding screens of mantle peridotite, that have undergone little or no crystal-plastic deformation. These largely solidified independently, with an aggregate composition similar to that of a primary MORB melt. Thus, the stratigraphy in gabbroic core complexes depends heavily on magma flux, and where this is high, incompatible element concentrations may be more easily mined by hydrothermal circulation where permeability permits.

These massifs are cut by several generations of faulting, any of which may localize hydrothermal flow and the extraction of incompatible elements. The earliest faulting is that associated with the unroofing of the core complex, which begins with the formation of a high-angle normal fault under purely brittle conditions, with offsets ranging from a few meters, to hundreds of meters, then to kilometers, and to 10's of kilometers. As the fault deepens, the nature of deformation goes from brittle fracturing, to cataclastic, and at depth to crystal-plastic deformation. With continued uplift, successively deeper higher-temperature modes of deformation are exposed. Rollover of the detachment footwall occurs as the core complex grows, with cross-cutting inward facing normal faults oriented parallel to the ridge axis, and parallel to the spreading direction, followed by late outward facing faults, providing new paths for hydrothermal circulation. Changes in spreading direction, and the dilatational stresses involved across active transforms can then be accommodated by reactivation of these faults, enhancing permeable fluid flow in old fault zones.

A critical factor, in all this, is the heat source for hydrothermal circulation, and the anomaly of high-temperature fluid flow in the apparent absence of a major heat source. A gabbro body that has already been unroofed on a detachment fault has already undergone considerable conductive and advective cooling. Likely significant is that spreading at the rift axis during core complex emplacement is highly asymmetric, with spreading in the direction of the core complex greatly exceeding that away from it. Thus, the plate boundary appears to migrate over and away from the axis of mantle upwelling and accretion found at the adjacent ridge segments. This mandates fault capture, and thus, rather than plunging down into the zone of mantle upwelling and accretion, as commonly supposed, the detachment fault cuts off faulting on the opposing rift valley wall, terminating beneath it, resulting in the asymmetric spreading of the newly formed plutonic section to form the core complex. This then displaces the plate boundary away from the axis of mantle upwelling, with the core complex overriding it. This then can explain the anomalous heat source required to explain the high temperature hydrothermal activity evident from the massive sulfide deposits found on the core complex footwalls as the core complex advances out over the zone of mantle melting.

Finally, to be considered is the nature of the contacts between gabbros and mantle. While the Penrose model for the ocean crust has constrained geologists to think in terms of sub-horizontal contacts between the crust and mantle, the reality is quite different. For example, the sub-horizontal gabbro-peridotite contact running for over 30 km along the eastern wall of the Atlantis II Transform, first identified as the crust-mantle boundary, is in fact intrusive, with highly evolved gabbros in contact with massive mantle peridotite. Such a contact can have virtually any dip up to near vertical, and can localize hydrothermal circulation where fluids interact with both peridotite and gabbro, a possible explanation for the apparent necessity of a basaltic influence on hydrothermal solutions in ultramafic hosted sulfide deposits.

Keywords

Gabbro, peridotite, mantle, fluids, tectonics, core complexes

The inactive hydrothermal vent fields in the Central Indian Ridge between 8°S and 18°S, Indian Ocean

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Abstract

High resolution mapping with geological sampling has been conducted by Korea Institute of Ocean Science and Technology in middle part of the Central Indian Ridge (MCIR) between 7°S
and 17°S. Total eleven ocean core complexes (OCCs) which is characterized by the gentle-dome structure and corrugations were identified through the high-resolution mapping. Plume signals over the MCIR revealed that hydrothermal activities were mostly distributed on the asymmetrical ridge sections where ultramafic massifs juxtaposed along one ridge flank near ridge-transform intersections or non-transform discontinuities (NTD). The seafloor observation targeted to several plume sites in MCIR resulted in the identification of new active and/or inactive vent fields at five locations. Inactive chimney fields are mostly located nearby or on OCC. Even though the inactive chimneys were observed, the strong multi-proxy plume signals imply a possible presence of active venting. The only active vent field with abundant benthic organisms was found at the summit of ridge flank of NTD within segment 3, where corrugation features in the steep inward-slope of the flank characterize OCC.
In OCC at 12.4°S (segment 4), inactive chimney field (Cheoeum chimney field; CCF) was identified and hydrothermal sulfide ores were recovered by a rock dredge. The sulfide ores seem like fragments of Zn-rich chimneys (up to 50 wt.% Zn). The Zn-rich ores are highlighted by high concentrations of Sn (up to 1,720 ppm Sn) as well as Au (up to 10.4 g/t Au). Major sulfide minerals of the chimney fragments are sphalerite, isocubanite, chalcopyrite, pyrrhotite and marcasite but the ores typically are accompanied by native gold and tin mineralization. Native gold predominantly occurs visible grain of inclusion (< 3um in diameter) hosted in sphalerite and/or isocubanite. Gold grains have low grades in Ag (< 15 wt.% Ag) and no other gold-bearing minerals except native gold were observed, indicating Au concentrations are mainly attributed to visible gold grain. FeS concentrations in sphalerite show a wide range from 6.74 to 42.69 mole % FeS during the mineralization advancing. Sphalerites in the early stage are depleted in FeS but trace elements tend to coprecipitate with late-stage sphalerites. The late-stage sphalerites are typically enriched in Sn, ranging up to 5.5 wt.% Sn. Tin mineralization spatially focuses on a grain-boundary between sphalerite and isocubanite, related to In and Ga coprecipitation. In the Sn-enriched sphalerites, a negative correlation between Zn and Cu + Sn with the uniform Cu/Sn ratios (almost 2:1) were recognized. TEM analysis indicates Sn-bearing inclusions are notably absent. Sn is incorporated into sphalerite as a solid solution, not a discrete inclusion phase based on STEM-EDS mapping and FFT pattern analysis

Keywords
Central Indian Ridge, Ocean core complex, Inactive chimney field, Gold, Sn-mineralization

Hull-mounted multibeam echosounder (MBSE): a cost and time-effective tool for detection of extinct seafloor massive sulfide deposits

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Abstract

Since 1977 and the discovery of the first high temperature (HT) hydrothermal vent, more than 300 sites are known today. Until recently, marine sulfides deposits, related hydrothermal activity and biodiversity were almost only the scientists' playground. However, with the world's growing demand for metals, seafloor massive sulfides (SMS) deposits are now seen as a possible mineral resource that could contributes to secure metal supply for human needs.

If exploration strategies for detection of active hydrothermal sites are now robust and very efficient, the active SMS will not (and must not) constitute a potential target for deep-sea mining due to environmental concerns and technical limitations. Recent studies on SMS deposits are rather focused on extinct and buried mineralized sites (e.g. Gehrmann et al., 2019; Murton et al., 2019) characterized by a lower biomass. Several geophysical techniques to explore and detect extinct SMS (eSMS) and buried SMS (bSMS) have been developed (e.g. Kawada and Kasaya, 2017; Szitkar et al., 2017, 2014) using different approaches (e.g. regional or local scale; ship-based or using underwater vehicles) with several degrees of success or limitation.

During the BICOSE (2014) and LEVE-SMF (2016) cruises, acoustic surveys were performed on the TAG hydrothermal district with the hull-mounted Kongsberg EM122 (12 kHz, R/V L'Atalante). The analysis of the seafloor backscatter data revealed the presence of numerous zones with low to very low backscatter strength values. Some of them coincide with known extinct SMS such as Shinkai mound, Southern Mound, Double Mound and Mir Mound (Figure 1). Other areas dominated by very low backscatter strength values were investigated and sampled with the HOV Nautile during the HERMINE cruise (2017). All of these acoustic anomalies were found to be very old and strongly oxidized eSMS deposits.

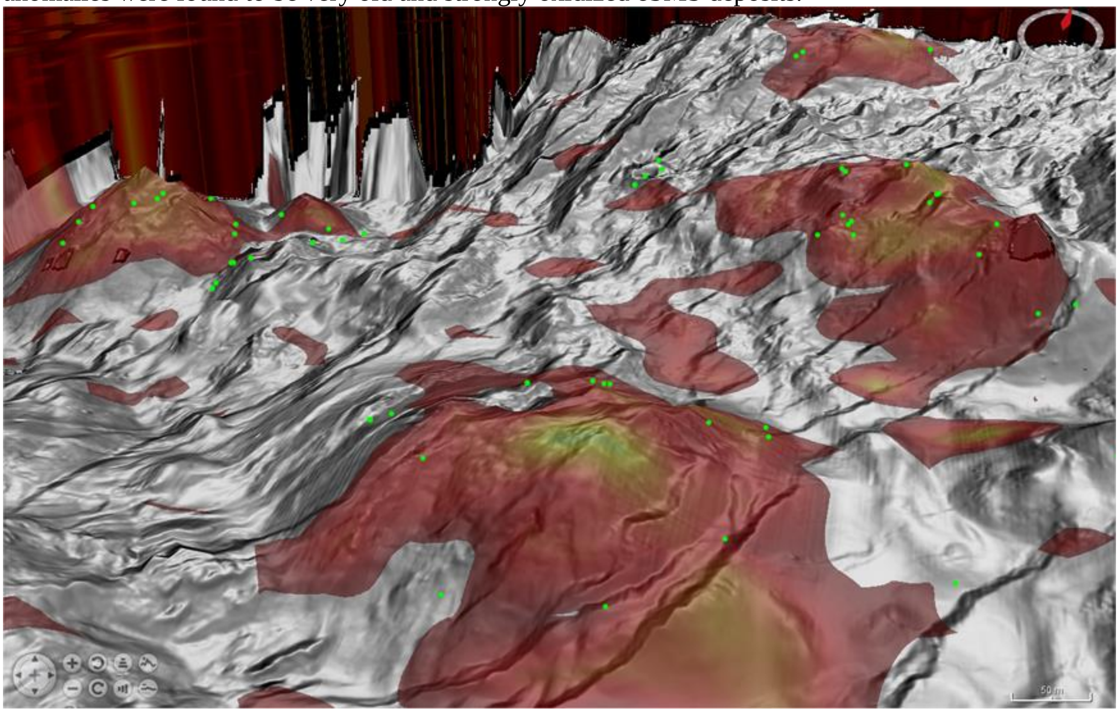

Figure 1 : Backscatter strength values surimposed on high resolution bathymetric map. The four zones with low to very low backscatter strength values correspond to Southern Mound, Double Mound, Shinkai Mound and an unnamed mound explored during HOV dives. Green dots are the location of rock sampling.

Few couples of hours of surveys are required to cover a surface of more than 70 km2 with the 12 kHz vessel hull-mounted MBES, whereas more than 20 days is needed to cover such a surface with an AUV. Therefore, hull-mounted MBES acoustic backscatter survey is a promising approach for cost and time-effective detection of eSMS deposits and thus for the evaluation of their resource potential at Mid-Ocean Ridges.

Keywords
Exploration, Extinct Seafloor Massive Sulfides, Acoustic backscatter data, 12 kHz hull-mounted multibeam echosounder

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Diversity of hydrothermal systems on Southwest Indian Ridge

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Abstract:
Ever since the first report of Longqi-1 high temperature hydrothermal field in 2007, increasing evidence suggests that the ultraslow spreading (full rate less than 2cm a−1) ridges characterized by melt-poor with thin or no crust, including the Gakkel Ridge in the Arctic Ocean, the Southwest Indian Ridge in the Indian Ocean and the Mid-Cayman Rise in the Atlantic Ocean, are not desert for hydrothermal activities. So far, 7 active hydrothermal fields, including high- and low-temperature, 5 inactive/extinct sulfide fields have been identified along this series of ridges, and numerous inferred active ones waiting for confirmation. As important endmember of global ridge system, they contribute a lot to the heat sources and heat transfer processes. Compared with the slow to fast spreading ridges, the hydrothermal areas on the ultraslow spreading ridges have comparable physical and chemical characteristics. For example, the highest temperature measured in Longqi-1 hydrothermal field of the Southwest Indian Ocean is up to 383℃, high salinity and high content of some trace elements (e.g. Au up to 20ppm). Although with relatively weak magmatism, locally enhanced magma supply can provide a possible source of heat along this category of ridges, such as the Duanqiao hydrothermal field formerly considered to be inactive, the latest survey shows that it is still emanating low to intermediate temperature hydrothermal fluids; while the Tiancheng hydrothermal area evolves from low temperature to intermediate temperature hydrothermal zone. Large-scale detachment fault is also the main controlling factor of hydrothermal activity of this series of ridges. Sulfide deposits on peridotites/serpentines were found in the eastern part of the Southwest Indian Ridge. Geophysical and geological sampling evidence shows that the above-mentioned Longqi-1 hydrothermal area is also located on the upper wall of detachment system. Interestingly, carbonate chimneys were also discovered along the Southwest Indian Ridge. The diverse hydrothermal systems along the ultraslow spreading ridges are similar to other hydrothermal systems along the slow-intermediate spreading ridge.

Keyword:
hydrothermal circulation; Ultramafic-hosted; local magmatic supply; Massive sulfides; Southwest Indian Ridge

All seafloor massive sulfide deposits are hydrothermal deposits, but not all hydrothermal deposits are seafloor massive sulfide deposits

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Abstract
A significant amount of research and exploration efforts has focused on finding active seafloor hydrothermal systems along mid-ocean ridges. Since the initial discovery of black smokers on the East Pacific Rise, the evolution of exploration methodologies and development of new technologies has advanced to the point where the discovery of new vent fields is becoming routine. However, the purpose of this Working Group is to advance our understanding of "hydrothermal ore forming processes". This requires a recognition that not all seafloor hydrothermal systems are necessarily ore forming systems. To make significant progress, our focus needs to shift from hydrothermal systems in general towards exploring for and understanding the formation of systems that are metal-rich and have generated, or are generating, seafloor massive sulfide deposits of large-enough size to be economically-viable targets for mining. Based on exploration and sampling efforts so far, very few (if any!) of the seafloor massive sulfide deposits discovered along the mid-ocean ridge system have high enough tonnage and metal grades to be considered economically feasible targets. In most cases, there simply is not enough information at the deposit scale for a proper evaluation of either grade or tonnage. Where deposit grades and tonnages for SMS deposits have been reported, they are often based on assumptions regarding the composition of the subseafloor material that makes up the bulk of these deposits. In this talk I will present examples of the variability in composition of hydrothermal deposits along the Mid-Atlantic Ridge and discuss why not all deposits that accumulate at high-temperature hydrothermal vent fields are necessarily ore-forming seafloor massive sulfide deposits.

Keywords
Seafloor massive sulfide deposits; hydrothermal systems, mid-ocean ridges, ore-forming processes, grade, tonnage

Extreme hydrothermal activity on Carlsberg Ridge during the last glacial stage: evidence from an off-axis sediment core

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Abstract
Hydrothermal activity at mid-ocean ridge is tectonically and magmatically controlled. Recently, pressure variations resulting from sea level changes are considered another driving force modulating the intensities of hydrothermal activity. Lund et al. (2016) showed, based on ridge-crest cores from the fast-spreading East Pacific Rise over the past 200.000 years, enhanced hydrothermal activity during the last glacial terminations. It is intriguing to find out how the hydrothermal activity at slow-spreading ridges changes with the time, how the timing of its hydrothermal venting history correlated with global sea level changes, and how far the hydrothermal signal can be recorded in deep sea sediments and to what extent it affects the environment.

Carlsberg Ridge is a slow-spreading mid-ocean ridge located in the northwest Indian Ocean. So far, we have discovered three active hydrothermal fields (i.e. Tianxiu, Wocan-1 and Daxi) on this ridge. A sediment core 28II (CR)-SO30 collected at the ridge flank 4.13°N, 69.34'E approximately 310 km east of the nearest ridge segment, 500km northeast of the ultramafic hosted Tianxiu field and 1100km northeast to mafic-hosted Wocan-1 field. On the basis of mineralogy and major, trace, and rare-earth element (REE) geochemical analyses and 14C dating, we aim to reveal the temporal variation of hydrothermal signals recorded by this core and explore the linkage between hydrothermal activity of the Carlsberg Ridge and the global sea-level changes as well as the potential impacts on the environment.

This 46.7cm long core can be divided into 3 units. Unit 1 (4-20 cmbsf) is yellowish gray pelagic calcareous claywith traces of altered basaltic fragments. Unit 2 (20-31 cmbf) is light brownish gray pelagic calcareous clay with traces of Mn oxide minerals and Fe-oxyhydroxide. Unit 3 (31-45 cm) is light brownish gray mottled with dark brown pelagic clay containing Fe-Mn oxides, Fe-oxyhydroxide and aluminosilicate minerals. Based on 14C dating using planktonic foraminifera, this core spans 23.2 ka and the sedimentation rates of 2.23 cm/ka for Unit 1 (0.38-10.5 ka), 2.74 cm/ka for Unit 2 (10.5-14.9 ka) and 1.85 cm/ka for Unit 3 (14.9-22.4 ka), respectively.

Geochemical analysis shows that Unit 2 and Unit 3, i.e. between 10 and 20 ka B.P, are more enriched in Fe, Mn, Zn, Ni, and Co, V, Cr, Zr, Rb, Ce, Li, B, etc. The fluxes of these elements reach a maximum at ~15 ka, coinciding with the last deglaciation (Termination I). The average flux of the hydrothermal sourced Fe and Mn in Unit 3 are about 1.1 and 3.2 times of those in the Unit 1, respectively. The down-core variation of (Fe+Mn)/Ti ratio changes from 15.6 to 18 with its peak located at 15 kyr, while A1/(Al+Fe+Mn) ratio changes from 0.61 to 0.56 and reach a minumum at 15 kyr. Both parameters are indicator for the contribution of hydrothermal components and confirm the involvement in far-field dispersal from the Carlsberg Ridge during low sea-level stand in marine isotope stage 2.

The REE and trace elements patterns also show clear evidence that from 20-24 cmbf down core has different spider patterns than the upper layer. Based on the hydrothermal signals recorded in this core, we suggest that the hydrothermal acitivity at Carlsberg ridge may up to 3.2 times stronger during the glacial age than at present. This explains why at the sampling site over 310 km away from the ridge crest the presence of hydrothermal sourced particles such as iron hydroxide settled from hydrothermal plumes, while during high sea level stands during the recent 10 ka, there is no hydrothermal signal recorded at this location. We further infer that the enhanced hydrothermal activities during the glacial stages may act as negative feedback for the sea level rise and have a far reaching impacts to the envrionment and ecosystem.

Keywords
Hydrothermal venting history, global climate change, Carlsberg Ridge, sediment core, geochemistry

Finding, mapping and evaluating seafloor mining prospects

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Abstract

With the exploration of seafloor mining targets already in progress and exploitation seeming inevitable in the next few years, standardizing the way in which we find, map and evaluate potential targets is increasingly important. The great expense involved in collecting detailed survey data at sea means that the survey data used to make decisions about the locations and sizes of resources are often sparser and more poorly constrained than they would be on land. While the advent of autonomous technology has increased our ability to collect near seafloor data, these facilities are limited in terms of the area they can cover and the number of datasets they can acquire, as well as presenting unique navigational and processing challenges. In this presentation we will discuss the main detection and surveying techniques currently in use for mapping seafloor massive sulphide (SMS) deposits as well as those used for mapping seafloor ferromanganese crusts and nodules.

With examples, we will summarise the main techniques and equipment used to explore for and assess marine mineral resources and the relative importance and usefulness of the datasets collected. We will compare the data collected for seafloor resource estimates with estimates carried out on similar resources on land, and explore the relationship between data availability, sample density and certainty. Doing so exposes knowledge gaps in seafloor resource estimates, particularly in terms of our knowledge of the subsurface and indicates the primary weakness in seafloor estimates is in understanding resource distribution and grade at depth. However, we also identify benefits to working on the seafloor, in particular the young age of the seafloor in regions of SMS mineralization means morphological indicators can be used to effectively predict general regions that are likely to be mineralized in order to reduce the area requiring detailed survey.
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Keywords

Seafloor mining, autonomous underwater vehicle, bathymetry,

Can submarine massive sulphide deposits be recycled?

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Abstract

There is ample consensus on the fact that we only have access to a very small part of the massive sulphide deposits, stockworks and disseminations that formed and lie on and within the oceanic crust. Recently Cathles (2011) and Hannington (2013) led the debate. Cathles (op cit) based on thermal considerations, concluded that the oceanic crust is a giant sms generator, which, at an efficiency of 3%, should generate 600 times more sms ore than the total amount of VMS ore found on land (850·106 t total metal precipitated in volcanogenic massive sulphide (VMS) ores on land (Franklin et al., 2005). The current inventory of sms deposits contains only about 100·106 t of metal (~50% of the total ore tonnage). If Cathles (op. cit.) is right, we have identified so far only ~0.2% of the sms ore that may have formed in the present-day oceanic crust. The profound implication is that new exploration models for sms deposits must be developed, to test the hypothesis. Still according to Cathles, hydrothermal processes produce labile copper in excess of 106x109 (to speak only of Cu). According to Hannington (op cit) massive sulphide deposits, nodules and manganiferous crusts account for only ∼3% of the Cu metal of the subducting slab. The vast majority of the submarine Cu resources and Cu precipitation in general are accumulated under the seafloor, and more will become inaccessible with time, as a consequence of sedimentation. The inventory of labile Cu available for subduction may exceed 500·109 t.

A significant part of the submarine Cu inventory ends up exposed on land, after a post depositional history, sometimes long and complicated, in ophiolites, in exposed arc sequences and in other, related mineralized settings. The representativity of the land mineralizations generated underwater is far from predictable, given the large array of specific factors which enable obduction and obduction-type phenomena. One thing we know for sure: a "large" sms deposit on the seafloor and a "large" deposit on land are completely different in size.

There can be no doubt that the labile Cu mineralization which is available to be subducted is gigantic. Can these mineralisations appear in supra subduction settings, as porphyry-Cu deposits, as hypothesized by Thurman (1996)? Another article of interest is that of Hutchinson and Hodder (1972), "Possible tectonic and metallogenic relationships between porphyry copper and massive sulphide deposits". This may be an ideal problem to handle with Cu isotopes. Existing data is highly suggestive of isotopic resemblance between the submarine deposits and porphyry-Cu deposits, with ∂65Cu mostly between 0 and +4 ‰. These data will become more and more reliable as the analytical precision increases (see Li et al. (2010); Rouxel et al. (2004).

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Keywords

Submarine massive sulphide deposits; porphyry-Cu deposits; Cu isotopes

Morphology and formation of SMS deposits in different geological settings

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Abstract

Data collected during last years demonstrates diversity in morphology of SMS deposits formed in different geological settings. Variability in shape of deposits is controlled by different way of hydrothermal fluids discharge (focused or diffused) which in its turn is determined by permeability of hosted rocks: low in basalts and high in gabbro-peridotites. Transformation of ultramafics to serpentinites during hydrothermal alteration processes considerably contributes to increasing of their permeability. As a result, classical mound-like structures are more typical for the deposits with basalt substrate whereas ultramafic setting is characterized by flatter morphology of SMS deposit.

SMS deposits hosted by ultramafics demonstrate variability in their morphology as well. Different types of SMS accumulations could be related to degree of their maturity. While flat mounds could be considered as primary, their following evolution could be result in "smoking crater" and "bread crust" structures formation.

Two scenarios of mound evolution are determined by different physical properties of surface mineralization: if it is strong enough and has no weak zones overpressure leads to explosion and "smoking crater" formation. Otherwise the cracking will follow weakened zones of the mound with slow fluids discharge through the generated cracks within "bread crust" structure.

Keywords

Deep-sea minerals, Seafloor massive sulfide deposits, Morphology, Geological setting, Mid-Atlantic ridge

Early Career Scientist Session

Lucky Strike: is it a TAG (Trans-Atlantic Geotraverse) precursory hydrothermal system?

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Abstract

Lucky Strike hydrothermal field is located in Mid-Atlantic Ridge (MAR - 37°N), in the Azorean plateau, southwest of the Azores islands. In the areas surrounding the active sites, the alteration processes affecting basaltic rocks are prominent and form hydrothermal breccias by the circulation of low temperature hydrothermal fluids in diffuse vents. These breccias are found near the vents and play an important role in the protection of subseafloor hydrothermal sulphide deposits forming an impermeable cap due to the high content in siliceous material. The forms of silica are mostly amorphous and precipitate when the fluid is conductively cooled. The process evolves gradually from an initial stage where there are just basaltic fragments and circulating seawater. The ascending hydrothermal fluid mixes with seawater, which favours the precipitation of the sulphide components (namely pyrite, chalcopyrite and sphalerite), also found in the breccias. Sealing of the initially loose fragments begins, the temperature rises below this crust, and the processes of mixing fluid circulation and conductive cooling are simultaneous. At this stage the fluid becomes oversaturated with respect to amorphous silica. This form of silica can precipitate in the open spaces and seal the system. Once the fluid is trapped under this impermeable layer, conductive cooling is enhanced and mixing with seawater is restricted, making the precipitation of amorphous silica more efficient.

TAG Hydrothermal Field is also on the Mid-Atlantic Ridge (26°N), characterized as one of the largest sites of high-temperature hydrothermal activity found on the seafloor and is comprised of active and relict deposits in different stages of evolution (Humphris et al., 2015). The system lies on basaltic oceanic crust as Lucky Strike.
Recently some intensive work has been developed in TAG (Murton et al., 2019). Combine observations based on surface geology and sub-seafloor drilling found, among other hydrothermal deposits, superficial (just below pelagic sediment) layers of dense jasper, several meters thick, that transitions downwards into massive brecciated sulphides. In the jasper samples overgrowths of sulphides, often comprising euhedral pyrite and minor chalcopyrite, were observed.
If the jasper formation is a result of silica precipitation from low temperature, diffuse hydrothermal venting that has resulted in silicification of pre-existing iron-rich sediments, the TAG jaspers are a late stage deposit on fading hydrothermal systems (Murton et al., 2019). The location of the jasper layer immediately above the massive sulphides suggests it acts as an impermeable barrier protecting from the contact with seawater.

It is remarkable the similarity with the ancient seafloor massive sulphide deposits studied in geologic record. Siliceous rocks, as jaspers, were found in the hanging wall of the ore bodies from the Iberian Pyrite Belt some decades ago. Barriga & Fyfe (1988) proposed a protecting role for these jaspers, saving the underlying ore bodies from oxidation.

In conclusion, the highly silicified breccias seems to show a precursory stage of the jasper material recovered from the inactive seafloor massive sulphide deposits from the TAG hydrothermal field. Although the content in iron is lower in the Lucky Strike breccias when compared with TAG jaspers, both have high contents in silica. They both seem to form an impermeable barrier protecting the lower sulphide deposits from the contact with seawater, but in different stages of evolution.
Comparative geochemical and petrographic works must be done to draw more accurate conclusions about these two MAR important hydrothermal systems.

Keywords

Seafloor Hydrothermal breccia; Jasper; Silicification

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3D Seismic Imaging and Potential Massive Sulfides Deposits of Geolin Mounds Hydrothermal Field in the Southern Okinawa Trough

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Abstract

Multi-scale geophysical and geochemical investigation including single-beam and multi-beam echo sounder, side-scan sonar, sub-bottom profiler, multi-channel seismic, heat flow measurement as well as multi-core, near-bottom water column, CTD mooring, gravity core and dredge sampling works have been conducted in a newly discovered hydrothermal field named as Geolin Mounds in the Southern Okinawa Trough. Vigorous flare features in water column and “rock grove” morphological characteristics above seafloor were observed in echo sounder and side-scan sonar data. Widely high heat flow anomalies (> 10,000 mW/m2) also exist in the survey area. Due to strong Kuroshio Current during multi-channel seismic data acquisition, serious streamer feathering effect (5-40°) happened. To take advantage of swath distributed CDPs caused by streamer feathering, we developed a pseudo-3D technique and produced a 3D seismic cube. In addition to specific features above seafloor, widely-distributed anomalies such as blanking zone and high-amplitude reflectors are observed around the Geolin Mounds hydrothermal field on our sub-bottom and multi-channel seismic profiles. Furthermore, 3D seismic cube provides estimation of the areas of blanking zone on selected time slice and better characterizes fault structures in the hydrothermal field. The geochemical analysis results present relatively high concentration of methane, rare earth elements and 3He/4He ratio in near bottom seawater samples. High Ag, Au, As, Bi, Cd, Cu, Fe, Pb, Sb, and Zn concentrations have been found in our sediment and rock samples. The time-series data of CTD mooring at Geolin Mounds revealed that temperature and methane concentration were simultaneously varied with time.

Based on the geophysical and geochemical investigation results, we believe that the Geolin Mounds hydrothermal field is without underlying submarine volcanos and hydrothermal fluid migration could be related to fault development. We suggest that the Geolin Mounds is in its embryo stage of evolution and is constantly supported by active hydrothermal circulation. Consequently, seafloor massive sulfides deposits can keep developing with hydrothermal fluid circulation along migration conduits which is probably created by fault structures nearby the field. We suggest that the Geolin Mounds hydrothermal field may grow sustainably and could provide high potential massive sulfides resources in the Southern Okinawa Trough in the near future. Furthermore, the Geolin Mounds hydrothermal field can serve as a good observatory for development of the seafloor edifice and ore mineralization associated with hydrothermal circulation activities in a back-arc spreading basin.

Keywords

Hydrothermal Field; 3D seismic; Seafloor Massive Sulfides Deposit; Geolin Mounds; Southern Okinawa Trough

Sulfide mineralization of the Saldanha hydrothermal field (MAR): constraints from sulfur isotope in-situ microanalysis

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Abstract

Multi-scale geophysical and geochemical investigation including single-beam and multi-beam echo sounder, side-scan sonar, sub-The Saldanha hydrothermal field (HF) is hosted atop a mafic–ultramafic seamount, located at a non-transform offset on the Mid-Atlantic Ridge (MAR). Here, transparent low-temperature (~9 ℃) fluids discharge through centimeter-sized vent holes without the formation of chimney structures. Although fluid temperature at the discharge area is low, geochemical analysis show that mineral deposits, including sulfides, were precipitated from fluids with temperatures higher than 200 ℃ (Dias et al., 2011). The hydrothermal deposits are composed of a matrix of serpentine + talc ± chlorite of high porosity, where calcite + chalcopyrite (Ccp) + sphalerite (Sp) + pentlandite (Pn) + pyrite (Py) were precipitated. Here, we present in-situ sulfur isotopes microanalysis determined by LA-MC-ICPMS. This technique is advantageous over traditional bulk analysis for tracing sources of sulfur and for understanding ore-forming processes. Saldanha sulfide minerals yielded δ34S values ranging from -1.37 to 14.34 ‰, with an average of 6.80‰ (Fig. 1). δ34S systematics of Ccp (3.63 to 14.34 ‰, average = 8.01‰), Pn (5.62 to 9.07 ‰, average = 7.27‰) and Py (-1.37 to 10.47‰, average = 5.20‰), indicate a disequilibrium between sulfide phases.

These δ34S values are more positive and of wider range than those of the high temperature hydrothermal fields along MAR, as for example Lucky Strike (1.5 to 4.6 ‰,), Rainbow (2.2 to 4.4 ‰) and Logachev (4.6 to 6.1 ‰; 350°C). However, values were within the range recorded for other modern sediment-hosted hydrothermal fields, such as Red Sea (-16.2 to +23.4 ‰), Escanaba Trough (-0.1 to +11.6 ‰) and Middle Valley (-8.0 to +12.4 ‰; Rouxel et al., 2004 and Zeng et al., 2016 and references therein). The distribution of δ34S values along the sediment depth showed that sulfide recorded higher δ34S values (maximum of ~14 ‰) in layers with lower Si/Al ratios and HREE enrichment with negative Eu anomalies and lower δ34S values (minimum of ~ -1.37‰) in layers with higher Si/Al and LREE enrichment with positive Eu anomaly (Fig. 2). Sulfide minerals in Saldanha field were precipitated within the subsurface due to mixing of upward diffused high-T hydrothermal fluids produced during the hydrothermal alteration of magmatic rocks with downward seawater. During this process, seawater sulfates were reduced to H2S by thermochemical reduction. However, the high δ34S values may have also resulted from the addition of 34S-enriched sulfur as consequence of complete serpentinization of mantle peridotites at high water/rock ratios. The negative δ34S values, in turn, may have been caused by the remobilization of sulfides precipitated by bacterial sulfate reduction.

Our results highlight the critical contribution of seawater and of high-T fluids that show hydrothermal alteration of magmatic origin and interaction with serpentinized-ultramafic rocks at depth for the mineralization of Saldanha deposits.

Keywords

Saldanha hydrothermal field, in-situ sulfur isotopes, sulfur sources

Reference

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Fig. 1

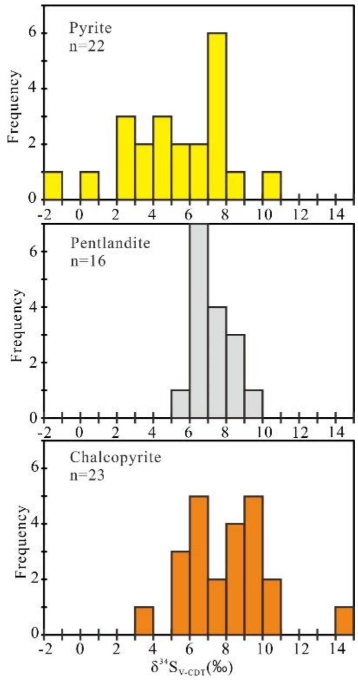
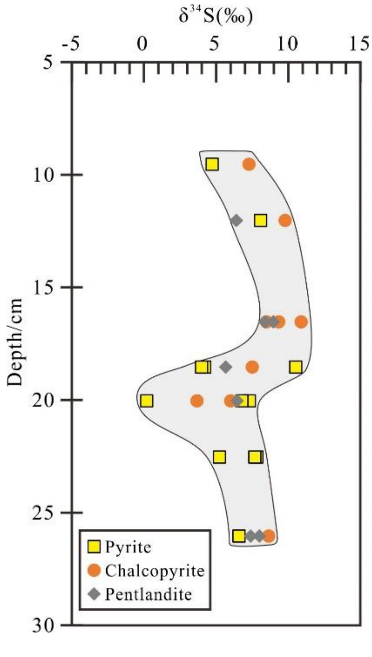


Fig. 1 Histogram of sulfur isotope values of sulfide minerals from Saldanha hydrothermal field.



Ultramafic rocks hosting sulfide mineralization along SWIR: insights from the sulfide sulfur isotopic and LA-ICP-MS trace-element compositions

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Abstract

The recently explored Tianzuo hydrothermal field, in the amagmatic segment of the ultraslow spreading Southwest Indian Ridge (SWIR), is closely associated with detachment faults. The field is hosted in serpentine-bearing ultramafic rocks where different sulfides precipitate, including high-temperature (isocubanite, sphalerite, and minor pyrrhotite) and low-temperature (marcasite and covellite) phases. Marcasite can be subdivided into marcasite I and II, with the former generally having a pseudomorphic texture after pyrrhotite and the latter typically growing around isocubanite or occurring as individual grains in quartz veins. In this study, mineralogy, sulfur isotopic, and in situ LA-ICP-MS trace-element compositions of sulfide minerals were used to elucidate the mineralization processes in ultramafic rocks hosting sulfides at this ultraslow spreading ridge. Sulfide minerals from the Tianzuo hydrothermal field have the greatest range of δ34S values (−23.8‰ to 14.1‰) found so far among modern sediment-starved ridges, with distinct δ34S values for low- and high-temperature phases. The high δ34S values of isocubanite (9.6‰ to 12.2‰) and sphalerite (9.1‰ to 14.1‰) indicate that sulfate, which precipitated during early phase hydrothermal circulation, might be the main sulfur source for these sulfides. Gabbroic intrusions generated the necessary heat for later high-temperature hydrothermal fluid circulation, providing homogeneous sulfur content and basaltic components in the reaction zone. This hypothesis is further evidenced by the enrichment in ore-forming metals such as Cu, Co, Sn, Te, Zn, Se, Pb, Bi, Cd, Ag, In, and Mn. The marked enrichment in Cu, Co, Sn, and Te in isocubanite compared with other metals is most likely due to the injection of magmatic fluids from gabbroic intrusions beneath the hydrothermal field. The intrusion of gabbroic magmas would have enhanced serpentinization reactions and provided a relatively oxidizing environment through the dissolution of anhydrite precipitated previously in the reaction zone, with high temperatures and low pH. This would have facilitated the extraction of metals by initial hydrothermal fluids, leading to the general enrichment of most ore-forming metals in isocubanite. Marcasite-II has the lowest and most variable δ34S values (−23.8‰ to −0.8‰), with the leaching of sulfide minerals formed by microbial sulfate reduction from sediments being the main sulfur source. Ore-forming metals in marcasite-II have compositions similar to those of isocubanite, except for strong depletion in magmatically derived Cu, Co, Sn, and Te. This means that serpentinization reactions also dominated ore-forming processes where marcasite-II precipitated, although these reactions were relatively weak. The enrichment of marcasite-II in Mo, Tl, and LILEs indicates that its mineralization was dominated by seawater convection. Low temperatures after the cessation of gabbroic magmatism and low rates of serpentinization during this stage hindered the extraction of metals from wall rocks, leading to low concentrations of ore-forming metals in hydrothermal fluids, apart from those generally abundant in seawater. Marcasite-I has variable and generally positive δ34S values (−0.1‰ to 12.0‰), with sulfur being inherited from pyrrhotite from the original thermochemical reduction of sulfate, mixed with additional volcanogenic sulfur. The study concludes that serpentinization reactions dominated both high- and low-temperature sulfide mineralization in ultramafic rocks of the Tianzuo hydrothermal field, and that gabbroic intrusions were crucial for high-temperature sulfide mineralization through providing additional metals, fluids, and heats; in contrast, low-temperature sulfide mineralization occurred during the cooling of gabbroic intrusions, with decreasing rates of serpentinization reactions and a significant influence of seawater. Intermittent magmatism represented by gabbroic intrusions, and high permeability caused by well-developed fractures associated with detachment faults, contributed to the formation of sulfides in the Tianzuo hydrothermal field. These factors possibly control sulfide mineralization in amagmatic segments of ultraslow spreading ridges.

Keywords

Sulfide, ultramafic rocks, sulfur isotope, trace element, SWIR.

Au and Te Minerals in Seafloor Massive Sulphides from Semyenov-2 Hydrothermal Field, Mid-Atlantic Ridge

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Abstract

Since the discovery of "black smokers" related to modern sea-floor hydrothermal activity within mid-oceanic ridges, their elevated contents of Au, Cu and Zn have been in spotlight. At the MAR, high gold content is associated with different types of host rocks — ultramafic (Logatchev, Ashadze-2 and Rainbow fields) and mafic (with Trans-Atlantic Geotraverse (TAG) field). A higher concentration of gold is commonly observed within ultramafic-hosted systems. It is generally known that gold deposition is controlled by metal enrichment in host rocks, favorable conditions for Au transport in the fluids, cooling/oxidation, mixing with seawater and the mechanism of precipitating (Hannington et al., Petersen et al., 2006). Elevated Te contents were found in seafloor sulphides associated with both mafic (Broken Spur) and ultramafic rocks (Logatchev)

Our study focuses on investigating the distribution of gold and tellurium in chimneys with zonality, massive sulphides without zonality and sulphide breccia cemented by opal and aragonite. In this study, we present the data of Au and Te mineral distribution in different mineral types within the Semyenov-2 hydrothermal field aiming to reveal factors controlling the distribution of Au and Te minerals in high- and low- temperature sulphides.

The Semyenov-2 hydrothermal field located at 13°31′N of the Mid-Atlantic Ridge (MAR) is associated with an oceanic core complex (OCC) and hosted by peridotites and basalts with minor amounts of gabbro and plagiogranites. Seafloor massive sulphides (SMS) are represented by chimneys with zonality, massive sulphides without zonality and sulphide breccia cemented by opal and aragonite. The mean value of Au (20.6 ppm) and Te (40 ppm) is much higher than average for the MAR SMS deposits (3.2 ppm and 8.0 ppm, respectively). Generally, these high concentrations reflect the presence of a wide diversity of Au and Te minerals associated with major mineral paragenesis: primary native gold, melonite (NiTe2) and tellurobismuthite (Bi2Te3) are related to high-temperature chalcopyrite (~350 ℃); electrum (AuAg)1, hessite (Ag2Te) and altaite (PbTe) are related to medium- and low-temperature Zn-sulphide and opal assemblages (260–230 ℃). Calaverite (AuTe2) and Te-rich "fahlore" Cu12(Sb,As,Te)4S13 are texturally related to the chalcopyrite-bornite-covellite. Enrichment of Au in sulphide breccia with opal and aragonite cement is driven by the re-deposition and the process of hydrothermal reworking of sulphide. The low-temperature fluid mobilizes gold from primary sulphide, along with Au and Te minerals. As a result, the secondary gold re-precipitate in cement of sulphide breccia. An additional contribution of Au enrichment is the presence of aragonite in the Cu-Zn breccia where the maximal Au content (188 ppm) is reached (fig.1).

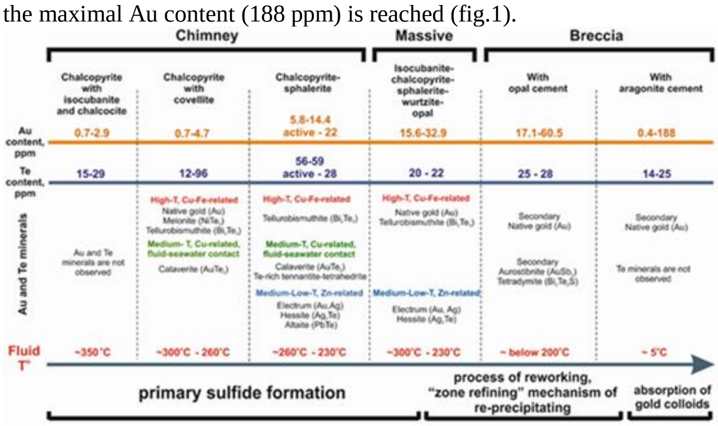

Figure 1. The distribution of Au and Te minerals in chimneys, massive sulphide and breccia from Semyenov-2 hydrothermal field (Firstova et al., 2019)

Keywords

seafloor massive sulphides; Mid-Atlantic Ridge; hydrothermal processes; gold; tellurides; minerals

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Difference in hydrothermal activity between slow and fast spreading centers

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Abstract

Hydrothermal flow extracts large amounts of heat from mid-ocean ridges and influences the mantle melting during new oceanic crust formation. Based on gravity inversion and thermodynamic numerical modeling, we study melt volume along global active mid-ocean ridges within 1 Ma isochrons. Overall, both observed and simulated melt volume increase linearly with increasing spreading rate, but a discrepancy between them is found at fast spreading centers (half spreading rate 50 < Rr < 95mm/yr) indicating a lower observed melting rate than model prediction. This is consistent with decreasing temperatures inferring from increasing Curie point depth (a geothermal proxy) and water depth from slow (10 < Rr < 50mm/yr) to fast spreading centers. Furthermore, MgO contents of global MORB suggest a roughly 20 ℃ temperature decrease in fast spreading melt lens. The discrepancy at fast spreading centers disappears when the modeling temperature is reduced by 20 ℃. Faults in brittle field could extend close to the shallower and wider axial magma chambers beneath fast spreading centers, inducing large amounts of micro-cracks in the deep and ductile gabbros. This fracture network would facilitate efficient whole crust hydrothermal circulations, which cool fast spreading melt lens by 20 ℃ and slow down the melting rate. In contrast, most hydrothermal circulations are constrained in the upper crust at slow spreading centers due to their small, deep and divergent magma chambers. The colder temperature at fast spreading centers supports the multiple sills crustal accretion model.

Keywords:
Spreading centers; Hydrothermal circulation; Fracture network; Melt volume.

Multi-stage detachment faulting controls hydrothermal activity in the Dragon Horn area (49.7 °E, SWIR): Insight from magnetic studies

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Abstract

The existing and evolution of detachment fault plays an important role in hydrothermal circulation at ultramafic mid-ocean ridges (MORs) where lack of enough magmatic supply. Near-bottom magnetic exploration considered as a crucial way for characterizing hydrothermal areas and detachment faults. Here, sea-surface and high-resolution near-bottom magnetic data and series rock samples were obtained on hydrothermal area in Dragon Horn, where developed detachment fault (DF) system, along ultra-slow southwest Indian ridge. Sea-surface magnetic results suggested that the DF1 system probably detached about 4.1 km to south and that took at least 0.34 Ma. Near-bottom magnetic results mapped the structure of DF1 system, revealed that the system undergone multi-stage detachment and left a slipped block on oceanic complex core (OCC) surface, which also can get support from the petrological properties of located rock samples and can be verified by magnetic forward modeling with 2-D geomagnetic models. Furthermore, we mapped the magnetic features of hydrothermal area where an obvious high magnetization dike presented in the main mound, and relatively low but without detailed low magnetization obtained in the hydrothermal area as survey line spacing is too wide and the weak anomaly drowned out by lavas. Nonetheless, we discussed the evolutionary relationship between DF system and hydrothermal activity and believed that DF2, DF1' and DF1 successively developed and dominated the activity of each vent field during 1.54~0.56 Ma BP, 0.56~0.38 Ma BP and 0.38~0 Ma BP, respectively. The research is a good example of how based on magnetic data to map structure of DF system, calculate its corresponding developed time and study its relationship with hydrothermal vent activity on ultramafic MOR.

Keywords

Detachment fault, magnetic survey, hydrothermal activity, Dragon Horn

Numerical simulation of hydrothermal plumes in stratified crossflows

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Abstract
A three-dimensional time-dependent computational fluid dynamic (CFD) model was developed to numerically solve the Reynolds-averaged Navier-Stokes equations and the energy equation. This model was used to simulate the interaction between a turbulent hydrothermal plume and surrounding fluids in a typical ocean environment with stably stratified crossflows, thus investigating the hydrodynamic mechanisms controlling the formation and distribution of submarine polymetallic sulfide deposits. The model results suggested that the turbulent viscosity reaches its maximum in the plume cap region, indicating that a significant turbulent mixing process could also be observed far from the vent. This fact implies that hydrothermal plumes may also play an important role in particle transport and biochemical reactions hundreds of meters above the seafloor. The results of the present simulation could be helpful for understanding the formation and distribution of seafloor deposits by implying the representative trajectories of the particles released from hydrothermal plume systems, and they could provide specific references for the evaluation of the metallogenic potential of polymetallic sulfides around mid-ocean ridges.

Keywords:
Hydrothermal plume dynamics; Stratified geophysical flows; Computational fluid dynamics

Poster Presentations Session

Uranium in seafloor massive sulfides at the Mid-Atlantic Ridge (MAR)

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Abstract
The recent study demonstrates the enrichments in uranium of SMS from some hydrothermal fields of the Mid-Atlantic Ridge (MAR) (Torokhov et al., 2002; Fouquet et al., 2010; Ayupova et al., 2018). However, the data of U content in SMS at the MAR is still limited. Here, we present preliminary data of U content in SMS deposits related to ultramafic and mafic rocks and to different geochemical types of massive sulfides.

100 samples of seafloor massive sulfides were recovered during several cruises of RV Professor Logatchev (Polar Marine Geological Exploration Expedition) from Logatchev, Ashadze, Semyenov, Pobeda, Irinovskoe ultramafic-hosted and Krasnov, Peterburgskoe, Jubileynoe, Zenith-Victoria and Puis des Folles mafic-hosted sites. The mean content of U is 3.53 ppm (N=76, excluding Pobeda samples). Average concentration of U in SMS related to mafic rocks (N=42) is 4.04 ppm and to ultramafic-hosted (N=34) deposits is 3.00 ppm. SMS are represented by different geochemical types: Fe-rich (N=17), Cu-rich (N=27), Cu-Zn-rich (N=21). Uranium concentration in Fe-rich samples is 3.48 ppm, Cu-rich - 4.09 ppm, and Cu-Zn-rich - 2.06 ppm. Based on the obtained mean values, uranium shows close values in SMS associated with different types of hosted rocks. Any correlation with geochemical specialization of SMS is absent as well.

The samples from Pobeda site are presented separately due to the highest uranium concentrations in SMS from this deposit. The value of U varies from 0.2 ppm up to 130 ppm with average 24.86 ppm (N=22). Any connection with geochemical types is not observed. The specific feature of SMS samples from Pobeda is the correlation between U content and age. The age is estimated > 177 ka (Gablina et al., 2018) which is rather older than SMS from other hydrothermal fields within the MAR (Cherkashov, 2017). Thus, Pobeda site is represented as example of long-lived hydrothermal system with several active and unactive periods. The highest U value (up to 130 ppm) is corresponding to the samples with relatively young age from 14.6 to 4.8 ka while low concentration is mainly observed in samples with age more 50 ka (up to 177 ka) (Fig. 1). We suppose that correlation between U grades and age are related to redistribution and re-deposition of U during active periods of Pobeda mature hydrothermal system evolution.

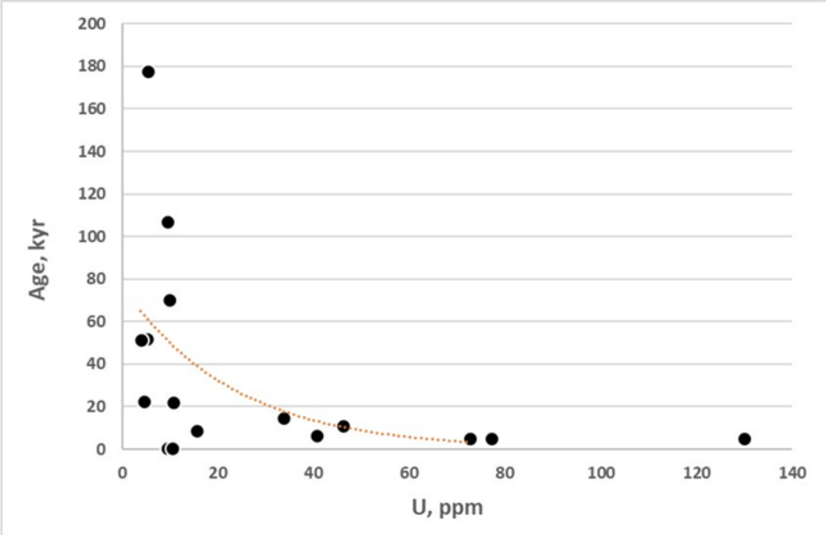

Figure 1. Age vs U content in SMS of Pobeda.

The factors affected to U enrichment are a still big challenge and need more investigations.

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Keywords
Mid-Atlantic Ridge, seafloor massive sulfides, SMS, uranium

The Daxi Vent Field on the Slow-Spreading Carlsberg Ridge: An Active Hydrothermal System at a Non-transform Offset

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Abstract
Along slow- and ultraslow-spreading ridges, the non-transform offsets (NTOs) at the segment ends normally present relatively low magmatic supply compared to that of ridge-segment centers (German and Parson, 1998; Gràcia et al., 2000). Thus far, seven NTO-related active hydrothermal sites have been confirmed worldwide (InterRidge Vents Database), including Rainbow, Saldanha, and Menez Hom. Most of these, however, are considered to be controlled by low-angle detachment faulting and ultramafic rocks. Here we present the newly discovered basalt-hosted Daxi Vent Field (DVF) located at a non-transform offset between two adjacent second-order ridge segments on the Carlsberg Ridge in the Indian Ocean. Water column and seafloor research using standard CTD as well as deep-tow and manned submersible Jiaolong deployments led to the discovery and sampling of the DVF at 6°48′N/60°10′E at a depth of ~3480 m. This vent field is situated atop one massif consisting of a 500-m high saddle dome that is slightly elongated in the NW-SE direction. The DVF consists of an ~80-m diameter ring of eight black smoker clusters, producing a complex of sulfide chimneys and beehive diffusers. The largest chimney is the so-called "Buddha Hand," which is ~24 m tall and vigorously venting. A total of seven species of megafauna were observed and/or collected from Daxi, including the alvinellid worm, which was collected in the Indian Ocean for the first time. Rimicaris kairei and actinostolid anemones were found to dominate the megafauna community in the core areas and periphery of the vent field, respectively. To the west and northeast of the active mound, older and extinct sulfide chimney complexes, as well as tan-colored and semi-lithified Fe-oxyhydroxide deposits, are widespread on the summits of these inactive sites. A high-angle (~70°) fault scarp with pillow lava sequence exposure separates the central active mound from the extinct mound in the northeast section. Our new data led us to hypothesize that sustained hydrothermal venting and deposition could also occur under volcanic control at the NTOs at the segment ends of slow-spreading ridges.

Keywords
non-transform offset; hydrothermal vent; biota; basalt; Carlsberg Ridge

Hydrothermal Fe-Mn deposits from low-temperature systems of the Mid-Atlantic Ridge

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Abstract

The mineralogical and geochemical features of hydrothermal oxyhydroxides collected in two sites from the Mid-Atlantic Ridge (MAR) are presented. **Saldanha field** (36°34'N, 32°26'W, ~ 2200 m; Dias and Barriga, 2006) is located at the top of a mount in a non-transform offset (NTO5) along MAR, south of the Azores, and it was discovered in 1998 during the Saldanha cruise. Here, transparent low-temperature (~9 ℃) fluids discharge through centimeter-sized holes without formation of chimney structures. However, geochemical data has demonstrated that sulfide deposits have been precipitated from fluids with temperatures higher than 200 ℃ within the subsurface (Dias, Früh-Green, Bernasconi, & Barriga, 2011). **Luso hydrothermal field (**38°58'N, 29°52'W, ~570 m; Morato et al, *in prep*) was recently discovered on the eastern slope of the Gigante seamount during the BlueAzores2018 cruise. Activity occurs at lower depths and is more focused, forming oxyhydroxide chimneys sometimes with orifices as wide as half a meter. The oxyhydroxides of Saldanha are Mn-rich phases occurring mainly in the form of crusts (sometimes containing millimetric micro-chimneys) at the top of the hydrothermal field. Microscopic and XRD observations of these crusts show alternate thin layers of acicular Mn oxides with massive cryptocrystalline Mn oxides corresponding to birnesite/todorokite and vernadite phases. SEM-EDS analyses revealed that these Mn-oxides are depleted in Fe and occur mostly as botryoidal textures, showing internal zonation. Microprobe and EDS data of this Mn phase also revealed high Mg contents. Occasionally, in the center layer of the sample, more reflecting minerals were identified revealing large spikes in Ag. Mn oxides textures collectively suggest that these minerals grow in open spaces within the sediment cover. Ca carbonate phases containing some microorganism tests were also identified (EDS signals of C and Ca) together with the Mn phases. Contrasting with the previous field, oxyhydroxides of Luso are Fe-rich phases, with a very low content of Mn in the form of chimneys walls. Chimneys display a clear zonation of their walls: the inner wall is white and formed by amorphous Si (opal-A with Si spikes in the EDS) and the outer wall, of an ochre color, is clearly enriched in Fe-oxyhydroxides. SEM-EDS analyses showed a dominance of needle textures in the outer wall alternating with more massive zones in the inner wall. The contact between the walls is abrupt and easily discernable by differences in texture and color. The inner wall, in direct contact with the emanating hydrothermal fluids, is clearly enriched in Si with minor Fe signals; the intermediate wall, although containing Si, is enriched in Fe with some trace contents in S and Ni; the outer wall has a high concentration in Fe and in elements that were driven from processes of oxidation resulting from the direct contact with the seawater. Discriminative diagrams show that, although Saldanha is clearly rich in Mn and Luso in Fe, both have hydrothermal origins. The differences observed in the oxyhydroxides composition of these two fields might be related to the physico-chemical changes occurring during the pathway of the fluids. In Saldanha, the mixture of the hydrothermal fluid with the seawater occurs at greater depths, promoting the precipitation of Fe, in combination with other metals as sulfides (such as Cu, Zn; see also Qiu *et al*, this meeting). Mn, in turn, remains in solution until more oxidizing conditions induce its precipitation. The fluids that reach the surface are thus enriched in Mn and depleted in Fe. In addition, the extensive contact with the seawater promotes the occurrence of scavenging processes, adding additional Mn to the oxyhydroxides. Contrarily, fluids from Luso occur in a more focused way, greatly diminishing the ability to mix with seawater. This allows the transport of higher concentrations of Fe until the fluids reach the seafloor. In the chimney orifice, the fluid meets the seawater and Si and Fe precipitates directly in the chimneys in the form of amorphous phases of silica and oxyhydroxides, respectively, due to cooling and oxidizing conditions by the mixing with seawater.

Keywords: Hydrothermal vent fields, oxyhydroxides, Fe-Mn deposits, submarine resources.
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The exploration of the Mid-Atlantic Ridge - characteristics of the Polish reserved exploration area.

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Introduction

Polish exploration research area is located in the Mid-Atlantic Ridge (MAR), encompassed by the Hayes, Atlantis, and Kane transforms fracture zones (26°09'-32°50' N) that split research area into two segments. The total length of the area is 876 km, and it is a part of the international seabed area beyond the limits of national jurisdiction of any State and claimed continental shelf. From the north, it borders with the Portuguese extended continental shelf and from the south with IFRAMER (France) exploration area.
The Mid-Atlantic Ridge is one of the most promising areas of the possible occurrence of seafloor massive sulfides (SMS), but the key challenge is to depict the location of the most significant deposits of a mining value, considering the technical and legal frame. In turn, this requires understanding the conditions of their formation. Based on the available data set, a map of the Polish exploration area highlights the most prospective areas of the possible occurrence of massive sulfides (Fig. 1). **Keywords:** Hydrothermal vent fields, oxyhydroxides, Fe-Mn deposits, submarine resources.

Morphostructural analysis of Polish prospective and exploration area

Segments of MAR (separated by the major transform faults) are also subdivided into smaller features by a non-transform offset which can be assigned to different structural type: geodynamic and magmatic with the domination of volcanic processes or tectonic where magmatism is reduced (German et al., 2016). It is assumed, that half of the SMS deposits in the Polish exploration area are associated with basalts (magmatic segments) and the second half (tectonic segments) - with uplifted lower crust and mantle rocks (oceanic core complex – OCC).

The magmatic segments are mainly characterized by generally higher bathymetric level, at the average (about 1000 m) relative depth of the rift valley and lack of major longitudinal tectonic steps, as well as significant intersegment dislocation intersecting and lack of uplifted local plutonic gabbro-peridotite rocks. Magmatic activity is low, and seafloor spreading might be accommodated by tectonic extension along faults [Escartin et al., 2008; Humphris et al., 2015]. The tectonic segments are characterized by relatively small length or expressed intersegment fragmentation, mosaic, and contrast of the flank structure and extensive development of the major differently oriented tectonic dislocations. As a consequence, the occurrence of the outcrops of plutonic rocks on one or both flanks of the rift valley of MAR [Cannat et al., 1995; Escartin and Cannat, 1999; Ciazela et al., 2015]. Based on available data, the SMS deposits associated with asymmetrical mode of accretion and gabbro-peridotite rocks (tectonic segments) are considered as promising for the large high grades SMS deposits.

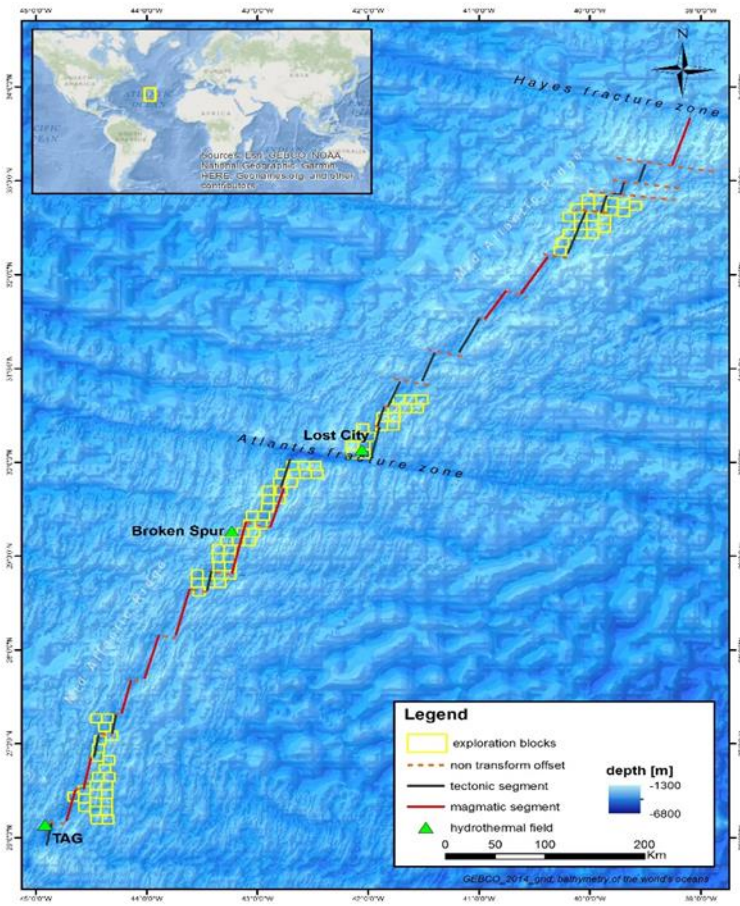

Figure 1. Map showing the detailed location of the polish exploration area with distinguished tectonic and magmatic segments and hydrothermal fields.

Nature value

Several biophysical processes are also imposed on the hydrological processes described above, causing different segments of the mid-ocean ridge (separated by faults) to form separate biogeographic units with ambiguously defined boundaries. Exploration polygons concentrated in five separate clusters (A-E) should be considered as diverse and different from each other, both geologically and biologically, despite their location within one geological feature (MAR). This will be taken into account when planning and preparing for the first research cruise for the Polish prospection and exploration area in the MAR. The most significant attention of the international community is concentrated in the area of the Atlantis Massif (29°56' N), partly located in the Polish reserved zone (cluster C). Within this area, at a depth of 750 - 900 m is located the famous field of alkaline (non-metallic) hydrothermal vents with a height of up to 60 m called "Lost City." These white chimneys are characterized by significant activity and the low temperature of ejected hydrothermal fluids. They constitute a record of at least 30,000 years of changes in their functioning (Blackmann et al., 2002; Früh-Green et al., 2003; Kelly et al., 2005). Marine fauna living on their surface characterize valuable forms of adaptation to these extreme conditions (e.g., chemosynthesis) (Van Dover, 2000; 2011). Atlantis Massif is the subject of intense and comprehensive international research conducted since 2000. Based on results obtained, with the consistent efforts of the international scientific community, efforts are made to cover this area with environment protection.

Next steps

The basic (environmental) research, planned as part of the cruise for the prospection and exploration area, aiming at the observation of the ocean floor as well as physicochemical measurements of the water column and the collection of oceanographic, biological data and geological samples. An important aspect is the observation and estimation of the size (occurrence and bulk) of polymetallic sulfide deposits. The research will comprise also active hydrothermal vents, which are rare and extreme habitats with exceptionally individual parameters. They are often places for the development of unique adaptations of living organisms and the concentration of mineral deposits. Planned research should provide helpful hints in response to several crucial questions related to hydrothermal areas. However, the main research potential will be direct to expired hydrothermal areas as well as inactive hydrothermal vents, which are also a potential source of polymetallic resources.

Keywords:
Mid-Atlantic Ridge, morphostructural analysis, hydrothermal fields, massive sulfides.

Stepwise hydrothermal dissolution of titanomagnetite dramatically reduces magnetization in basaltic ocean crust: direct evidence from the Southwest Indian Ridge

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Abstract

Mineralogical alteration is considered as a major cause for the hydrothermal-related magnetic lows on basalt-based ocean crust. However, little direct evidence is documented how hydrothermal alteration affects the magnetic properties of submarine basalts. In this study, we collected both fresh and hydrothermal-altered basaltic samples from the Southwest Indian Ridge (SWIR). Optical microscope observations reveal that with enhanced hydrothermal activity, fresh basalts were first chloritized, and then brecciated with hydrothermal deposits cementing the fragments. Electron microscope analyses indicate that ultrafine-grained titanomagnetite particle clusters are the major magnetic remanence carriers in fresh basalts, in addition to micron-scale dendritic and skeleton titanomagnetites. During chloritization, those interacting single-domain (SD) magnetic mineral inclusions were firstly consumed, followed by dissolution of large dendritic and skeleton particles. As a consequence, the magnetic properties of partially chloritized basalts are dominated by pseudo single-domain (PSD) and multi-domain (MD) particles, and completely chloritized or brecciated basalts show paramagnetic behavior, resulting in pronounced decreases in natural remanent magnetization (NRM). Our results establish an important link between seafloor hydrothermal alteration and the simultaneous response of magnetic properties. The documented pathway here is consistent with geological, geophysical and geochemical evidences from different hydrothermal sites, which is potentially responsible for the observed widespread hydrothermal-related magnetic lows on basaltic ocean crust.

Keywords
Seafloor hydrothermal alteration, southwest Indian Ridge, rock magnetic properties, petrographic analysis, basalt

Seismic observations of an active detachment faulting system beneath the Longqi hydrothermal field at the ultraslow spreading Southwest Indian Ridge

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Abstract

Hydrothermal processes in detachment settings at slow and ultraslow spreading ridges differ greatly from those at melt-rich faster spreading ridges. Active detachment faulting provides the possibility for off-axis high-temperature hydrothermal vents located far away from the heat source beneath the axial volcanic ridge. Seismic data from the Mid-Atlantic ridge revealed that the hydrothermal fluid may exploit detachment faults to extract heat from a melt zone near the crust-mantle interface. However, the knowledge of detachment fault process beneath hydrothermal fields at the slowest spreading ridges is still insufficient. Here, we report new insights on the seismicity beneath the Longqi hydrothermal field at the ultraslow spreading Southwest Indian ridge from three ocean bottom seismometer monitoring experiments. The seismicity outlines the subsurface geometry of a twin detachment faulting system (DF1 and DF2). The strongly flexed DF1 is a mature detachment system with a domed-shaped OCC where ultramafic rocks exposed on the seafloor. We suggest that heat is extracted from a possible heat source at a minimum depth of 13 km beneath the axial volcanic ridge and transported through the twin detachment faults to be released at the vents. Additionally, the non-transform discontinuity on the western margin of the Longqi-1 field and local faults also facilitate hydrothermal circulation. A great diversity of hydrothermal systems in Longqi field are hosted by the distance away from the ridge axis and non-transform discontinuity respectively. Our study provides baseline observations for a Longqi-type of hydrothermal circulation characterized by an inside corner setting associated with detachment faulting and non-transform offsets.

Keywords

microearthquake, OBS, detachment fault, hydrothermal circulation

Diversity of metal sources for sulfides in hydrothermal fields in the Southwest Indian Ridge

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Abstract

The Southwest Indian Ridge (SWIR) is an ultraslow-spreading ridge where large hydrothermal fields (HFs) are widely distributed. The HFs differ in geological settings, basement rock compositions and mineral associations, but are commonly associated with massive sulfides and sulfide-rich hydrothermal vents that are rich in mercury (Hg) and Cadmium (Cd). However, the source of Hg and Cd remains not well understood. We measured Hg and Cd isotope compositions in sulfides from two large HFs, named Duanqiao and Yuhuang, in the SWIR. The results show that Hg and Cd isotope fractionation in Yuhuang is much larger than those in Duanqiao, suggesting the dominance of magmatic/mantle Hg and Cd in the Duanqiao HF, but a mixture of magmatic/mantle and seawater Hg and Cd to the Yuhuang HF. We thus propose Hg and Cd isotopes as potential source tracers of Hg and Cd in HFs and infer that magmatism may not only serve as a direct Hg and Cd source in HFs, but may also drive seawater circulation and cause the precipitation of Hg and Cd from hydrothermally circulated seawater.
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Hydrothermal fields in the southern Okinawa Trough off northeastern Taiwan

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Abstract

The southern Okinawa Trough (SOT) is a back-arc basin of the Ryukyu subduction system. It is characterized by well-developed active normal faulting and volcanism, favorable geological conditions for the formation of Seafloor Massive Sulfide (SMS) deposits. In order to investigate and evaluate the mineral resources potential in the SOT, Central Geological Survey (CGS), Ministry of Economic Affairs, Taiwan (R.O.C.) has initiated a 4-years program since 2016. In that program, intensive geophysical, geochemical and seafloor image investigations have been conducted in the SOT. We have identified six hydrothermal fields in the investigation area including Yonaguni Knoll IV-1 (YK4-1), Penglai Fault Zone (PFZ), Geolin Mounds (GLM), Mienhwa Volcano (MHV), Fire Dragon Volcano 1 (FDV-1) and Fire Dragon Volcano 2 (FDV-2). These hydrothermal fields were discovered mostly by the CGS program except that YK4-1 has been reported previously by Japan (Nunoura, 2004; Inagaki et al., 2006; Hongo et al., 2007; Suzuki et al., 2008; Gena et al., 2013; Ishibashi et al., 2015).

Based on geophysical data, volcanic activities, normal fault zones, and gas plumes are commonly observed in the central rift zone. Widely distributed mineral mounds are mapped by the deep-towed sidescan sonar images in the PFZ and GLM sites, and mineral mounds are confirmed by seafloor images taken by deep-towed video systems of ATIS and FITS. As shown on the real-time seafloor images, vapor-rich vent fluids and chimney-mound structures are widely distributed on the seafloor in the active hydrothermal fields. Water column and cored sediment samples collected at the hydrothermal sites show notably geochemical anomalies resulted from the intense hydrothermal activities. Relatively high concentrations of CH4, CO2, DIC and 3He/4He ratios have been found in the near bottom seawater samples at the FDV-1, PFZ and GLM sites. In addition, the cored sediments show relatively high concentrations of Ag, Cu, As, Sb, Bi, Cd, Pb and Zn. Mineralogical analyses of the chimney-mound fragments indicate that the GLM site mineralization is characterized by low sulfidation deposits of pyrrhotite, isocubanite, galena, bismuth, and other minerals, whereas the ore specimens collected from the MHV site contain mainly sphalerite, galena, and chalcopyrite, implying intermediate sulfidation mineralization. Recently, several hydrothermal mounds and black smokers were recorded and sampled by remotely operated vehicle (ROV) in the MHV site onboard R/V LEGEND in 2019. The black smoker fragments taken in the MHV site contain mainly pyrrhotite, sphalerite, stibnite, barite and galena. The results signify the potential existence of rich metals resources in the hydrothermal fields in SOT off northeastern Taiwan.

Keywords

Hydrothermal Field; Seafloor Massive Sulfide Deposits; Mienhwa Volcano; Geolin Mounds; Southern Okinawa Trough; Off northeastern Taiwan

Can Magnetites Provide New Information about the Physical and Chemical Conditions inside Hydrothermal Vents?

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Abstract

Understanding the physical and chemical condition inside subsurface hydrothermal vents is a big challenge even for modern-day scientific investigations which include ocean drilling efforts. Here I present an unusual discovery of rock samples with high magnetic remanence inside the hydrothermal vents of Manus Basin, Papua New Guinea during Ocean Drilling Program Leg 193. The samples were discovered approximately 170-200 m and around 400 m below sea level. Post-cruise on-land experiments suggests that the magnetization intensity of these samples can reach more than 50 times higher than an average seafloor basalt (~ 5 A/m). The cause of these highly magnetized samples is a mystery. To address the issue, we conducted electronic microscope observation and found that the rock samples are comprised of many micrometer-scale magnetites. It is thought that these small magnetites individually represent single or pseudo-single domain magnetites but together form unusually strong magnetization. The fact that these patches of strong magnetic rocks are found at 200 and 400 m below sea level suggest that these depths represent a sharp boundary between low (at the bottom) and high (at the top) oxygen fugacity zones. It is thought that Fe-rich fluid migrating from below towards the seafloor upon encountering this oxygen-rich zone very quickly precipitated the small grain magnetites. Such zones would have been erased by hydrothermal alteration but for some reason our samples remained unscathed. We also explore various ways that regions of high magnetization intensities can form on the seafloor or below the seafloor near hydrothermal fields. Further studies are going to be made by comparing the grain size and shapes of magnetites formed in different geological setting such as those similar to banded iron formation and ancient massive hydrothermal deposits such as in Iberian Pyrite Belt. It is hoped that by looking at the occurrence and the characteristics of hydrothermal magnetites, one may provide new insights into the physical and chemical conditions of subsurface hydrothermal system as well as the fate of those microbes that depend on electric potential differences.

Highly siderophile elements and Osmium isotopes in abyssal peridotites from the Southwest Indian Ridge: Implications for evolution of the oceanic upper mantle

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Abstract

Abyssal peridotites are extensively exposed on the seafloor of amagmatic segments at the ultraslow spreading Southwest Indian Ridge (SWIR). We presents abundances of highly siderophile elements (HSEs; Os, Ir, Ru, Pt, Pd and Re) and Re-Os isotope compositions, major and trace element concentrations of nine spinel-facies peridotites from the Dragon Bone amagmatic segment (~53 ℃) and from the easternmost part (~63.5 ℃ and 69.5 ℃) of SWIR. Although these peridotites experienced intense serpentinization and seafloor weathering, their Os isotopes and platinum-group elements are not significantly affected by the low-temperature alterations. The 63.5 ℃ peridotites display sub-chondritic Os/Ir and chondritic Pt/Ir ratios, and slightly variable Re/Ir and Pd/Ir ratios. The observed positive covariance between 187Re/188Os ratios and γOs, Re and Pd abundances can be explained most likely by interaction of mantle residues with radiogenic basaltic melts, which is consistent with the petrographic observations indicative of melt infiltration. The 53 ℃ peridotites, on the other hand, display larger variations in Os isotopes and relative HSE abundances, indicating a more complex evolutionary history. The enhancement of Re abundance and radiogenic Os in some 53 ℃ samples can be attributed to the influence of melt-rock reaction, most probably with S-undersaturated hydrous melts. Specifically, sample 21V-S9-D5-2 shows superchondritic 187Os/188Os isotope ratio, as well as enrichment of Cu and Pt abundances, indicative of interaction with an oxidizing agency. Although the Re-Os isotopes of SWIR peridotites are superimposed by variable metasomatic processes, they preserve the ancient Os isotope signature (~1 Ga) and record the melting episode at ~0.7 Ga during the closure of the Mozambique Ocean. We infer that the ancient depleted and hence buoyant mantle exists beneath the SWIR, which may support the weakly magmatic rifted Marion Rise.

A Quantitative Method for Active Fault Migration Distance Assessment on Both Sides of The Southwest Indian Ridge 46°-52.5°-Based on Multi-Beam Data

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Abstract

Fracture-fissure system, as the main circulation channels of the hydrothermal fluids of mid-ocean ridges, it is the crucial factor controlling the mineralization of hydrothermal sulfides deposits. Analysing and narrowing the migration Distance of active faults on both sides of mid-ocean ridges will help search for the potential hydrothermal vents and explore hydrothermal sulfides deposits. We use multi-beam bathymetry data and extracted geographic information such as slope, roughness, and curvature from filtered bathymetry to identify the fault characteristics and quantitatively measure the fault elements such as fault spacing (ΔS) and fault heave (ΔX) in Southwest Indian Ridge(SWIR) 46 °N–52.5 °E.Considering the Sequential Faulting Model of mid-ocean ridges, we quantitatively assess the maximal migration distance of an active fault, which is the distribution range of active faults（XAF）,on either side of Southwest Indian Ridge(SWIR) 46 °N–52.5 °E. The result indicates the maximal migration distance of an active fault in our study area ranges for 1.23–2.46 km. The distribution range of fault spacing ΔS is from 2.79km to 4.42km. The maximal migration distance of an active fault and fault spacing varies greatly along axis, and there are larger values in the center area (extremely high values in 50.25 °E and 48.52 °E areas) than both end areas. We conclude the faulting ranges in SWIR 46 °N–52.5 °E are positively related to the axial variation of magmatism. The comparison parameters of the along axis variation indicates that when there is a sufficient magma supply, a higher degree of magma melting corresponds to a greater M value and a larger faulting range and fault spacing..

Keywords
Multi-beam bathymetry, Mid-Ocean Ridges, Migration Distance of Active Faults

Crustal thickness Anomalies Across the Carlsberg Ridge in the Northwest Indian Ocean basin from gravity analysis

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Abstract

The oceanic crust thickness of mid-ocean ridges and adjacent ocean basins can well reflect the characteristics of magmatic replenishment of mid-ocean ridges, which is of great significance for the study of magmatic activities and tectonic evolution in the mid-ocean ridges and their surroundings. As a typical slowly spreading mid-ocean ridge, the Carlsberg Ridge in the northwest Indian Ocean is the frontier area of international hydrothermal sulfide investigation. In this paper, crustal thickness model derived from gravity is used to invert the crustal thickness of Carlsberg Ridge in the northwestern Indian Ocean, and the crustal thickness distribution and magma replenishment characteristics around the Carlsberg Ridge are analyzed quantitatively. It is found that the average thickness of the oceanic crust around the Carlsberg Ridge is 9 km, with no obvious changes in thickness, with the minimum thickness of 5.3 km and the maximum thickness of 13.7 km. The frequency distribution of the thickness of the oceanic crust around the Carlsberg Ridge has obvious normal distribution characteristics, and the oceanic crust in the northwest Indian Ocean can be divided into three types: thin oceanic crust (0~8.7 km), normal oceanic crust (8.7~9.5 km), and thick oceanic crust (9.5~13.7 km).The thickness of the oceanic crust in Northwest Indian Ocean is controlled by regional tectonic background and mantle differential melting. The thin oceanic crust is mainly affected by fault zones, while the thick oceanic crust is mainly affected by plate tectonics.

Keywords
Residual mantle Bouguer gravity anomaly; Oceanic crust thickness; Magmatic replenishment; North-west Indian Ocean; Carlsberg Ridge

Geological mapping at Southwest Indian Ridge Qiaoyue Seamount(~52°10′E): Implication for prediction of hydrothermal field

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Abstract

The Chinese Dayang cruise has conducted Deep-towed line surveys of hydrothermal activity on segment #25 of the ultra-slow spreading southwest Indian ridge (SWIR; full spreading rate ~14 mm/yr) from 2009 to 2018. During the DY115-20 cruise in 2009, Junhui was discovered at central and southern segment #25. We focused on Qiaoyue Seamount (~52°10′E) situated at easternmost region of segment #25 near Gallieni transform faults. Previous studies has revealed the similar geological setting (i.e., inside corner zone) is conducive to the occurrence of hydrothermal activity .

In this study, We first used the high-resolution and high-density ship survey information, including multibeam bathymetry and Deep-towed video and photo data acquired during the cruise of the R/V *Dayang Yihao* (DY115-20 Leg 7) and the cruise of the R/V *Xiangyanghong 10* (DY125-49 Leg 4), coupled with sampling information in the study area. Then Regional geological mapping was carried out. In addition, turbidity anomalies were detected from Miniature Autonomous Plume Recorders (MAPRs). Two favorable hydrothermal fields (P4 and P8 zone) were predicted, which may have the different origin for hydrothermal activity. Ultramafic rock (predominantly peridotite, partially serpentinized) is primarily exposed in P4 zone, the serpentine petrothermal exotherm of peridotite provides sufficient heat for hydrothermal activity there; The P8 zone is characterized by extensive development of magmatism and faults, implying the hydrothermal activity there probably related to high permeability caused by abundant faults. And four (P1、P2、P3 and P5) zones are inferred hydrothermal field.

Keywords
Qiaoyue Seamount; Segment #25; Geological mapping; Hydrothermal activity

Synthetical anomaly characteristics of the 26th segment of the Southwest Indian Ocean Ridge and implications for submarine hydrothermal activity

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Abstract
The 26th segment of the ultra-slow spreading Southwest Indian Ridge (SWIR) is located between 50°50′-51°20′E, with non-transform discontinuous zone (NTD) in the west and Gallinie transform fault in the east. It is mainly oblique spreading, and the transition at both ends is symmetrical spreading, with strong regional tectonic activities and relatively weak magma supply. Chinese Dayang cruises have been carried out in this ridge segment to obtain geological data and water abnormality information, and to delineate the potential areas of hydrothermal activity in this region. According to the videos and photos, the composition of seafloor morphology are mainly basalts, breccias and sediments. Basalt and sediment distribute widely, and breccias distribute mainly in strips along tectonic fissures. Regional tectonism are well developed, mainly north-dipping normal faults with East-West direction.The faults have a larger scale and a longer extension. We delineate five anomalies of seafloor morphology in the study area, namely carbonate chimney, possible hydrothermal sediments, cemented carbonate, rock alteration and suspected hydrothermal related megabenthos. In addition, 12 turbidity anomalies, 8 Eh anomalies and 6 H2S anomalies were detected based on the sensors (e.g. Miniature Autonomous Plume Recorders (MAPRs), RBR Turbidity Profiler (RBR)) on the survey lines. According to the magmatism, tectonic and bottom current in the region, we predict five potential areas of hydrothermal activity in this ridge segment. It is considered that this ridge segment has the possibility of forming large scale hydrothermal vents and the potential of forming large polymetallic sulfide deposits.

Keywords
Abnormality of substrate , Abnormality of seawater , Delineation of hydrothermal activity

Exploring the role of microorganisms in sulfur deposition in hydrothermal environment via metagenomic data mining

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Abstract

Metal sulfide is widespread on the sea floor, and they take the form of massive sulfide chimneys near hydrothermal vents. Sulfur deposition at the chimney is a result of mixing between the reducing hot vent fluid and oxic cold sea water. These reductive compounds (such as H2, CH4 and reduced metals) in vent fluids provide chemical energy to support the microorganisms, which are known to facilitate mineral deposition. However, the mechanisms by which microorganisms cause deposition of hydrothermal minerals are less understood. Many sulfur-oxidizing bacteria produce an insoluble intermediate S(0) during oxidation of sulfur or thiosulfate, whereas sulfur-reducing bacteria produce sulfide that reacts with iron to form pyrite particles. As sulfur-cycling microorganisms exhibit different metabolic pathways, we hypothesize that different metabolic pathways would result in metabolic products at different concentrations, which would affect the type of minerals being formed.

It has been hypothesized that microbial biofilms are a medium to concentrate metabolic products, and thus promote mineral deposition. Chimney surfaces are covered with microbial biofilms, however, the correlation between biofilm formation at hydrothermal vents and the formation of sulfur minerals has been less studied. This study aims to analyze metagenomes from deep sea hydrothermal chimneys for the abundance of genes related to the formation of biofilm and that related to the sulfur cycle, and thus to deduce their correlation. If a positive correction exists, we could further investigate whether the deposited minerals are byproducts of energy metabolism or they serve as energy reserve.

Geochemistry of hydrothermal fluids from Carlsberg Ridge

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Abstract

Metal sulfide is widespread on the sea floor, and they take the form of massive sulfide chimneys near hydrothermal vents. Sulfur deposition at the chimney is a result of mixing between the reducing hot vent fluid and oxic cold sea water. These reductive compounds (such as H2, CH4 and reduced metals) in vent fluids provide chemical energy to support the microorganisms, which are known to facilitate mineral deposition. However, the mechanisms by which microorganisms cause deposition of hydrothermal minerals are less understood. Many sulfur-oxidizing bacteria produce an insoluble intermediate S(0) during oxidation of sulfur or thiosulfate, whereas sulfur-reducing bacteria produce sulfide that reacts with iron to form pyrite particles. As sulfur-cycling microorganisms exhibit different metabolic pathways, we hypothesize that different metabolic pathways would result in metabolic products at different concentrations, which would affect the type of minerals being formed.

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Keywords
Geochemistry, Hydrotherml fluids, Subsurface processes

Metal stable isotopes as tracers to constrain hydrothermal ore-forming processes

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Abstract

Multi-collector inductively coupled plasma mass spectrometry (MC-ICPMS) now provides for precise and accurate measurements of metal (e.g. Fe, Cu, Zn, Mg, Ba, V) stable isotope ratios. Some metal stable isotopes have been proving powerful tracers to investigate the hydrothermal ore formation processes. Copper isotope ratios in magmatic and hydrothermal ore-forming environments were analyzed to address the source of copper in hydrothermal system and investigate the equilibrium Cu isotope fractionation at different temperatures1. In situ iron isotope ratios from hydrothermal hematite, siderite and goethite provided the primary hydrothermal fluid histories and the spatial resolution that adds a further dimension to the interpretation of stable Fe isotope fractionation2. However, the other metals (e.g. Tl, Ba, V) have been routinely measured at a precision that is high enough to resolve nature variations. The metal elements have different bonding environment from those of H, C, O and S and many of these elements have high atomic numbers and more than two stable isotopes and are redox-sensitive, which make them unique tracers of hydrothermal ore-forming processes.

Keywords
Metal stable isotopes, hydrothermal process

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Substrate and anomalies interpretation in the region of 48.22°E~48.67°E of the ultraslow-spreading SWIR: Implications for magmatism and hydrothermal activity

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Abstract

The Southwest Indian Ocean Ridge (SWIR) is the largest ultraslow-spreading ridge in the world, and it experienced complex structure-magmatic process, which makes it an excellent place to study magmatic activities and the interaction between hotspot and mid-ocean ridge in the ultraslow-spreading ridge area. The ridge segment between 48.22°E-48.67°E is located in the area between Indomed TF and Gallieni TF. Based on the interpretation of the photographs and videos of 16 survey lines in this area, which were got by China ocean research, the substrate of this area can be divided into sediment, pillow basalts, breccia rocks and cementing carbonate rocks, and the geological anomalies can be divided into alteration anomaly, biological anomaly and cementing carbonate rocks According to the regional tectonics and topography, the substrate classification map and geological anomalies map of study area was drawn. In addition, according to the data detected by the sensor attached to the towing body or AUV, the scope of 8 turbidity anomalies and several chemical anomalies in study area were obtained. These achievements are of great significance to deepen the understanding of regional magmatic and tectonic activities and hydrothermal metallogenic rules.

Keywords
SWIR; Ultraslow-spreading; Substrate interpretation; Anomaly interpretation; Magmatic activity

Geological characteristics and delineation of hydrothermal anomalies around 55°20′E of Southwest Indian Ridge

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Abstract

The 55°20′E area of the Southwest Indian Ridge, located at the #21 segment, is at the intersection of symmetrical and oblique spreading where tectonic are well developed. Deep-towed line surveys of hydrothermal activity were conducted during the Chinese Dayang Cruises from 2009 to 2018, with high-resolution and high-density ship survey information, including multibeam bathymetry and Deep-towed video and photo data acquired. In this study, we interpret video and photo data to geological map this area for the first time, and divided the distribution of magmatic rocks, sediments and alterations in this area. In addition, turbidity anomalies (detected by Miniature Autonomous Plume Recorders (MAPRs), combined with the water depth and topography of this area, we predict six turbidity anomalies in this area. A large number of chlorite basalts are exposed in the two of these turbidity anomalies, where faults and small fissures are well developed, making it possible for hydrothermal activity. We predict two potential areas for next expedition of exploration, the P-1 and P-2. During the DY125-49 cruise in 2018, the Dechun hydrothermal area is found in the predicted P-2 prospecting zone, where is comparable to previously studied similar geological setting (i.e., inside corner zone) with conducive to the occurrence of hydrothermal activity. We also predict that there may be hydrothermal activity similar to Dechun in P-1 prospecting zone.

Keywords:

Southwest Indian Ridge; Geological mapping; Hydrothermal activity; prospecting zone;

Traceability Analysis of Seafloor Sediments Based on ArcGIS and Its Application in the Longqi Hydrothermal Field on the Southwest Indian Ridge

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Abstract

The application of traceability analysis methods in the seafloor hydrothermal field is of great significance for the hydrothermal deposition process and the exploration of sulfide resources. The sediments in the seafloor hydrothermal field are uniquely affected by plume sedimentation. The infiltrated seawater is heated by the heat source to dilute and enrich various metal elements, after ejecting the surface of the seabed, it continues to rise to form a hydrothermal plume. The diffusion of the hydrothermal plume affects the range of hydrothermal material settlement, in which a small amount of coarse particles settles near the nozzle, and more than 90% of the hydrothermal material diffuse and settles into the distant sediment. At the same time, the hydrothermal field sediments are subjected to secondary migration under the driving of gravity and submarine underflow. In this paper, a new attempt is made on the traceability analysis process for the sedimentary, model of the submarine hydrothermal activity field, so that we can try to understand the possible source areas of sediment at a certain point.

The Longqi hydrothermal field is developed on the high terrain of the southeast slope of the central rift in the southwestern Indian Ocean, and the surrounding terrain is complex. This paper takes the known Longqi hydrothermal field as an example, based on the 50m precision terrain raster data acquired by the shipborne multi-beam and comprehensively considering the regional underflow information, the gravity-driven hydrothermal sediment migration were analyzed. The GIS method was used to extract the steepest direction of the Longqi hydrothermal area, and the submarine valley was obtained as the sediment enrichment area. A mode of secondary migration and enrichment of sediments in the hydrothermal field to the steepest direction is proposed. Based on this, the source area range of the abnormal station of heavy mineral content was calculated.

The purpose of this study was to investigate the secondary migration process of sediments that have undergone sedimentation of hydrothermal plumes, and to further explore the application of traceability analysis methods in seafloor sulfide prospecting. A small-scale provenance analysis of the heavy mineral content anomaly station in the Longqi hydrothermal area, and the results shows that the location of the mining area can be well indicated.

Keywords:

ArcGIS, Sediment Traceability Analysis, Southwest Indian Ocean, Mid-Ocean Ridge

Cold seep activity research based on the geochemistry of nodules from northeast land slope.

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Abstract

Polymetallic nodules in the South China Sea generally have similar characteristics to normal nodules in the ocean. In 2018, the "Sea Dragon III" ROV found a patch of polymetallic nodule on a hill on the north-east slope of the South China Sea, with a depth of about 1,200 meters. The newly found nodules are very different from previous ones. The shape of polymetallic nodules are predominately column-shaped and branch-like. Under the microscope, the nodules usually have empty cores and two layers. The inner layer is mainly composed of hematite, goethite, etc. and contain a small amount of pyrite. The outer layer is similar to normal polymetallic nodules. The results of the EPMA and LA-ICPMS analysis are also consistent with these features. The outer layer is similar to the nodules in other parts of the South China Sea, while the inner layer is rich in Fe, but depleted in Mn, REE. The major elements contents of the inner layer are similar to the hydrothermal nodules, and the distribution patterns of REE are similar to those of cold spring pore water and carbonate sediments. The occurrences of sulphides in the inner layer indicate a much reduced environment, and hematite may be the oxidized product of the inner sulphide. As the carbon and oxygen isotopes of bulk rock ($\delta 13C$ -30.91‰, $\delta 18O$ 4.57‰) provide important evidences for the existence of cold springs in this area, we speculate that the inner layer of these nodules initially formed in the cold spring environment. Under the effect of isocurrent flow, they were exposed on the surface of the seafloor, then oxidized and further growing to form the nodules currently seen