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深圳市地质学会 编

中国地质大学出版社

YUEGANG SHENZHEN
DIZHI KEXUE YU GONGCHENG

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前　言

本书内容凸显了珠三角地区近期地质科学与地质工程的应用成果主题，其中涵盖了基础地质研究最新成果；对深港地区的火山岩、深圳地区第四纪地质的分布特征和成因，提出了一些新的看法；对深圳地区岩土工程的理论研究和实践经验进行了总结，所涉及的内容面广，诸如滨海饱水软粘土主固结理论的研究、大面积填海的工程地质问题和建筑地基的处理方法、香港地区的工程地质勘察经验推介、供水调蓄工程库坝承压水、库坝填筑土质量等的分析。在岩土体热传导机理分析的基础上，研究地铁系统的围岩传热机理；岩土工程勘察土工试验指标统计分析 Excel VBA 程序的应用；在岩溶地区应用 LC 桩复合地基技术的探讨；通过上海一栋 13 层在建楼房的倒塌事故，根据岩土工程的理论和计算，对事故调查专家组所分析的原因作一些解读和补充，以及系统介绍了瑞雷波法对旋喷桩质量检测的应用效果。地质环境与地质灾害防治的理论与实践方面，对暴雨型公路病害成因类型及发育机理进行了探讨，同时对西气东输二线工程（广东段）地质灾害危险性评估进行了研究。地震地质的调查评价，对世界级的大型工程项目之一的港珠澳大桥工程近场地震地质论述、详细分析了场区的断裂构造活动性，并讨论了场址地震地质灾害问题。另外，2005 年以来，开展了深圳市活断层探测与地震危险性评价；矿床地质研究方面，作者根据广东省三个构造岩浆岩带的分布特点，论述了广东省岩浆岩成矿特征及找矿方向。最后，以本省丰富的地质遗迹资源为例，概述广东地学旅游资源与可持续发展等内容。总之，这些宝贵的科技成果，为地方建设、区域发展、政府决策、地学科普、教育、研究等领域，提供了一个很好的平台。

本书的论文主要选自 2009 年 9 月在深圳市银湖旅游中心召开的“2009 粤港地区地质科学与地质工程（深圳）研讨会——地球科学与社会”学术交流会议。

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基础地质

香港中侏罗世古火山颈群的发现及其意义

黎权伟

(前香港地质调查组)

摘　要:香港中侏罗世屯门组主要由安山质熔岩、凝灰岩和凝灰角砾岩夹少量凝灰质砂岩组成。其中,凝灰角砾岩初期曾误作沉积砾岩,经调查后确认为是火山成因的凝灰角砾岩。按岩相分析,可分为火山通道相的安山-英安质熔岩、爆发角砾岩和空落相的凝灰角砾岩。火山通道相又可分为火山颈相和岩墙相,分布在屯门组东西两侧。在青山东麓,出露一列北北西向呈断续线状分布的火山颈群。由於岩性复杂,火山颈相的爆發角砾岩至今仍有人误认为是沉积成因的砾岩,从而在地质勘探和工程设计上造成混乱,引致不应有的经济和時间上的损失。因此有必要深入研究,还事实本來之面目。

关键词:屯门组　火山颈　安山-英安质熔岩　爆发角砾岩

Discovery of palaeovolcanic neck group of the Middle Jurassic age in Hong Kong and its significance

Li Quan-wei

(*Previous Hong Kong Geological Survey*)

Abstract: The correct geological data of an area provides the base for engineering design. For a long period, the rock type in the area stretching from Tuen Mun to Tin Shui Wai in Hong Kong was misinterpreted. The volcanic tuff breccia was misidentified as sedimentary conglomerate; the aphanitic andesite and fine ash tuff were misjudged as siltstone or sandstone. Based on this incorrect identification, a fluvial deposit model was assumed which was misleading to the geological investigation and foundation design. After detailed field observation, thin section identification, chemical composition study and comparison with those in other countries, a series of palaeovolcanic necks were discovered and confirmed. The Tuen Mun Formation has been shown to comprise andesitic lava and tuff with marble clasts bearing tuff breccia and subordinate tuffites.

Key words: Tuen Mun Formation; volcanic plug; andesitic-dacitic lava; explosive breccia

1 前 言

由于屯门组火山岩中的粗火山碎屑岩，岩性复杂，对其认识经历了一个反复的过程。由初期看法有错误至逐渐有所认识，再出现不同看法，又引发很大的争论。希望这次能通过深入调查，掌握事实和证据，达至对事物的正确认识。

1971 年 Allen P. M. 和 Stephens E. A. 把现今屯门组分布范围的地层分为两个组：由屯门至钟屋村为浅水湾组，岩性为沉积岩和水成火山碎屑岩；由良景村至网井围为落马洲组，主要为变质的沉积岩和火山岩。1982 年香港地质调查组重新在全港开展 1∶20 000 地质测量工作，把新发现有安山质火山岩的地层定为屯门组。但沿青山东麓断续分布火山角砾岩，因该区植被浓密和缺少钻孔资料，负责该区的 Arthurton R. S. 误认为是沉积砾岩，并将该区地层定为青山组(Arthurton 等，1988)(图 1)。

香港政府因新界西北区的地下大理岩存在溶洞而影响城市发展，1988 年与英国自然环境研究院协议，由香港地质调查组负责该区 1∶20 000 的地质测量工作，英国地质调查所 Frost D. V. 等负责该区 1∶5 000 的地质测量工作，共同查清该区地质特征和地下溶洞的分布。全部野外工作于 1990 年完成，大大加深了对该区地质的认识，促进了该区建设的发展。当时由于条件所限，仍存在不足之处：如 1∶20 000 新田幅地质图(GCO，1989)、1∶5 000 后海湾幅和山背幅地质图(GCO，1988)，当时因地面缺乏岩石露头和钻探资料，在天水围和网井围地区的地层仍保留 Allen 等(1971)所定的落马洲组的名称；直到后来钻了 40 多个钻孔，发现该区主要为火山岩，因此重新定名为屯门组。Darigo(1989，1990)和 Frost(1990) 均发表文章作了详细论述。Darigo 还将含岩屑凝灰角砾岩定名为天水围段，强调含大理岩岩屑的凝灰角砾岩是火山碎屑岩，不同于元朗组沉积的层状大理岩。其不足之处是没有对岩石做化学分析，未能完全摆脱 Allen 等认为是落马洲组沉积岩的影响，所以对天水围段的叙述仍保留有砾岩。

为了详细了解岩石的力学性质，香港土力工程处(Geotechnical Engineering Office 或 Geotechnical Control Office 以下简称为 GEO 或 GCO)于 1990 年由 Irfan T. Y. 主编的《元朗-屯门地区大理岩和其他岩石的工程性质》(Publication No. 2/90) 对该区岩石作了详细的力学试验，证明含大理岩岩屑的凝灰角砾岩相对粉砂岩夹大理岩的力学性质，两者完全不同，其抗压强度前者要比后者或单独的大理岩和粉砂岩要大 2～10 倍。

香港土力工程处 1994 年出版的 1∶20 000 新田幅基岩地质图，根据钻探资料，证实天水围地区的岩石属屯门组火山岩后。因为天水围段主要以凝灰角砾岩为主，考虑到要和青山地区岩石名称的统一，取消了天水围段，而以地质符号 tb 取代。2000 年香港地质调查组由 Kirk P. A. 等主编的 1∶100 000 地质图，因青山组的岩性基本上和屯门组相同，遂将青山组并入屯门组。在图例中明确指出屯门组是由安山岩和凝灰岩夹凝灰角砾岩、层凝灰岩组成(GEO. 2001 中文版，2000 英文版)。其后香港有地质学者持不同看法，认为天水围和青山地区的火山角砾岩属沉积砾岩，再次引起争论。香港多位地质学者也先后发表文章指出该岩系属沉积成因的错误观点，如 Chan(2005)，Chan J. 等(2005)，Lai 等(2004)，Lai(2005)和 Lai 等(2006)，Chan & Kwong(2009)。可惜直至现在，香港仍有地质著作坚持沉积砾岩的看法。另外自 2003 年以来，该区不少地质勘探报告都出现把火山角砾岩误作沉积岩，影响了工程建设。为了弄清真相，作者对该区重新做了详细野外考察，并到世界著名火山地区，如美国的 Shiprock、

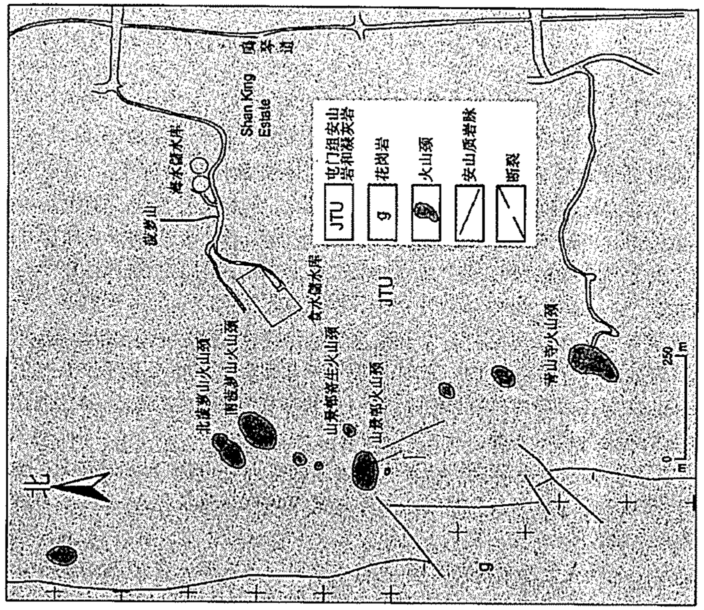

图 2 经实地调查证实砾岩并不存在，但出露一列由火山角砾岩和熔岩组成的火山颈

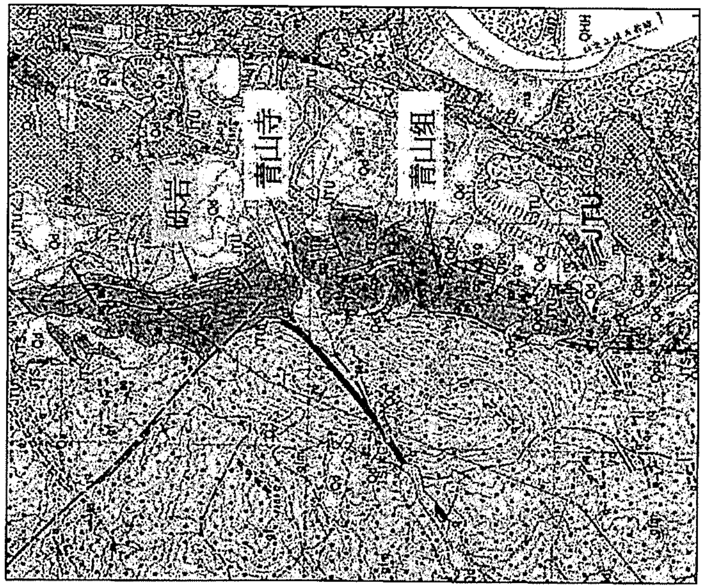

图 1 香港 1988 年出版之 1∶20 000 青山幅地质图有一层断续延长 1 100m 之砾岩

菲律宾的Pinatubo、冰岛、我国的长白山、腾冲和台湾阳明山，作了实地调查和对比。发现沿青山东麓的火山角砾岩组成一列线状、断续分布的古火山颈(图2)，再次证实青山组属沉积砾岩是错误观点。

2 区域地质简介

香港中侏罗世屯门组分布于新界西北部，从屯门经天水围延伸至深圳河口，位于NNE向的青山断裂和屯门断裂之间的断块内(图3)，西侧为花岗岩，东侧主要为早石炭世的砂岩、粉砂岩和大理岩。屯门组主要以安山岩-英安岩系列的熔岩为主，夹凝灰岩和凝灰角砾岩，还有少量凝灰质砂岩。其地质年代根据^{40}Ar-^{39}Ar测年为181±3Ma～182±3.5Ma，属中侏罗世，是香港最早的火山岩(Sewell等，2000)。

由于屯门组形成年代久远，1.8亿年以来长期遭受风化侵蚀，粗略估计已侵蚀到原地表下约800～1 000m。近地表部分的岩石，如火山泥石流堆积和喷发沉积物大部分已受到剥蚀，遗留下来的主要是火山底部或根部的岩石(图4)，类似美国新墨西哥州的Shiprock火山颈。屯门组的火山岩按岩相可分为以下4种。

(1)喷溢相　主要为熔岩，其岩石化学成分主要为玄武安山岩，其次为安山岩和粗安岩，个别为英安岩。广泛分布于散石湾村至良景村。安山岩呈深灰色至深绿色，常含斜长石斑晶，基质多为隐晶质，致密块状。

(2)火山通道相　又分火山颈相和岩墙相，主要由熔岩和角砾熔岩组成，两者常伴生一起。西侧火山颈分布由青山寺至菠萝山。东侧地面多被浮土覆盖，钻孔资料显示由屯门医院至虎地很可能有火山颈。岩墙在西侧见于山景村的火山颈南面和圆头山，东侧出露于亦园村，亦见于洪水桥至天水围的钻孔中，均隐伏于地下。岩墙常与火山颈伴生，长达几十米至300m，宽1～2m。有些岩墙亦含有围岩的岩屑，火山通道相的熔岩化学分析结果，主要为英安岩，其次为粗安岩。

(3)空落相　分布于火山口外围，出露不多，主要为凝灰岩。如青山寺火山颈南侧和菠萝山火山颈东侧。

(4)喷发沉积相　范围较小，仅见菠萝山以西的山脊，主要为凝灰质砂岩。

3 屯门组火山碎屑岩和火山颈的特征

通过多年来到世界各地对火山的实地观察，火山颈具有共同特征。在地面上呈圆形或圆筒形；岩筒内由熔岩和爆发角砾岩组成，亦可由其中一种岩石组成，如美国新墨西哥州的Shiprock火山，火山颈常与岩墙共生在一起(图5、图6)。如岩石难于风化，会形成突起地形，相反会形成圆形的洼地，如山东蒙阴的超基性岩岩筒。由于火山颈形成时仍处在地壳深处，安山质岩浆温度高达800～1 200℃使岩屑在岩浆中会产生不同的物理和化学变化，如产生爆裂、弯曲、拉长，变窄和尖灭等现象，由于常见爆裂作用，又称爆发角砾岩。岩屑主要由早期凝固的火山岩和地壳深部的围岩组成，但均由熔岩胶结，又称角砾熔岩。火山口或火山颈群如受深部断裂控制，在地表会呈线状排列，如云南腾冲和黑龙江省的五大连池。岩屑形状可以是角砾状，经过岩浆的长途搬运亦会变成浑圆状，如辽宁瓦房店的岩筒。通常火山有多次喷发，强烈期以喷出爆发角砾岩为主，平静期以溢出熔岩为主。火山颈内常见密集似头发丝的排气构造。在台湾省阳明山现代火山的喷气口可见此类构造，它们不同于近地表的气泡。火山颈内常发育平行板状或环状节理，它们均可作为鉴定火山颈的标志。

屯门地区火山颈分布于青山寺至菠萝山一带，呈北北西向断续线状排列，目前查明的火山颈有9个，未来可能有新的火山颈会被发现。火山颈在地面上近似圆形，椭圆形或雨滴形，直径由20～100m，高20～60m。地貌上呈突起地形。剖面上呈圆柱形。火山颈之间的间距50～250m。火山颈由熔岩或角砾熔岩组成。熔岩在火山颈内呈脉状或岩墙状，对火山颈内的熔岩采样，经化学分析多为英安岩。岩屑多为早期凝固的熔岩或凝灰岩，也可以是深处泥盆纪的石英砂岩、粉砂岩和石炭纪的石灰岩，胶结物主要是熔岩。岩屑边缘产生变质作用，对铁镁质火山岩岩屑会形成青盘岩化、绿帘石化、绿泥石化等反应边，对石灰岩会发生交代作用，形成大理岩或含透辉石、透闪石、硅灰石和石榴石的矽卡岩。

3.1 青山区屯门组的火山碎屑岩和火山颈

2000年后香港有若干地质著作把屯门组的火山碎屑岩当作沉积砾岩，如《香港前第四纪地质》(Sewell，2000)第69页，虽然将原青山组合并入屯门组，但叙述时仍采用旧资料，照搬《香港地质调查报告第3号新界西部地质》(Langford，R. L. 1989)中有错误的资料，把原先青山组的岩石仍按沉积岩去描述，造成地质报告与同时出版的地质图不一致的现象。该书第69页描述屯门组下部岩性由大量外生碎屑岩和火山碎屑岩组成，在西侧(相当原青山组范围)主要以石英砂岩、变质粉砂岩和千枚岩为主。《香港地质考察指引》(土力工程处，中文版2007、英文版2008)第51页认为由青山寺至菠萝山的岩石主要为砾岩和角砾岩，由碎屑胶结。成因是破火山口的坍积层或火山口湖的近岸沉积。《香港工程地质实践》(GEO，2007)也有类似的错误，在书中第35页，插图3.2.3表示的砾岩露头实际上就是火山角砾岩。主要原因是这些著作忽略了或没有参考前人的最新研究成果，同时缺乏对火山岩相和火山构造的实际研究。没有搞清楚岩石的产状形状，加上完全没有对火山颈内的岩石做过任何化学分析，无法对隐晶质或细粒的岩石做出正确的岩石鉴定。因此无法区别层状的砾岩和筒状或岩墙状的火山角砾岩。

(1)青山寺火山颈　土力工程处1988年出版的1∶20 000青山幅地质图，从屯门的青山寺至菠萝山分布有一层砾岩，断续延长达1 100m(图1)。后经重新考察，认为这层砾岩并不存在，因此土力工程处2000年出版的1∶100 000香港地质图，完全不表示这层砾岩。近年青山寺在维修过程中打了9个钻孔，充分显露出青山寺座落在一火山颈上(图7～图10)，该火山颈外形呈水滴状，长120m，最宽处50m，往山上变窄和尖灭。岩矿鉴定熔岩成分主要为安山岩，主要矿物有斜长石、角闪石，少量黑云母、辉石、石英和榍石，次生矿物有绿泥石、绿帘石和绢云母，基质为隐晶质。岩芯中可见少量斑晶为斜长石，呈长柱状，1～3mm，从火山颈的熔岩中采了6个样品作化学分析，其结果做TAS图解，主要为玄武粗安岩和英安岩。爆发角砾岩的岩屑粒径10～300mm，大多为棱角状至次棱角状。岩屑成分主要有早期凝结的安山岩和凝灰岩，其次有石英砂岩、粉砂岩和石灰岩。胶结物为熔岩。熔岩与含铁镁矿物的岩屑接触常见有反应边现象，如青盘岩化；与石灰岩接触会产生硅卡岩化。岩屑与熔岩的接触变质作用，只能在地壳深处随高温岩浆向地面喷发过程中相互作用形成。青山寺的岩石露头可见明显的岩浆流动构造(《香港地质考察指引》第52页一幅插图误认为是沉积成因的纹层)。青山寺火山颈外围出露有凝灰岩和安山岩。

(2)山景村火山颈　在山景村正西 650m,岩筒呈椭圆形,长轴 80m,宽轴 50m。地貌上突起,呈约 50m 高的陡崖(图 11～图 14),即《香港地质考察指引》第 53 页上的插图——“菠萝山西露头”。由多期喷发的熔岩和爆发角砾岩组成,与美国新墨西哥州的 Shiprock 火山颈甚为类似。熔岩的化学成分主要为玄武安山岩。在岩筒南部残留排气构造,排气管道呈垂直、互相平行,密集似头发丝状。它们由火山颈底部延伸至顶部,高约 50m。类似台湾阳明山现代火山的排气构造。另外在其南面约 30m 和东侧约 50m 各有 1 个小型火山颈(亦称寄生火山颈),还有 3 条岩墙。

(3)山景村寄生火山颈　在山景村正西约 80m,近似圆形,直径约 50m,高 20m,即《香港地质考察指引》第 54 页上的插图——“菠萝山西的砾岩”。岩筒内的岩石亦为熔岩和爆发角砾岩。熔岩的化学成分主要为安山岩,岩屑主要为早期凝固的熔岩和凝灰岩。最大特点是岩屑呈浑圆状或次圆状,直径可达 80cm。火山岩筒的节理呈同心圆状和垂直环状(图 15)。

(4)菠萝山火山颈　可分南北两个火山颈,二者相距约 60m,均呈椭圆形。南菠萝山火山颈长轴约 85m,宽轴 50m,高约 55m。北菠萝山火山颈长轴约 95m,宽轴 50m,高约 20m。两者岩性均由多期喷发的熔岩和爆发角砾岩组成。从岩筒内熔岩岩脉延伸的不同方向,可分辨出起码有 5 次喷发旋回(图 16～图 18)。熔岩的化学分析结果主要为英安岩。岩屑主要为早期凝固的熔岩,其次为砂岩和石灰岩。石灰岩岩屑因动热变质作用,会变为透闪石或硅灰石大理岩。因韧性变形岩石会产生压扁和拉长的现象(图 19)。岩筒内有显着的排气构造。在《香港工程地质实践》(GEO,2007)第 140 页,插图 6.2.7 中间的一幅图表示的砾岩,实际上就是北菠萝山的火山颈(图 20、图 21)。

3.2　天水围地区的屯门组火山碎屑岩

Sewell R. J. 主编的《香港前第四纪地质》(2000)第 38 页插图 3.5 把天水围地区的屯门组火山岩当作石炭纪落马洲组的沉积岩(图 22),与同时出版的 1∶100 000 地质图完全不一致,原因是引用了过时的资料。1994 年出版的 1∶20 000 新田幅基岩地质图(GEO)(图 22),归纳了香港地质调查组和英国地质调查所地质学者们在该区多年来共同工作的研究成果,以丰富的钻探资料进一步证实该区为屯门组火山岩。

从天水围一直向南延伸至洪水桥和屯门医院,钻探均发现有大量含大理岩岩屑的凝灰角砾岩岩墙。在亦园村地面出露两条互相平行的岩墙,岩墙内有典型的大理岩岩屑,均发生硅卡岩化和青盘岩化(图 23～图 25)。

在灵渡寺可见一块巨石由凝灰角砾岩、凝灰岩和熔岩组成,呈互层状,可能是空落相的产物(图 26)。另外,灵渡寺有些砾石中可见有溅落的熔岩条带,仍可见到岩石表面有熔岩浆屑呈垂直向下的流动构造(图 27),说明当时是在火山口附近的空落堆积。

Sewell 有关天水围地质的插图影响很大,后来出版的地质著作也跟着重犯这个错误。如《香港钻探地质》(Fletcher. 2004)第 110 页插图 16.2 和《香港工程地质实践》(GEO,2007)第 105 页插图 5.5.1 都原封不动地引用了 Sewell 有问题的插图。

3.3　屯门组火山岩因动热变质产生糜棱岩化的岩石

屯门组火山岩因为处于广东莲花山大断裂带内,燕山运动时受到强烈的地壳运动影响,在屯门组内产生北东和北西向的断裂。受动热变质作用影响,岩石会发生韧性变形,产生糜棱岩化。往往在断裂带两侧由外向内,岩石发生递进变质现象。熔岩中的大理岩岩屑和其他岩块

角砾会被拉长和压扁(图 19、图 28)。因此,含大理岩岩屑的角砾熔岩或凝灰角砾岩很易被人误认为是粉砂岩夹薄层大理岩。

4　屯门-天水围地区地质勘探中的编录问题

作者发现 2003 年天水围地区部分钻探编录把屯门组的火山碎屑岩当作沉积岩,除直接向有关方面反映外,还直接发表文章(Lai 等,2004)指出存在的问题,可惜没有被采纳。另外从土木工程署图书馆查阅屯门-天水围地区由 2003 年以来的 1 200 个钻孔资料,发觉对屯门组的岩石命名错误相当严重,钻探编录的岩石命名 60%以上是有问题的。主要是把火山碎屑岩中的大理岩岩屑当作层状大理岩,把隐晶质的熔岩和火山质凝灰岩当作粉砂岩或砂岩。编录中出现的错误与《香港前第四纪地质》、《香港工程地质实践》和《香港地质考察指引》等地质著作中,把屯门组部分火山碎屑岩当作沉积岩描述有很大关系。

由于城市发展的需要,香港在屯门、元朗和天水围平原地区建设新市镇,要建造不少高层建筑。由于中侏罗世屯门组火山岩与石炭纪大理岩在该区内互相毗邻(图 3),两类岩石均有大理岩,加上风化程度深,又有变质作用影响,因此增加了鉴别上的困难,容易产生混淆。石炭纪的大理岩因有岩溶问题易于形成溶洞,溶洞最大可高达 24.5m,溶洞间可互相连通,最长可达 45m,对高层建筑的地基稳固性会造成严重影响。因此,凡有大理岩分布的地区,均被香港政府划为城市发展的限制区。在这样的区域内建筑物的地质勘探和设计施工有严格要求。在沉积大理岩地区的钻探,钻孔深度必须穿过没有溶洞的新鲜大理岩 20m。相对于火山岩钻孔深度的要求,只需钻穿中度风化的岩石 5m 便可以。屯门组的爆发角砾岩虽含有大理岩的岩屑,仍属火山岩,与石炭纪的层状大理岩明显不同,岩溶程度也有很大差别。大理岩岩屑一般只有几厘米至 50cm,甚少达到 1m,而且大理岩岩屑均被熔岩胶结,在火山岩中形成的溶洞互不连通,风化后只呈蜂窝状,岩溶程度只属轻微至中等。另外,两者的岩性、力学和工程性质也完全不同,对地基工程的影响程度也不一样。在野外地质测量工作中,必须把两者严格区别开来,才能正确地进行地质勘探和地基工程设计。经我们检查过的 1 200 个钻孔,由于误作沉积的大理岩,钻探深度要求往往超过规定,初步统计多钻达 9 809m,结果必然影响工程设计和增加地基打桩的深度,导致增加建设成本和影响工程进度。

5　屯门组火山岩的化学成分

香港地质调查组对屯门组火山岩做过 11 个样品的化学分析(Langford 等,1989),(Sewell 等,1997),主要在火山口外围的喷溢相熔岩,而对火山颈相的熔岩没有做过任何分析。由于该区的火山岩大部分都是隐晶质或粒径很细,肉眼和显微镜难于鉴定。为了彻底搞清楚屯门组火山岩的成分,参照国际地科联的建议,我们共采集了 18 个岩石样品做化学分析,包括火山颈相、岩墙相、喷溢相和空落相的熔岩,其结果用 TAS 图解法将岩石进行分类(图 29、表 1)。由于火山颈岩石含有大量围岩物质,必须严格区分。因此,只选择熔岩的纯净部分做化学分析样品。为了保证质量,所有岩石化学试样只采集没有风化、没有蚀变、没有变质和没有渗杂围岩碎屑的新鲜岩石样品。

为了检查样品结果的可靠性,把同一地点同一岩性的样品分送不同实验室。把他们的分

表 1 香港屯门组火山岩的主要化学成分(Wt%)

编号	样品编号	位置	座标		岩石名称	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	LOI	合计
			E	N													
1	HK856	屯门海水储水库	1427	2889	玄武安山岩	54.39	1.01	17.19	8.5	0.15	3.87	7.26	2.36	2.05	0.21	0.67	99.33
2	HK3788	翠林花园	1517	2910	粗安岩	53.46	1.48	18.45	9.39	0.11	1.3	4.54	4.57	4.94	0.79	—	100.47
3	HK10246	良景邨	1407	2932	玄武安山岩	53.13	1.02	17.63	9.2	0.17	4.61	8.79	1.34	1.96	0.27	2.0	100.12
4	HK10247	屯门食水储水库	1400	2880	玄武安山岩	52.02	0.89	17.55	9.06	0.29	3.56	11.62	0.96	1.73	0.27	2.06	100.01
5	HK10378	山景邨	1388	2852	玄武安山岩	55.97	1.01	16.79	9.5	0.16	4.39	5.5	3.13	1.55	0.22	1.92	100.14
6	HK10379	山景邨	1388	2858	玄武安山岩	53.99	0.95	18.32	8.95	0.15	3.93	7.94	2.28	2.06	0.24	1.46	100.27
7	HK10380	山景邨	1396	2854	玄武粗安岩	51.6	1.12	19.14	10.55	0.17	4.72	3.81	0.9	5.61	0.24	1.91	99.77
8	HK10382	山景邨	1409	2864	玄武安山岩	53.44	1.02	18.0	9.42	0.16	4.36	6.92	3.85	0.58	0.25	1.82	99.82
9	HK10417	彩晖花园	1599	2984	英安岩	65.99	0.6	16.18	4.98	0.07	0.82	3.52	3.42	3.21	0.25	1.23	100.27
10	HK10421	大兴花园	1541	2896	粗面英安岩	63.49	0.73	18.73	3.17	0.07	1.06	2.88	6.42	2.29	0.25	0.9	99.99
11	HK10444	建荣街	1484	2861	安山岩	59.96	0.87	16.57	7.97	0.14	2.26	6.95	2.71	1.65	0.24	0.88	99.32
12	TM-1	青山寺 DH3 2.8m	1387	2807	玄武粗安岩	52.360	0.745	17.621	7.315	0.078	3.224	9.971	3.420	3.531	0.509	1.100	99.873
13	TM-10	灵渡寺	1607	3351	英安岩	65.945	0.783	10.578	6.044	0.170	1.012	9.472	2.340	3.803	0.107	0.733	100.986
14	TM-37	良景邨	1395	2985	粗面英安岩	66.963	0.521	15.521	4.324	0.075	1.023	2.109	4.283	3.976	0.157	0.899	99.850
15	TM-59	南菠萝山	1372	2863	流纹质凝灰岩	77.357	0.135	12.200	1.658	0.031	0.378	1.017	2.327	3.727	0.009	0.867	99.705
16	TM-61	南菠萝山	1371	2860	玄武安山岩	53.283	1.047	17.838	10.582	0.147	3.602	6.654	2.662	2.152	0.247	1.765	99.979
17	TM-64	南菠萝山	1366	2850	安山岩	60.777	0.673	17.587	6.501	0.089	2.951	5.009	2.960	2.179	0.266	0.799	99.792
18	TM-65	屯门海水储水库	1425	2889	玄武安山岩	52.309	1.104	18.355	9.312	0.167	4.431	7.791	2.502	1.616	0.262	1.796	99.645
19	TM-65B	屯门海水储水库	1425	2889	玄武安山岩	52.279	1.096	18.710	9.722	0.144	2.978	8.153	2.441	2.571	0.223	1.396	99.713
20	TM-68	南菠萝山	1364	2852	英安岩	70.315	0.662	14.492	4.587	0.063	1.583	1.185	0.688	3.788	0.100	3.130	100.592
21	TM-70	南菠萝山	1364	2849	粗安岩	58.489	0.857	20.679	7.549	0.060	2.311	0.465	0.080	6.350	0.144	2.329	99.312
22	TM-71	南菠萝山	1366	2850	粗面英安岩脉	68.965	0.205	15.879	2.179	0.037	2.324	1.215	2.841	6.664	0.018	0.532	100.855
23	TM73	山景邨	1375	2885	玄武安山岩	56.29	0.76	19.19	8.92	0.17	3.95	1.11	0.42	3.96	0.10	4.83	99.69
24	TM77	菠萝山东	1371	2862	流纹质凝灰岩	72.80	0.31	13.79	1.94	0.05	0.70	1.74	3.12	4.54	0.09	0.75	99.81
25	TM81	南菠萝山	1372	2882	英安岩	68.77	0.53	14.16	3.89	0.07	1.56	3.04	2.99	3.73	0.11	0.91	99.77
26	TM102	青山寺 DH4 16.4m	1387	2807	英安岩	70.05	0.34	14.39	2.30	0.06	0.97	2.95	1.98	4.46	0.09	2.13	99.71
27	TM103	青山寺 DH7 13.6m	1386	2809	流纹岩	70.75	0.30	13.10	1.91	0.05	0.88	3.23	1.53	5.24	0.08	2.65	99.71
28	TM104	青山寺 DH3 2.5m	1388	2808	玄武粗安岩	52.00	0.83	18.61	7.58	0.05	3.35	7.76	4.08	3.76	0.48	1.00	99.48
29	TM106	青山寺 DH7 14m	1386	2806	英安岩	69.26	0.30	13.77	1.92	0.05	0.88	3.42	1.73	5.40	0.08	2.94	99.73
30	TM107	青山寺 DH7 16m	1386	2809	英安岩	69.53	0.30	13.62	1.87	0.05	0.95	3.36	2.82	4.68	0.09	2.45	99.72

资料来源:编号 1～2(GCO,1989),3～11(Sewell,1997),12～22 香港大学地球科学系,23～30 广州地球化学研究所。

析结果相互比较,发觉分析结果基本合乎要求。如香港大学分析的 TM1 和广州地化所分析的 TM104 结果都是玄武粗安岩;英国 Nottingham 大学分析的 HK856 和香港大学分析的 TM65 和 TM65B 结果都是玄武安山岩。

屯门组火山岩的化学分析结果,说明岩浆喷发表现出一定的规律。火山强烈爆发期喷出的熔岩,分布在火山颈内的主要为英安岩;火山宁静期喷逸的熔岩,广泛分布于屯门谷地,多为玄武安山岩;流纹质凝灰岩分布于火山锥外围,亦见于火山颈内早期凝固之角砾;空落相的溅落熔岩条带,主要成分为英安岩。这种现象也符合世界其他地方岩浆喷发的规律。在地壳深处的岩浆房,母岩浆可能是玄武岩,在上升喷发过程中,与富含 SiO_2 的围岩发生同化或混染作用,产生英安岩和粗安岩等岩石(图 4)。

由于地质勘探过程中,常把隐晶质的安山岩当作粉砂岩。我们专门对邻近的石炭纪粉砂岩做了化学分析,两者的化学成分相差甚大。粉砂岩的 SiO_2 为 76.74%,但安山岩均低于 63%,粉砂岩的 SiO_2 大大高于安山岩;相反粉砂岩的 Al_2O_3 只有 11.58%,大大低于安山岩的 15.5%。

6 屯门组火山岩的力学性质

屯门至天水围地区的地质勘探常误将火山岩当作沉积岩,但是它们的岩石力学性质完全不同。有学者已对屯门地区的岩石做过不少力学性质试验,如 Irfan(GEO,2000)和(Chan and Kwong,2009)。详细结果可参考他们的著作,现仅将有关主要岩石的单轴压力试验结果列于表 2 以供参考。

表 2 岩石单轴压力试验结果

含大理岩岩屑的凝灰角砾岩 (MPa)	钙质砾岩 (MPa)	泥质砾岩 (MPa)	细粒凝灰岩 (MPa)	大理岩 (MPa)
a. 150—296[1]	9.3～31.2[3]	4.0—27.4[4]	c. 111—194[2]	d. 65—138[1]
b. 195—329[2]				
产地:a. 天水围 b. 青山寺 c. 屯门、天水围 d. 元朗				

资料来源:[1]GCO,1990;[2]Chan 等,2009;[3]Fugro 岩石力学实验室;[4]FIGG 岩石力学实验室(所有岩石试样均为新鲜的完整岩石)

岩石力学试验结果说明,火山碎屑岩与沉积砾岩有着完全不同的力学性质。含大理岩岩屑的凝灰角砾岩、角砾熔岩的单轴抗压强度比沉积砾岩强 5～10 倍,比大理岩强 2～3 倍。粉砂岩一般强度为 30MPa,细粒凝灰岩亦比其强 3～6 倍。因此岩石定名不准确,会对工程设计形成不必要的错误,并会对工程发展在经济上、时间上和成本控制上造成重大损失。

7 结 语

香港不少地质工作者经过几十年的努力,在屯门至天水围地区做了大量的野外调查和艰苦的研究工作。对该区的地层和岩石,经过反复摸索,对粗火山碎屑岩的认识由浅入深,由最

初误认为是沉积砾岩，到确定为火山颈相或岩墙相的爆发角砾岩。要正确区别火山成因的爆发角砾岩和沉积成因的砾岩，关键在彻底搞清楚岩石的产状、形状。区分层状的砾岩和筒状的火山岩，对隐晶质的火山岩，单凭肉眼或薄片鉴定是不够的，应按照国际地科联(IUGS)(Le Meitre,2002)的建议，采集化学分析样品进行试验，对火山熔岩和细粒凝灰岩才能有一个正确的认识，对香港的工程地质才能提供正确的资料，对香港工程建设才能作出合理的、正确的设计，也才能节省地质勘探和工程建设的成本。

8 致 谢

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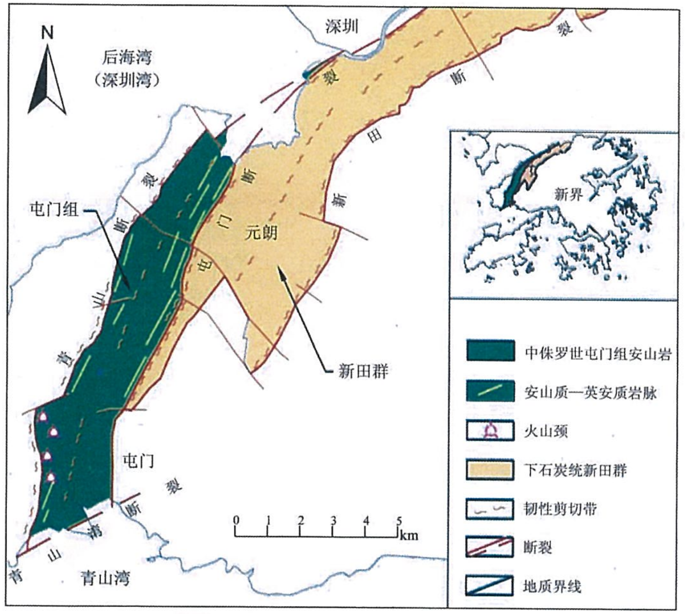

图 3　香港屯门组分布示意图

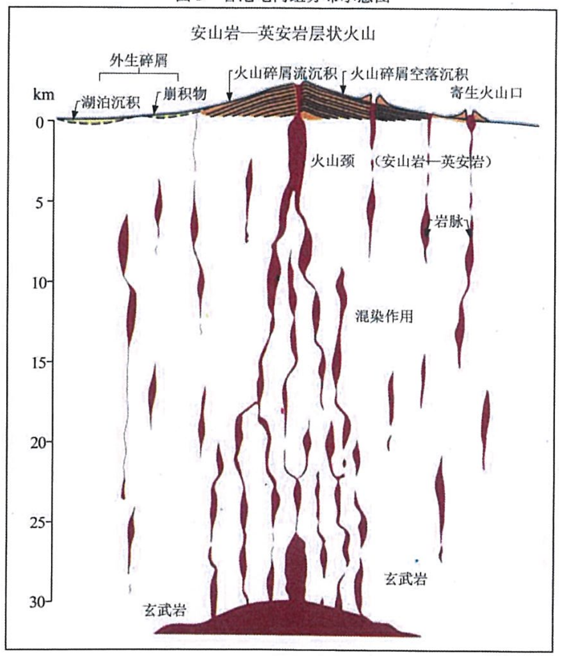

图 4　安山岩从地壳深部至地表岩浆成分演化示意图(据 Hildreth, W. 修改)

图 5 美国新墨西哥州 Shiprock 的火山颈

图 6 Shiprock 火山颈由爆发角砾岩和熔岩组成

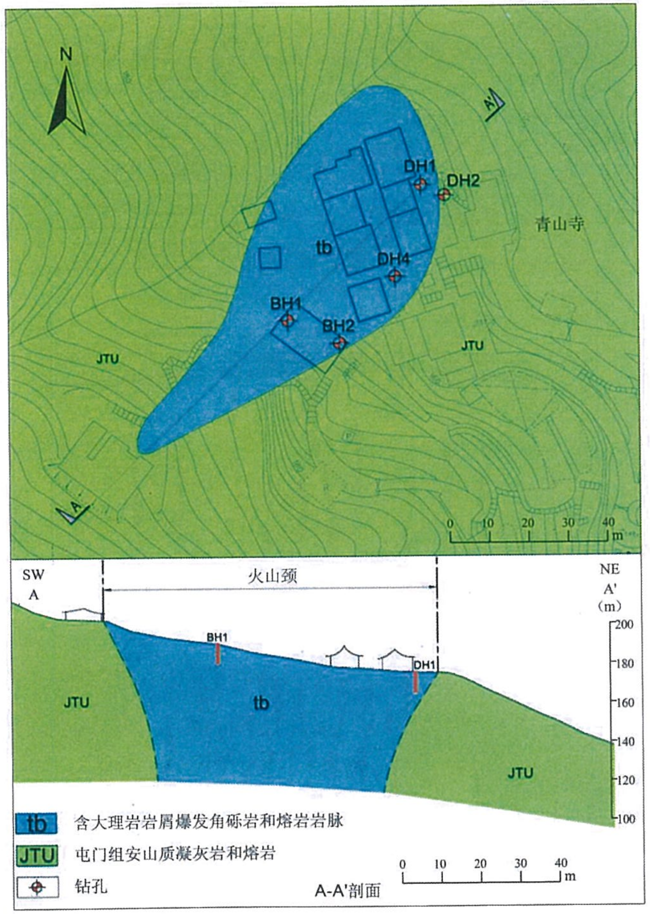

图 7 青山寺火山颈的产状形状

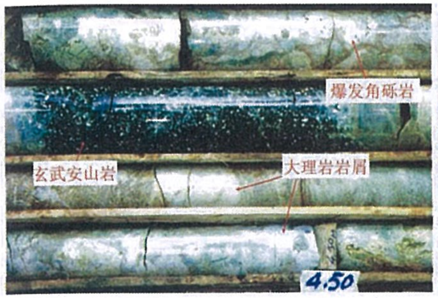

图 8 青山寺火山颈内之玄武安山岩和爆发角砾岩

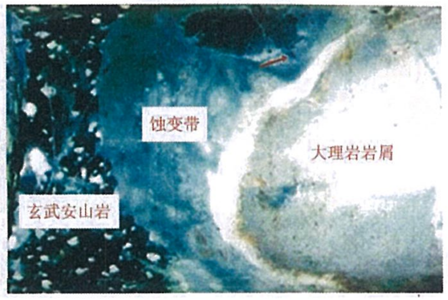

图 9 青山寺火山颈玄武安山岩与大理岩岩屑接触的蚀变带

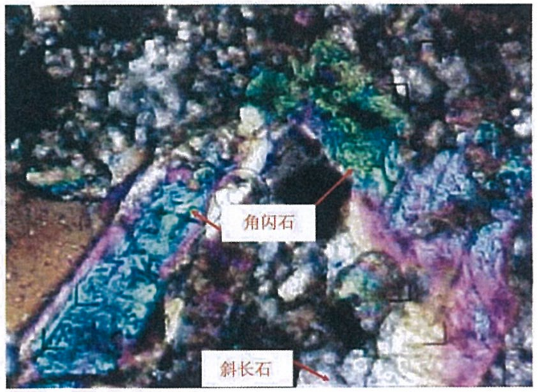

图 10 薄片中青山寺的安山岩

图 11 山景村火山颈由爆发角砾岩和熔岩组成，地貌上呈突起悬崖

图 12　山景村火山颈的排气构造

图 13　台湾阳明山安山岩的排气构造

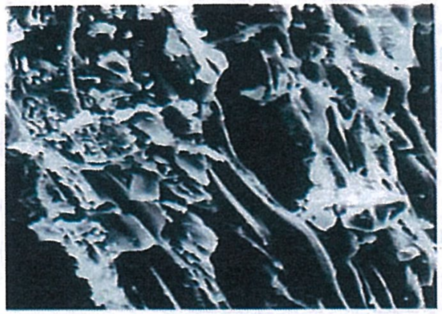

图 14　电子显微镜下台湾火山岩的排气构造(据宋圣荣)

图 15　山景村寄生火山颈的环状节理

图 16　南菠萝山的火山颈

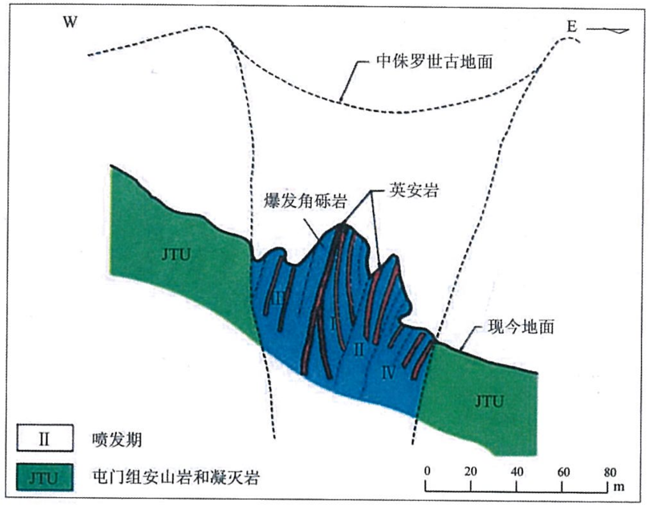

图 17　南菠萝山古火山颈剖面示意图

图 18　南菠萝山英安岩侵入爆发角砾岩及其接触关系

图 19　南菠萝山火山颈内的大理岩岩屑因韧性变形被压扁和拉长的现象

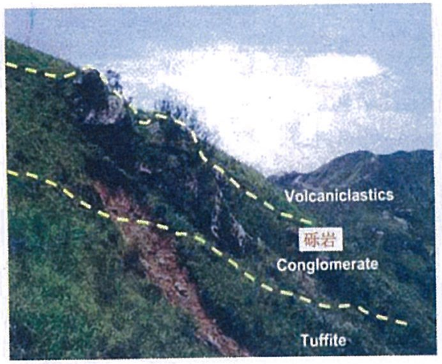

图 20 《工程地质实践》140 页，插图 6.2.7 北菠萝山的砾岩

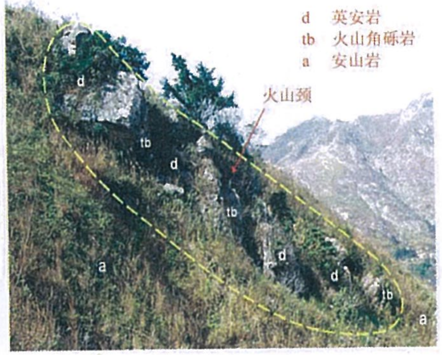

图 21 经调查证实北菠萝山应为英安岩和爆发角砾岩组成之火山颈

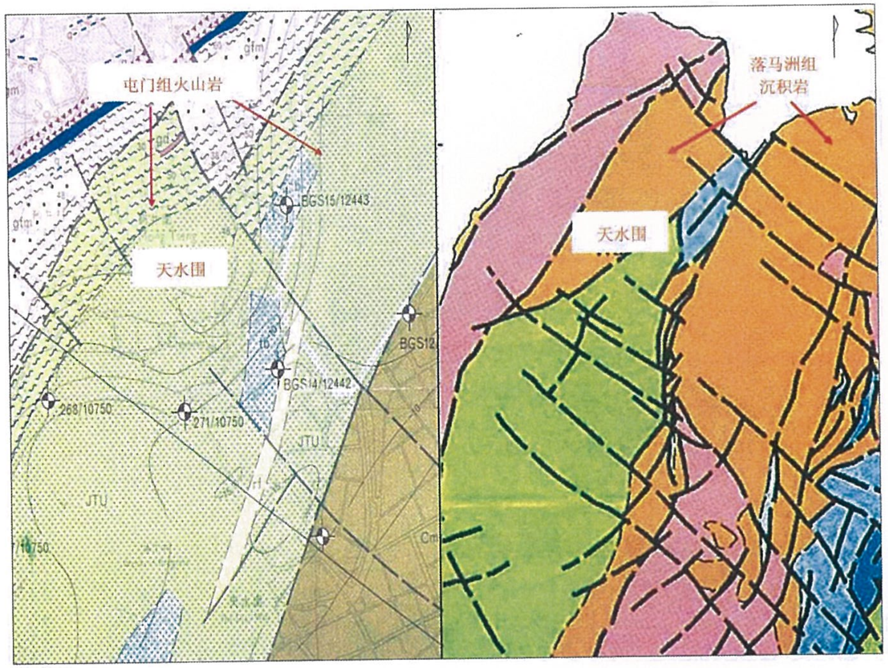

图 22 左图为 1994 年综合香港地质调查组和英国地质调查所地质学者们的共同研究成果而出版之地质图(GEO)，天水围地区属屯门组火山岩。右图为 2000 年出版的《香港前第四纪地质》(Sewell 等)第 38 页，插图 3.5 错误地引用过时之资料当作落马洲组沉积岩

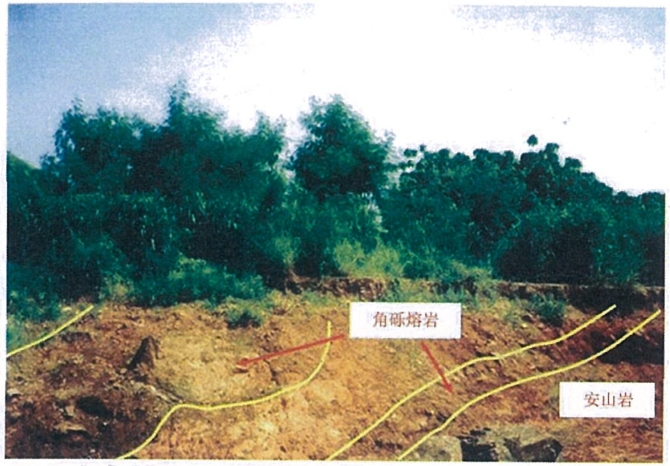

图 23 亦园村两条角砾熔岩岩墙

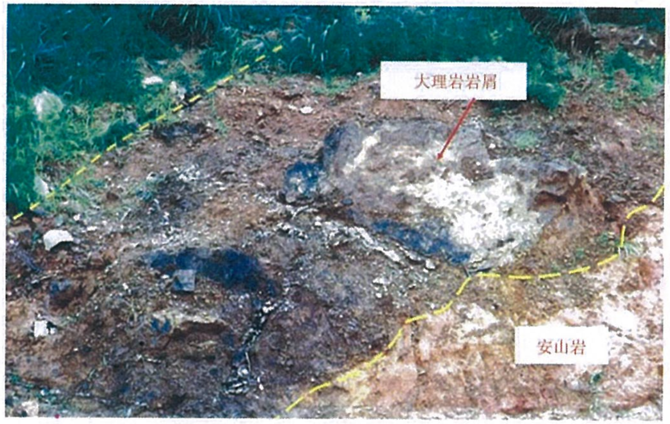

图 24 岩墙内出露的角砾熔岩和其中的大理岩岩屑

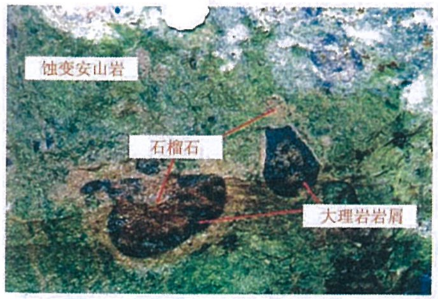

图 25 亦园村角砾熔岩内熔岩和岩屑间的蚀变带

图 26 灵渡寺的火山碎屑空落堆积由凝灰角砾岩、凝灰岩和英安质熔岩组成

图 27　灵渡寺火山碎屑空落堆积的浆屑

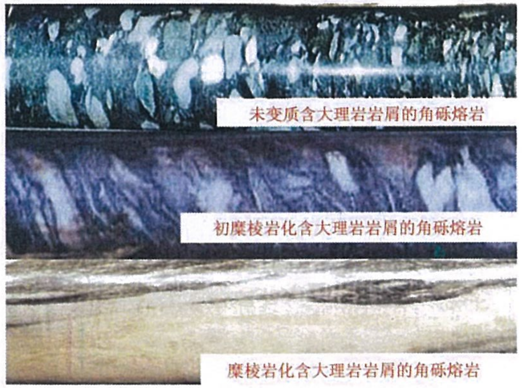

图 28　屯门组糜棱岩化含大理岩岩屑的火山碎屑岩

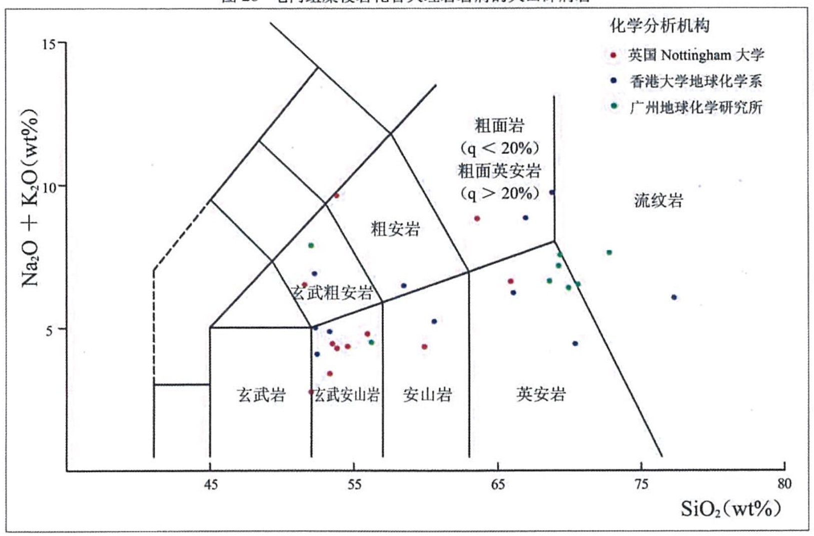

图 29　香港屯门组火山岩的化学成分 TAS 图解

中国香港东南沿海流纹岩系六方柱节理
——香港世界地质遗产再议

李作明[1] 林海勇[2]

（1. 香港地质学会；2. 香港理工大学土木及结构工程学系）

摘 要：香港流纹岩系六方柱节理产出于香港东南沿海半岛及海岛地带，包括香港岛南和东端及其附近岛屿，果洲群岛中，南、北两岛及其附近岛屿、西贡半岛南部海湾粮船湾岛、滘西洲岛、万宜水库东坝及大浪湾两侧半岛一带方圆近 40km^2 的海陆之内，均呈现六方柱陡崖，犹如并排手风琴或由海中挺拔腾空，十分壮观和奇特，实为世界罕见。

目前已知构成六方柱节理的岩石系列包括流纹岩、球粒状流纹岩、凝灰熔岩、流纹质熔岩、凝灰质熔岩、泥球状凝灰岩及碎屑状凝灰岩，可见厚达 300m 以上。西贡地区两个流纹岩年龄测试为 1.409 亿年及 1.45 亿年（据岩石中锆石鉴定），相当于早白垩世沉积岩层的植物化石鉴定年龄近似。这意味着上述岩石是中生代晚期华南陆上花岗岩浆活动中喷发阶段所形成，具厚层状流纹构造及块状构造，同时岩石具均匀结构，流向构造倾向南东。岩石六方柱节理十分明显，主要呈六方柱，少量五方柱，直径大者可达 1.3m，小者 0.7m，一般超过 1m。石柱可见高度 40～50m 以上，柱柱栉比，十分壮观。

香港上述岩浆岩构成了北东东粤东莲花山岩浆活动带西南端。而上述流纹岩构成六方柱节理可能是喷发温度较高且喷发较固定和均匀而稳定的结果，才形成原认为基性喷发活动方有的六方柱节理而在酸性喷发出的岩石也可以形成六方柱节理的新认识，而且柱柱均匀。

根据现今所了解的资料，包括世界各国，特别是美国、英国、俄罗斯、日本、菲律宾、印尼的地质辞典、参考书及文献，凡举六方柱节理，其母岩必是玄武岩。多少年来我国也有同样的描述，只是有玄武岩才有六方柱节理，直到 20 世纪七八十年代开始提出浙江省临海县山区及吉林省四平地区出现流纹岩中也具有六方柱节理的描述，可惜地处山区，风化严重及植物覆盖，六方柱出露不显。

香港于 1953 年便有流纹岩六方柱节理报导。1971 年及 1985 年在区域地质报告中也有提及。1997—2000 年方比较详细描述上述流纹岩六方柱节理特征。

原处于大陆山岳丘陵的香港流纹岩六方柱节理，经过几千万年的变迁，时至今日却已处于滨海地带，这是因为经过第四纪四大冰期后间冰期阶段，近一万年来气候温暖，冰雪融化，海水上升，促成原在现代海岸以南约 200km 的海水面向北入侵，海水升高达到今日的海平面，于是香港东南接受近东西向的海侵，入侵海水面不断侵蚀香港东南海滨。原处于山地丘陵也变成了半岛和岛屿，海水日夜的涨潮退潮，大面积侵蚀上述流纹岩六方柱节理，便促成现代高达近百米的六方柱海蚀崖、海蚀洞、成排手风琴的六方柱群。其规模大，还有海中挺拔的六方柱十分壮观，成为我国甚至世界上罕见的海滨地区酸性流纹岩六方柱地质地貌特殊景观，十分稀罕，蔚为壮观，是具有世界性意义的地质及地貌景观。当然也具有科学价值和意义，故此具有进一步研究的价值，是十分有必要保护的自然历史遗产。

关键词：六方柱节理 流纹岩及其凝灰岩 粗面安山岩 玄武岩

The rhyolite columnar joint in southeast shore of Hong Kong, China——Re-discussion world geoheritage of Hong Kong

Li Zuo-ming[1], Lin Hai-yong[2]

(1. *Hong Kong Geological Institute*; 2. *Hong Kong Polytechnic University, Department of Civil and Structural Engineering*)

Abstract: Hexagonal joint of Hong Kong rhyolite is produced in the coastal peninsula and area on the island in southeast of Hong Kong, including south, east and nearby Island of Hong Kong Island. Southern part of Sai Kung peninsula and east dam of High Island reservoir. The area is few kilometer including the seas and the land, appear Hexagonal joint and cliff pull out soaring like accordion side by side or from the sea, very grand, peculiar, real and rare for world.

Have already known the rock series which form joint of Hexagonal include the rhyolite at present, the ball like and granulous rhyolite, welded gray lava, flow lava, globular tuff and tuff, it is obvious it reaches more than 300 meters thick. The age result of two rhyolite in Sai Kung area is 140.9 million years and 145 million years (appraise according to the zircon in the rock). In other words it is similar that early cretaceous includes age of fossil qualification of plant which deposit the rock stratum with the rock generation. This means the above-mentioned rock is spent in the hillock magma activity by land in South China in later period of Mesozoic Era eruption stage takes shape, line structure and blocky structure flow to have thick layer of formses, the rock has even structure at the same time, it is inclined to the southeast to flow into the structure. The hexagonal joint is very obvious, mainly present hexagonal column, a small amount of pentagonal columns, the large one of diameter can be up to 1.3 meters, the small one is 0.7 meters, generally exceeds 1 meter. The stone pillar can be seen and present more than 40～50 meters high, each column is placed closely side by side, very grand.

The Hong Kong above-mentioned magmatic rock forms the north southwest end of active belt of magmatic rock of east Lian Hua mountain of East Guangdong. And the above-mentioned rhyolite may erupt higher and eruption fixed then under very stable temperature to forms joint of hexagonal column, it forms to be base of the eruption and the hexagonal column that activity have can form the hexagonal column and joint in acid rock that gush out originally just, and the column and column is even.

According to the materials understood now, including the countries all over the world, especially geological dictionary, reference book and literature of U. S. A., Britain, Russia, Japan, Philippine, Indonesia, etc., all hexagonal column, the rock must be basalt. Our country has the same description too over the years, just there is basalt that has joints of hexagonal column, until last 70th of the first century, mountain of Jilin Province Zhejiang Province bordered on the sea the description with joint of hexagonal column in the rhyolite appeared in the areas of the mountain area in the county and well balanced mountain of Jilin Province, it's a pity that is located in the mountain area, weather serious and vegetation coverage, hexagonal column appears not to reveal apparently.

Hong Kong was a hexagonal joint report of rhyolite in 1953. Mentioned in the geological report of area in 1971 and 1985. Described the above-mentioned rhyolite hexagonal joint characteristic in detail in 1997—2000.

In Hong Kong rhyolite hexagonal joint of the mainland lofty mountains hills originally, through several ten million annual changes, but already been in the strand area even to this day, this is because pass the interglacial stage after Quaternary Period four major ice ages, climate warm to take the past 10,000 years, ice and snow melt, sea water rise, facilitate, face the north to invade in modern sea water of an area about 200 kilometers south of coast originally, the sea water rises and reaches the sea level of today, then southeast China of Hong Kong accepts and invades in the near and east-west sea, invading and corroding the southeast seashore of Hong Kong constantly the sea water. It is turned into peninsula and island too that in the hills of mountain region originally, the rising tide day and night of sea water ebbs tide, corrode the hexagonal joint of rhyolite by a large scale, the hexagonal joint form the sea cliff and sea cave. Hexagonal joint group of the accordions in row up to about 100 meters, the scale is large, and hexagonal joint prolonging and pulling out in the sea is very grand, it is even only visible special view of geological ground form of rhyolite hexagonal joint of seashore area in the world to become our country. Very rare, have world meaning while being very grand. Certainly have scientific value and meaning too, firm this has value further studied, very necessary protect this nature legacy of history.

Key words: hexagonal joint; rhyolite and tuff; trachyandesite; basalt

1 前 言

香港地区位于中国华南珠江河口东岸，南部面向南中国海，属粤东莲花山山脉南西西向入海末端，在地貌上属里亚士式丘陵半岛及岛屿地貌。

在地质构造上香港地区属于粤东莲花山大断裂带南西末端，具泥盆系、石炭系、二叠系，侏罗系，白垩系及第三系地层，历经印支运动及燕山运动形成北东东向粤东莲花山大断裂褶皱带。中生代末期花岗岩浆活动及火山喷发活动十分强烈。至今产出的花岗岩类岩石、流纹岩及其大量凝灰岩体占香港陆地面积的 85%(图 1)。

在香港地区东部及东南部，九龙半岛的清水湾半岛向北东经果洲群岛、滘西洲、缸瓮群岛，再经万宜水库、粮船湾海，东伸直至大浪湾、蚺蛇尖、大滩海及塔门岛大约 100km² 陆地范围内，出露晚期侏罗纪—白垩纪早期中酸性—酸性粗面英安岩及流纹岩以及它们的凝灰岩，它们在沿海地带形成香港最奇特的地质景观(图 2)，即发育显著的柱状节理特别是六方柱节理。岩柱自海中裸露上升挺拔或在沿海形成海蚀崖，栉比成岩柱群，高达百米，十分雄伟和壮观。

在当前世界和中国范围内，都是十分罕见的，堪称美妙雄伟的世界级的地质历史遗产。

2 岩石六方柱的地质特征

香港东部西贡地区半岛及岛屿出露的柱状节理岩柱可分内外两带，内带位于东部沿海岛屿及半岛上，后者则位于清水湾半岛北至东北经西贡再经北东至东海岸塔门岛，为一种六角面体乃至多角体的岩石，其地质地貌特征如下：

(1)内带

果州群岛-粮船湾半岛及大浪湾一带产出最奇特的六方柱地质地貌景观，主要和最显露的岩层和地区一是香港东南方的果洲群岛(图 3)，二是前者东北 2km 的缸瓮群岛，三是万宜水库东坝及西贡东海岸和蚺蛇尖一带，方圆数十平方。

岩石主要有流纹岩及其凝灰岩、流纹质凝灰岩、其他还有流纹质熔岩、石泡流纹岩、珍珠状流纹岩及球粒状流纹岩等(图 4、图 5、图 6)，岩石颜色呈沉暗灰红色，致密块状。流纹岩及熔岩可见大量红色长石及石英碎斑，均匀分布在岩石中。所含长石及石英碎斑大小 0.5～0.2cm，基质呈灰紫色，质地较均一，基质为霏细质岩石时具流纹构造(图 7、图 8、图 9)。上部主要是流纹质细火山岩，另一种较普遍的岩石是火山灰凝灰岩，它的特征是有大量较大的长石碎斑及少量石英碎斑(图 8、图 9)，基质由极细的玻璃质及极细霏细质物质组成，常与流纹质熔岩互层，前者常见于岩石中，呈火焰式结构，意味着岩石形成同时具有细浮石碎粒，上述主要岩石种类可相间互层，但以细火山灰凝灰岩为主，以粮船湾万宜水库地区粗略估计约厚 400m。在上述岩石地区广泛发育近于垂直的柱状节理，规模巨大，处处皆是。

果洲群岛节理以六方柱为主，且较均匀，平均直径为 1～1.2m，自海中升起挺拔高耸指天，鬼斧神工，十分雄伟和壮观(图 10、图 11)。这里险奇著称，所有柱石都位于直立崖岩之上。由于海蚀作用及风化作用以及海水上升下降之潮汐作用，岛上顺节理或断裂易形成高达 10m 的海蚀洞，以及顺火山冷却面形成空穴及柱石倾倒呈石炮状，人们称之为炮台石(图 12)。这是因为柱状石顺冷却界面裂开倒立呈炮状故得名。北岛银瓶颈与大灶口洞，直崖下海近 40m，十分险要。由果州群岛向北东跨海约 10km 即瓮缸群岛。在果洲群岛海域，六方柱遍布南果洲岛、北果洲岛、东果洲岛共 10 余个大小岛屿向东北到瓮缸群岛由火石洲、峭壁洲(瓮缸洲)、伙头坟洲(晨曦岛)及横洲四大主岛及若干小岛组成，它们组成列岛在海浪涨退潮作用下构成海上石林群，六方柱全部裸露。这些洲产出许多许多六方柱节理发育的绝伦地质景观。吊钟洲南峰有垂直六方柱形成"金鱼摆尾"(图 13)，牛尾海岛，近于垂直的巍峨瑰丽天然宫殿的六方柱屏障，顺淘空六方柱节理形成巨孔空穴，气穴喷水洞穴，洞顶具燕子的燕子岩。火石洲岛由于是六角柱岩石组成、断裂被海水两边侵蚀形成穿洞拱门，可过小艇，又称关刀大洞。晨曦岛最出名的是吊钟洞(图 14)、大空穴、虎昭洞(图 15)、沙塘口洞峭壁以及气宇轩昂的一柱擎天(图 16)。

自瓮缸群岛向北经天后庙、白腊湾(图 17)及白腊仔处处可见六方柱屹立，在海平面以上的 50m 均裸露无遗且多具海蚀洞(图 18)。再往东是破边洲和万宜水库。

万宜水库周围因六方柱节理也形成大量的岩峭直壁地貌景观，如龙脊岩留音洞(图 19)。巨大六方柱石排列成屏幕似风琴壁(图 20)，这里六方柱大小均匀，平均直径是 0.8～2.0m，高达 50m(图 21)，万宜水库东坝外和防波堤之间留音洞、斧劈崖、断柱岩在海蚀作用的顺岩石六

方柱劈裂隙形成孤岛叫破边洲，十分壮观(图 22)。万宜水库南边岩坡面向南中国海，每年平均具有 12 次台风侵犯，冲蚀悬崖加以海浪打击，湾里形成大量的椭圆球状海成砾石。在万宜水库东坝建筑开挖出六方柱近于直立但在凝结时滑移并被后期的基性辉长岩脉充填而形成六方柱折曲的壮观景象(图 23、图 24)。这些开发的陡壁揭示许多构成六方柱的岩石类型和特征。有些岩石可见新鲜的流纹质凝灰岩，其中可见肉红色钾长石和深灰色石英的碎斑，就是这些碎斑凝灰岩形成巨石层状陡壁以及局部的扭曲。这些岩石可能是还处在塑性状态时，因岩石层本身的重力下滑作用在局部的扭曲，根据这种扭曲的方向可推测岩层原始倾斜方向。

顺破边洲、跨东坝以东便是浪茄湾，两岸柱石林立壮观，在浪茄湾、大湾和二湾之间出露火山角砾岩，可能是上述岩石的母岩。接着向北至西湾山，万宜水库以东直至西湾、大湾，蚺蛇尖山及赤径，均分布流纹质凝灰岩。

这些沿海地区，六方柱岩石面向东南沿海，海蚀强烈，形成六方柱地区内带。自将军澳向北东经马鞍山以南，可见凝灰岩柱状节理，再经赤径在南蛇尖直至塔门岛。自将军澳向南西跨蓝塘海峡至香港岛东南高连巨山、紫罗兰山沿线直至奇力山以南，均有柱状节理岩柱出现。

(2)外带

清水湾中端-西贡东北部塔门一带自清水湾半岛西岸佛堂洲及附近岛屿及铁蓼洲一带直至半岛石尾头出露流纹带状粗面安山岩、玻璃质凝灰岩及流纹状熔岩。清水湾及太庙湾出露的粗面安山岩也出露直径 2～2.5m 的六方柱节理。它们倾向北东延伸经大滩海峡两岸然后延伸至塔门岛东岸。后者出露为粗面灰晶凝灰岩。岩石褐灰色深灰色与内带岩石颜色不同。就岩性及产状上得知其是位于外带的流纹岩系列岩石之下。就岩柱规则表面上次于内带。但岩柱巨大到直径 2～2.5m，高达 10m 以上。在塔门岛南边沿海柱石多边而且多顺冷却面节理形成柱状叠石(图 25)。

上述六方柱节理广泛分布于粮船湾流纹岩岩组及其凝灰岩之外，分布于上述岩组的下覆地层清水湾组中的大庙湾段粗面英安岩中亦发育多角边柱节理。

大庙湾段在清水湾和大澳门半岛以及佛堂角地带出露主要为粗安质熔岩和流纹质熔岩包括细火山灰凝灰岩和层凝灰岩。在清水湾一带产出大于 2m 的六方柱节理，岩石中具少量石英残斑及主要为斜长石及碱性长石的碎斑岩。

在大庙湾一带主要分布粗面英安岩，石英斑晶约 7%，大量斜长石和碱性长石斑晶，约 2cm，基质为细晶质。它们构成灰绿色具流纹质构造。岩石具酸至中性。其中两个岩石化学分析结果见表 1：

表 1

	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	H_2O^+	H_2O^-	P_2O_5	总数(%)
甲	62.33	0.58	16.73	1.19	3.4	0.15	0.1	3.22	2.5	6.12	1.64	0.15	0.21	99.32
乙	65.89	0.53	15.58	1.07	3.14	0.11	0.96	2.78	3.27	5.2	1.34	0.15	0.21	100.23

注：资料来自 Hong Kong Geological Survey Memoir No.4

西贡地区东北大滩至塔门岛亦产生六方柱节理，主要产于长滩及其周围地区至黄石公园，东山淇山半岛、蛋家湾、高流湾及塔门岛。六方柱节理所属岩石多为块状粗灰凝灰岩，含碎屑，

含花岗岩碎屑,斑杂岩碎屑和火熔式凝灰岩。在高流湾以北塔门亦可清楚见多面体柱。塔门镇以东海滩即可见著名的多为节理体——吕字岩。

上述多面节理柱的岩石均属酸性岩,化学成分见表 2。

表 2

	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	CaO	Na_2O	K_2O	H_2O^+	H_2O^-	P_2O_5	总数(%)
黄石公园	73.58	0.25	13.09	0.9720	1.15	0.06	1.48	3.2	4.9	0.74	0.22	0.06	99.56
海下	72.94	0.28	13.14	0.6074	1.73	0.06	1.94	3.04	4.68	0.94	0.1	0.06	100.24
海下湾	74.43	0.21	12.22	0.6320	1.15	0.06	1.9	2.94	4.86	0.65	0.15	0.04	99.84

注:资料来自 Hong Kong Geological Survey Memoir No. 4

3 六方柱节理岩石地球化学特征与对比

香港东南沿海及将军澳、石澳、西贡、万宜水库直至塔门,包括上述内外两带的具六方柱节理及柱状节理英安硫纹质岩系熔岩及其凝灰岩,经香港土力工程处组织测定结果及海内外对比见表 3。

依据上述香港六方柱节理母岩外带的粗面英安岩和内带的流纹岩及其凝灰岩化学分析与邻区广东省同时代岩性相似,也与中国和世界同类岩石化学分析平均值相近,以 SiO_2 为准,外带粗面英安岩中含 63.33%～66%,内带流纹岩及其凝灰岩则为 73%～76%,故属流纹岩无异。

4 香港六方柱节理母岩的年龄探讨

根据在香港火山岩区各种火山岩系中所含沉积岩夹层中发现到的各类植物化石,经鉴定其时代均为早白垩世。

而香港土力工程处根据铀-铅法分析取得的资料结果,香港于外内带所取得的粗面英安岩及其凝灰岩,其时代为早白垩世 142.7±0.2Ma。而在内带所取得的流纹岩及其凝灰岩,其时代为稍晚的早白垩世 140.9±0.2Ma 及 140.7±0.2Ma。这说明香港具有六方柱节理的火山岩及其凝灰岩与广东省的大量分布的流纹岩及其凝灰岩称为高基坪群火山岩系时代相似。也与浙江省东部和南部出露的具六方柱节理的寿昌火山岩相类似。根据香港流纹岩的时代与相关的侵入相酸性花岗岩,即:香港花岗岩体,南丫岛及蒲台岛黑云母花岗岩,其时代年龄是 140±7Ma。同时在广东省东部沿海也有相应时代的黑云母花岗岩,包括粤东铸镔洞空晶花岗岩。

综上所述,香港含柱状节理的英安流纹岩及其母岩花岗岩类与广东东部包括莲花山山脉的岩浆岩同属中生代欧亚大陆东南边缘包括浙江、福建、广东及香港等地火山活动活跃带。是太平洋板块向欧亚大陆板块俯冲挤压下导致大陆板块上隆,在大陆仰冲板块上,自沿海向内陆形成了火山弧带和板内构造变异带,引导俯冲下物质重熔,形成大量中酸性岩浆,进而顺早期断裂上涌形成花岗岩及相应的火山岩,并形成北东东向莲花山岩浆带。香港有幸也发育了侏

表 3

元素 \ 取样位置	清水湾 HK6010	清水湾 HK6011	海下路 HK6832	粮船湾	万宜水库 HK6003	广东平均值(%)	世界平均值(%)	中国平均值(%)	世界平均值(%)	世界平均值(%)	广东平均值(%)	世界平均值(%)	广东省东边石基坪	香港红磡
SiO_2	62.33	65.89	72.94	75.03	76.14	74.0	64.33	72.06	72.82	65.68	46.10	49.20	67.63	74.24
TiO_2	0.58	0.53	0.28	0.33	0.1	0.19	0.51	0.29	0.28	0.57	2.16	1.84	0.42	0.13
Al_2O_3	16.73	15.58	13.14	12.30	12.82	13.01	16.03	13.40	13.27	16.25	14.49	15.74	14.76	12.34
Fe_2O_3	1.19	1.07	0.6074	0.29	0.47	1.27	2.49	1.82	1.48	2.38	2.74	3.79	1.33	1.38
FeO	3.4	3.14	1.73	1.44	1.01	1.30	3.17	2.11	1.11	1.90	8.55	7.13	3.32	1.07
MnO	0.15	0.11	0.06		0.08	0.07	0.16	0.08	0.06	0.06	0.22	0.20	1.05	0.06
MgO	0.1	0.96	0.5	0.09	0.03	0.27	0.31	0.28	0.39	1.41	9.13	6.73	0.82	0.15
CaO	3.22	2.78	1.94	1.35	0.68	0.57	1.30	0.75	1.14	3.46	8.28	9.47	2.62	0.82
Na_2O	2.5	3.27	3.04	3.65	3.16	1.73	5.43	3.74	3.35	3.97	3.55	2.91	3.59	3.13
K_2O	6.12	5.2	4.68	5.41	5.27	5.35	5.35	4.55	4.30	2.67	1.45	1.10	3.62	5.12
H_2O^+	1.64	1.34	0.94	0.26	0		0.29	0.63	1.10	1.50		0.95		0.28
H_2O^-	0.15	0.15	0.1	0.16	0									0.10
P_2O_5	0.21	0.21	0.06		0.01	0.04	0.09	0.10	0.07	0.15	0.56	0.35	0.08	0.02
S				0.25										
总计	99.32	100.23	100.24	100.56										
岩石名称	粗面英安岩	粗面英安岩	细流纹凝灰岩	流纹岩	细火山灰玻璃质凝灰岩	流纹质熔结凝灰岩	粗面岩	流纹岩	流纹岩	英安岩	玄武岩	玄武岩	英安岩	黑云母花岗岩
单位作者	据香港土力工程处	据香港土力工程处	据香港土力工程处	据 David	据香港土力工程处	据广东省地质志	据李石黎彤	据李石黎彤	据李石列梅特尔	据李石火山岩	据广东省地质志	据李石列梅特尔	据广东省地质志	据广东省地质志
参考资料	1997	1997	1997	1954	1997	1988					1988		1988	1988

罗—白垩纪岩浆火山带，而含柱状节理的火山岩系岩石则成为香港产生晚期中生代火山岩地带。它们的结构决定当时是属于大陆边缘境内形成，而非海洋中形成。而香港火山岩带也就是粤东著名的莲花山岩浆—火山岩带西南末端，成为大陆性花岗—火山岩带的一部分。

5　香港火山岩六方柱节理成因机理

上述香港六方柱的岩石是属于中酸性英安岩—流纹岩系列的粮船湾组，主要岩石为细火山灰凝灰岩，包括流纹岩及其凝灰岩，其化学成分见表 4。

表 4

SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	H_2O^+	H_2O^-	P_2O_5	总数
76.14	0.1	12.82	0.47	1.01	0.08	0.03	0.08	3.16	5.27	0.6	0.12	0.01	100.49

岩石中含二氧化硅特高，而钾也高但铝则低，显然不同于目前世界上或中国一般认为六方柱节理只存在于基性的玄武岩的专属性。相反，香港六方柱节理的岩石属酸性流纹岩系列，因此我们可以按基性岩六方柱节理成因机理分析香港的六方柱。

我们设想一般认为基性玄武岩六方柱节理的产生是冷却前岩浆温度在 1300℃左右，鉴于基性岩浆化学性能形成岩浆冷却快且流动快，我们根据资料与实地观察玄武岩六方柱直径一般在 20～30cm 左右。那么，对于酸性熔岩岩浆只要成分较均匀，温度达到 1300℃以上，其粘致度可以保持相当的话，当遇应力之作用如地震作用便会使岩浆向不同中心收缩。有机会有序地冷却，相信也可以缓慢由冷却面往下部逐步冷却，形成比一般玄武岩更大块的六方柱节理。这就是为什么世界和中国各地所见到的六方柱直径在 20～30cm，而香港果洲群岛、瓮缸群岛及粮船湾水库一带的流纹岩及其凝灰岩则可形成大至 1.2～1.5m 的六方柱。

当今世界上中外著作中，描述岩石六方柱节理或柱状节理，都以玄武岩为基本，一般认为基性岩浆喷发温度高达 1 100～1 300℃，二氧化硅粘度低，岩熔流动性快，温降快。一般设想拟上述条件，假设岩浆表面有任何 3 个冷却的中点，彼此发生冷却收缩，相互形成的张力破裂首先形成 3 个 120°的裂面，自冷却面向下垂直扩张，在冷却面上则形成一中心，周围 6 个任何冷却中心，彼此的冷却收缩而形成张力作用裂面，自然可形成漂亮显著六方柱节面。由于冷却较快，这些玄武岩浆自然形成六方节面，自冷却面传入岩浆内部导致形成六方柱了。

如今，香港却在酸性火山岩发生有六方柱节理，实属罕见。为何形成六方柱节理，我们可以设想，岩浆中含较多二氧化硅、钾高而锂低、铁镁质低条件下，岩浆质地较均匀、温度均匀在 1 300℃左右流动性较快，火山口较高铁，镁少，质地较轻，熔浆斜坡大，也可以形成为基性岩浆的特点，进而也可产生六方柱节理。且六方柱直径可比玄武岩大，这就是为什么世界及中国各地所见玄武岩六方柱节理直径在 20～30cm 而香港果洲群岛的流纹岩及其凝灰岩则可形成大致 1.2～2m 的六方柱了(图 26、图 27)。

6　香港东南沿海岩石六方柱节理(含多边柱节理)地貌景观的形成机理

印支运动时期，香港地区就从属于华南地区(粤)北东东—南西西向莲花山大断裂褶皱带。

到侏罗纪至早白垩世燕山运动不断，华南地区太平洋板块向北与欧亚大陆板块碰撞，在后者板块地壳重熔上升发生大规模的酸性花岗岩质岩石侵入和火山喷发活动，其中顺着莲花山岩浆-火山岩带，它们的活动波及香港形成两期燕山花岗岩及相应的火山岩系(现今香港陆地面积统计占 85%)。香港东南地区流纹岩浆爆发，火山物质均匀，温度高，有幸在凝固过程中形成大量六方柱节理。香港从而形成岩浆—火山岩火山口山地及丘陵地带。

第三纪早期，香港地区以南广大地区与北向扩张形成著名的南中国海，香港面对南中国海渐形成低山丘陵地带。第四纪以来，珠江经香港的出河口是在现今海岸以南 120km 的南海大陆架位置。

直到晚更新世，大约 15000 年前以来，全球第四间冰期来临，冰水溶化海水面上升，南海海水面呈东西向向北，顺古珠江口推进，已有资料记载南海北侵已达到现今海平面以上的 30 余米的水位，那么可以冲刷香港东南果洲群岛的六方柱节理岩石。这次海侵已北上到达广州市以北的地区，这次海水面上升顺南海沿近东西走向海岸带北侵。这样才可能以近东西走向近海冲刷南西西—北东东向莲花山岩浆—火山岩带的南西末端的香港地区。于是香港东南沿海分布的六方柱节理形成低山丘陵，被海水侵蚀作用将岩石六方柱完全暴露于香港东部及南部数百平方公里的海岛及陆地，形成重要的岩石天然屏障。海蚀作用帮助六方柱冲刷裸露，成为美丽的均匀的六方柱地貌景观，气势磅礴，峭壁耸立，许多六方柱群自海中直立挺拔高耸入云，十分壮观。以酸性流纹岩及其凝灰岩形成独特的六方柱群而令其纹理清晰，气势恢弘，这种十分雄伟和壮丽的地质地貌景观在中国十分罕见，在世界范围内也是特有的！

7　香港与内地六方柱节理岩石

中国和世界各地在介绍六方柱节理岩石时，近百年来基本上只以基性玄武岩为蓝本。其中，中国地学辞典及岩石著作也以玄武岩为主(表 5)。

中国辽宁教育出版社出版《岩石与矿物》一书中，叙及六方柱节理时就列举了北爱尔兰巨人岬玄武岩。1980 年地质出版社出版《地质辞典》描述了柱状节理以火山岩特别是其中一基性熔岩和某些次火山岩中发育的呈多角柱状的节理。

由岩浆或熔岩流冷却收缩而成柱体垂直屹立的冷却面发生，断石近六角形，例如玄武岩、安山岩等的柱状节理。台湾省 1994 年出版地质书籍中描述了澎湖列岛玄武岩六方柱(图 28)。

1981 年李石葵所著《火山岩》中指出柱状节理的岩石也在北爱尔兰、南高加索以及江苏南京六合方山和四川嘉陵江上游的玄武岩中，常见柱状节理。而流动性岩浆的酸性火山岩中柱状节理很不发育，经常出现的是水平节理和板状节理。我国福建漳州滨海国家地质公园及台湾省澎湖列岛，也是由规模宏大的第三纪玄武岩六方柱节理经海蚀作用后形成了独特的第三纪玄武岩火山海蚀地貌，从而构成了独特景观。

除已发表各地玄武岩六方柱节理外，还有少量地区的粗面岩及英安岩六方柱节理，见表 6。

内地有没有发现酸性流纹岩及其凝灰岩中，有六方柱节理呢？自 20 世纪 50 年代起直至 70 年代经过正规 1∶200 000 比例尺地质测量，各省的报告中透露已不断发现流纹岩的六方柱节理。

1979 年,地质出版社出版了浙江火山岩结构图册。在国内首次描述浙江省文成党口西园,平阳大渔,衢县项家,隔海大嶨头的流纹质熔结凝灰岩及流纹斑岩的柱状节理(图 29),见表 7。在我国浙江省中南部和滨海海蚀流纹岩及其凝灰岩规模宏大,除 10 余县具酸性六方柱,滨海数县均有着全国规模最大的地质景点。

表 5　中国部分地区六方柱(含多面体)节理的玄武岩

省/自治区	地点	具六方柱(含多角) 节理的玄武岩
广东省	佛山、西借岗	第三纪玄武岩
广东省	徐闻、海安镇	第三纪玄武岩,直径 0.5m,长可达 20m
广东省	湛江、徐闻、节岭文部村,硇州岛	第三纪,第四纪玄武岩 150～180 万年前,长 20m,玛尔湖六方柱
海南省	海口 马鞍山	附近玄武岩六方柱
海南省	临高 北海岸	沿海玄武岩六方柱
云南省	腾冲县中心	三万年前玄武岩年轻石柱、六方柱
贵州省	丽江 河学	二叠纪玄武岩六方柱
四川省	峨眉山 金顶	二叠纪玄武岩六方柱
福建省	漳州市漳浦翟	玄武岩 规模巨大 25 百万年前
福建省	漳州市林进屿	
福建省	漳州市龙海市	2460 万年的有 $0.7km^2$,玄武岩六方柱沿海裸露多种形态
福建省	漳州市牛头山	具有多种形成的六方柱,斜立直立环状态
福建省	漳浦县南碲南	直立高耸岛为学古色,顶尖,高 60 多米,40 多万松
台湾省	澎湖列岛	一千万年前玄武岩,多呈玄武岩崖岸,环状体,斜立柱状体,放射状柱状节理,澎湖列岛与福建省漳浦之岛玄武岩及六方柱均相似
江苏省	南京市六合方山	玄武岩
江苏省	盱眙	玄武岩
黑龙省	西南部柴河	$4.75\times10^4km^2$,六方柱,正方体和菱形玄武岩柱群,15km 长
黑龙省	柴河一绰尔河谷	玄武岩六方柱
吉林省	长白山十五连沟	玄武岩,高 20 多米,直径 60cm,粗大茎高
河北省	张北大疙瘩村、汉诺坝	玄武岩柱状节理
山西省	大同火山群	玄武岩柱状节理
山东省	应县石柱沟	玄武岩柱状节理成峭壁
山东省	铜井湾	玄武岩柱状节理成峭壁
广西壮族自治区	涠州岛	玄武岩岩柱及石蛋

表 6

省	地点	具六方柱节理的粗面岩
广东省	佛山　西樵山	粗面岩,早第三纪次火山岩
江苏省	镇江　北固山	粗面岩

表 7　内地具六方柱节理流纹岩及其凝灰岩分布(部分)

省/自治区	地点	具六方柱节理的流纹岩及其凝灰岩
吉林省	四平,山门	20 世纪 70 年代区测指出四平具 1.1 亿年流纹岩
浙江省	宁波市象山花岙岛	流熔结凝灰岩,岛及半岛,神奇瑰硕,早白垩世
	宁波市岔路镇	流熔结凝灰岩,早白垩世
	宁波市茶院镇	流熔结凝灰岩,六方柱节理个体直径 130cm,柱高近 40m,早白垩世
	临海市大嶨头	流熔结凝灰岩,六方柱 4～8m 不等,直立具瀑布
	临海市桃渚镇	流纹质碎斑熔岩及流纹岩,直立柱为 4～8m 不等,早白垩世
	乐清市雁荡山	流熔结凝灰岩,雄伟壮丽,六方柱正直立,直径 20～50cm(见图 30)
	文成县党口西园	流纹斑岩柱体,个体 20～40cm,早白垩世
	平阳县大渔镇	流纹质熔结凝灰岩,早白垩世六方柱节理
	衢县项家	流纹质熔结凝灰岩,六方柱,断面直径 20～30cm,早白垩世
	衢州市湖南镇	流熔结凝灰岩,六方柱,早白垩世
	天台县雷乡	流熔结凝灰岩,六方柱,早白垩世
	台州市上盘镇椒江区	流熔结凝灰岩,六方柱
	永嘉市枫林镇	流纹质熔结凝灰岩,六方柱,早白垩世
	青田县贵岙乡	流纹质熔结凝灰岩,六方柱,早白垩世
	仙居县上张乡	流熔结凝灰岩,六方柱,早白垩世
	永嘉县枫林镇	流熔结凝灰岩,六方柱
	永嘉县花坦乡	流熔结凝灰岩,六方柱
河北省	张家口山台岭沟	流纹岩,六方柱,直径 20～40cm,6700 万年,早白垩世
	张北县	流纹岩六方柱状节理
辽宁省	关门山	流纹岩六方柱状节理
内蒙古自治区	太仆寺旗(宝昌镇)	流纹岩六方柱状节理
内蒙古自治区	赤峰市	流纹岩六方柱
山东省	即墨	流纹岩六方柱

香港西贡沿海地区早白垩世流纹岩及其凝灰岩出现于滨海及海中耸立指天，香港以30km² 面积，出现数千万根六方柱节理石，尖山海岛及半岛台地相间分布，十分壮观和美丽。虽规模远不及浙江地区，但地质地貌景观集中，在沿海地区也属佳品。

在地质地貌上香港是欧亚大陆与太平洋板块碰撞中，中生代末岩浆喷发活动重要地区之一，属研究重要地区之一，具有世界自然地质历史遗产的价值。

8 六方柱(含多边柱)节理在国际上的描述

近百年来，大量文献描述和论述柱状节理(含六方柱节理)，其描述母岩都是基性玄武岩(表 8)，俗话说：要说六方柱节理非玄武岩莫属。

表 8　世界各地著名六方柱及其母岩(部分) 列表

国家	地点	六方柱
北爱尔兰	Giant's Courseway	早白垩世玄武岩六方柱，世界著名的六方柱标准地点，还有 4 或 5 方柱节理
美国	Valles 火山口，新墨西哥州	玄武岩及凝灰岩，超过 100m 厚
美国	黄石公园	玄武岩柱状节理，5 千万年前玄武岩六方柱
英国苏格兰	Fingal's Cave	Staffa, Scotland, Basalt lave，柱状节理
美国	California Devils Postpile	玄武岩垂直六方柱，2 万年前形成(见图 32)
美国	加州 National Monument	California 美国著名玄武岩六方柱节理
美国	Devil Tower in Wyoming	玄武岩火山颈六方柱，40 万年前直火山颈六方柱是美国著名六方柱景观(见图 33)
美国	Buhl, Idaho	玄武岩六方柱，直径 0.5～1 m 宽
美国	Oregon 东部	玄武岩六方柱
美国	盐河火山岩，亚利桑那州	玄武岩六方柱
美国	Washington 东部	玄武岩六方柱
美国	科罗拉多河，大峡谷西	玄武岩岩流，六方柱厚 100m
澳洲	Kiama	玄武岩六方柱节理

(1)美国 Julia & Jackson，1995 出版地质术语汇编说柱状节理在基性岩流和有时在其他喷出岩或侵入岩形成平行，棱柱形的切面是多边形它是冷却时收缩固结形成的。

(2)美国 Stan Chermicoff & Ramesh Venkatakrishnan，1995. Geology 书上描述柱状节理是基性岩浆冷却体积收缩形成的破裂模式，称柱状节理可形成五至六边多边玄武岩柱，书中举例“北爱尔兰岛 Giant Causeway 玄武岩组成六方柱结构的玄武岩柱体直径约 20～30cm(图 31)，类似结构的玄武岩亦可在北美东华盛顿，东 Oregon 州，南 Idaho 州，东加州，黄石国家公园和东部 Wyoming 州。”部分地区指出安山岩含安山质高铁镁岩石可形成柱状节理，也说流纹岩流亦形成了柱状节理。

(3)Allsa Allaby & Michael Allaby，1999 年在地质科学辞典上说：“玄武岩和粒玄武岩岩浆在冷却和发展形成多边形节理系统，常呈正方形冷却。”

(4)1997 年，J. P. Michel 等在地球科学辞典指出柱状体是玄武质岩浆冷却成均匀柱状玄武岩。

(5)2006 年，Jacqueline Smith 则认为岩浆岩形成六边或五边节理柱，特别是玄武岩熔岩，最好的例子是苏格兰 Fingals Cave。

9 香港与世界各地流纹岩及其凝灰岩六方柱比较

目前世界上各国地质辞典、参考书、课本及著作在描述六方柱节理均以基性玄武岩为其母岩。凡是提及柱状节理(含多面体) 的母岩，言必是基性玄武岩，如美国第四版本 Glossary of Geology，认为六方柱并以玄武岩及其他岩石为例来描述。美国地质辞典 Physical Geology 及英国辞典，还有德国、日本、俄罗斯等国家均以玄武岩为例的六方柱节理。美国斯坦福大学出版的 Geology in the field 也举例夏威夷玄武岩六方柱为例。其中多以北爱尔兰 Staffa 地区临海地区出露的现已成为世界地质公园 The Giant's Causeway 为标准化，它以玄武岩为例作为六方柱节理经典，然而根据 Charle Hepworth Holland 等以第二版《爱尔兰地质》一书中在 Giant's Causeway 六方柱岩石柱中，中部组也有一小段夹有流纹岩质的流纹岩六方柱，但人们一直未予留意(见表 9)。

综上所述，世界柱状节理(含六方柱) 主要发育于(特别是板块交界地区)基性玄武岩内，似乎很少出露中生代酸性火山岩，故而只熟悉基性火山岩及其六方柱，相反中生代时期中国大陆地区特别是沿海地区在中生代是酸性岩浆和火山活动最强烈时期，固而酸性六方柱特别发育在浙江及香港地区。

表 9　世界各地部分流纹岩及其凝灰岩柱状节理

国家	地点	六方柱
美国	Chiricahua	流纹岩流纹质凝灰岩，多面体柱体，2 700 万年形成
美国	National Monument	
美国	新墨西哥州圣菲(Santa Fe)	西北部由熔结凝灰岩组成柱状节理
美国	黄石公园	流纹岩六方柱
北爱尔兰	Giant's Courseway	在玄武岩组中段具流纹岩夹层，亦具六方柱状节理

10 香港酸性火山岩六方柱节理的美学、科学价值及自然历史遗产意义

香港在 20 世纪 50 年代，David 博士在编著《香港地质》中已根据三四十年代加拿大英皇哥伦比亚大学地质学家在香港所作野外地质调查的野外成果在报告中首次公开岩石部分，香港流纹岩普遍有柱状节理，特别是六方柱节理。1971 年 P. M. Allen 博士等所作香港地质测量报告中述及香港东部清水湾、东果洲群岛等岛以北至万宜水库广泛分布流纹岩及其凝灰岩发育有大量六方柱状节理，但香港坊间则没有按此成果利用而是循规世界六方柱节理岩石必是玄武岩无疑，一直称“香港玄武岩”。这一误导直至最近才改称为流纹岩。

香港英安-流纹岩六方柱节理，集中于香港东部及东南部沿海及西贡半岛，其规模不及内

地如浙江省东部及南部10多个县份具有大面积分布的流纹岩及其凝灰岩六方柱节理，但却具有小而集中的特点。而香港的面积广且呈海屿及半岛出露加上有海蚀作用使其可呈裸露柱体集中出现，成排在海中出露，高耸挺拔，瑰丽壮观。

世界研究柱状节理及多角节理（包括六方柱及五方柱）方面，香港在时间上还是比较晚，前者测重于岩浆粘度，温度及冷却特征，而对于发育于酸性火山岩中的柱状节理未作发现报道，公开具体实例，报导也欠丰，更不用说对酸性火山岩柱状节理的研究成果。一般来说对基性岩柱状节理当然较为系统。

中国一般书籍中对柱状节理的专门描述也限于基性岩玄武岩。近年来开始对酸性流纹岩中的柱状节理也有所报导，这是可喜现象，但尚须同步赶上，特别是对酸性岩柱状节理的机理特征以及与其他同类构造有何异同。提出中国酸性岩柱状及六方柱节理成因研究、机理及其素材和范例，它所代表中生代晚期欧亚大陆华南地块与太平洋板块相互作用的意义，同时为研究古地理、古气候、古火山岩浆活动规律很有科学价值和意义。

香港流纹岩系及其凝灰岩的六方柱节理于沿海、滨海和海中产生岩石裸露，研究比较清楚和完整，而且在华东和华南地区具有较完整的早白垩世，所以具有重要的地质意义及科学价值。

世界上描述六方柱节理的岩石出产于非海滨地区比较多，唯英国北爱尔兰 Staffta 地区 Antrim（安特里米郡）和 Fingal's Cave（芬克尔洞），主要景观是海岸上发育在白垩纪玄武岩中4万多根直径38～50cm节理石柱，绵延约6km，形成壮观的玄武岩石柱林。1986年该景观被联合国教科文组织批准为世界自然和文化历史遗产。

总之，耸立于香港东南沿海的香港流纹岩及其凝灰岩，十分壮观奇特的地质景观世界罕见，符合世界自然地质历史遗产的标准，应申请世界自然地质历史遗产加以保护和认可。

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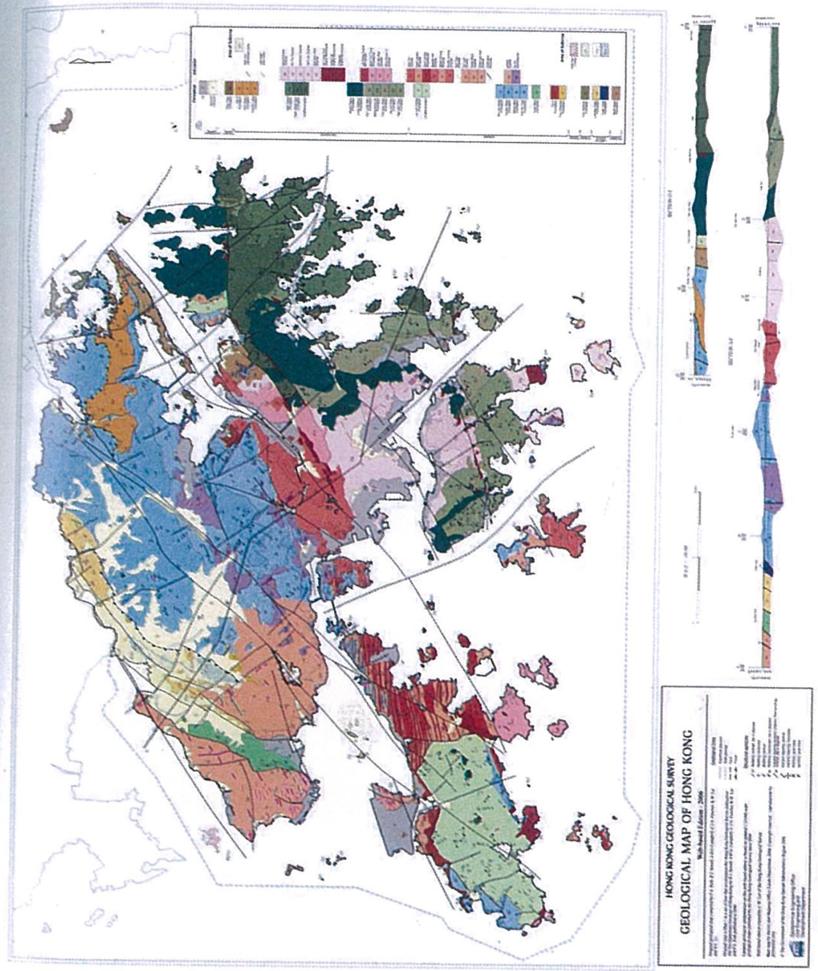
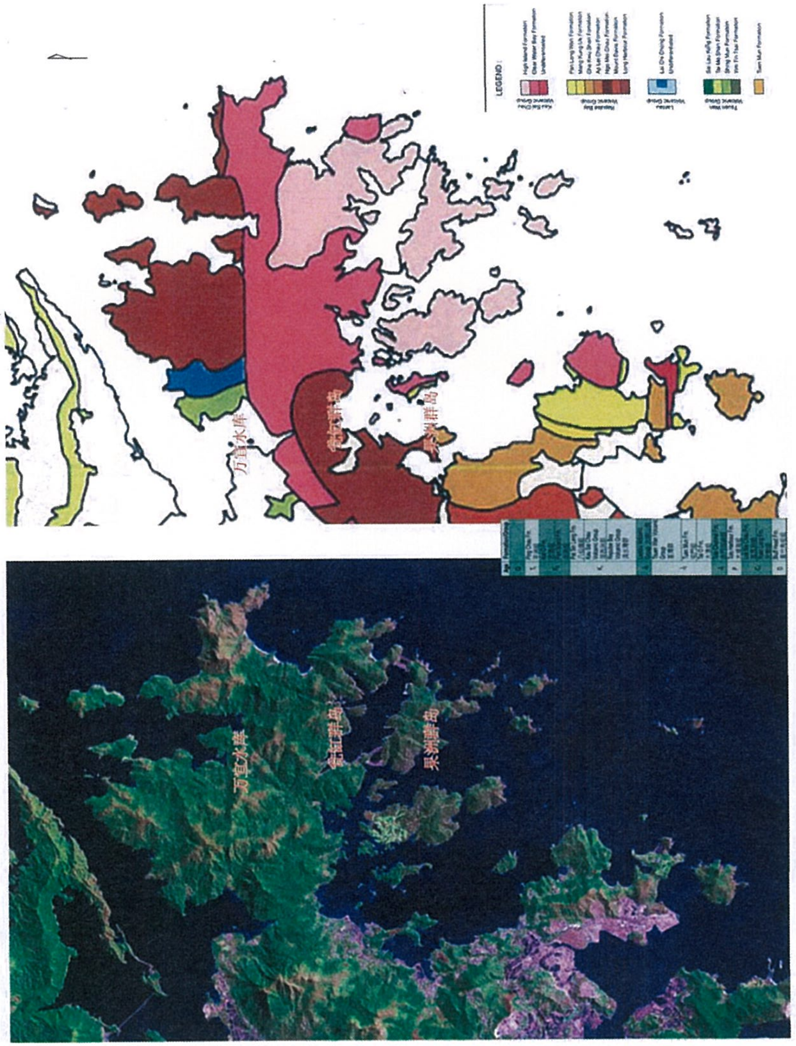


图 1 花岗岩、流纹岩及其凝灰岩体占香港陆地面积的 85%



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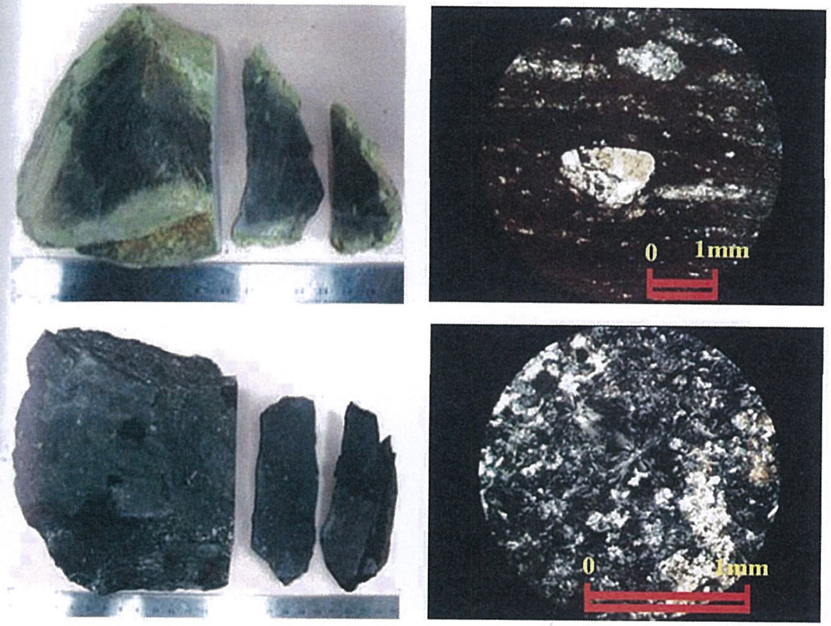

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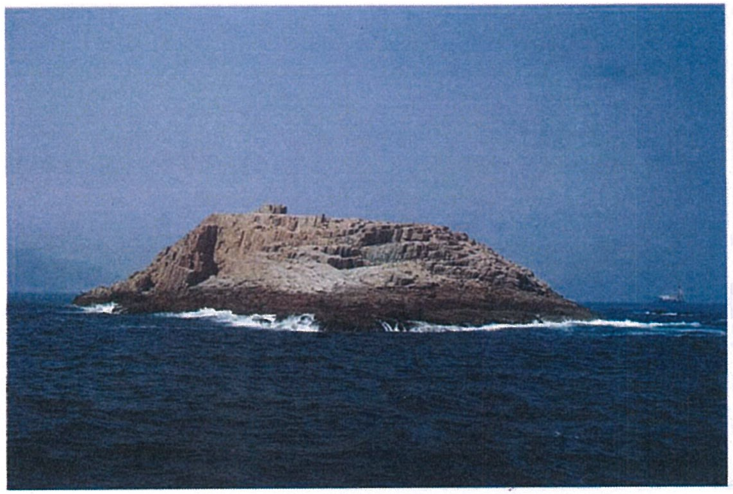

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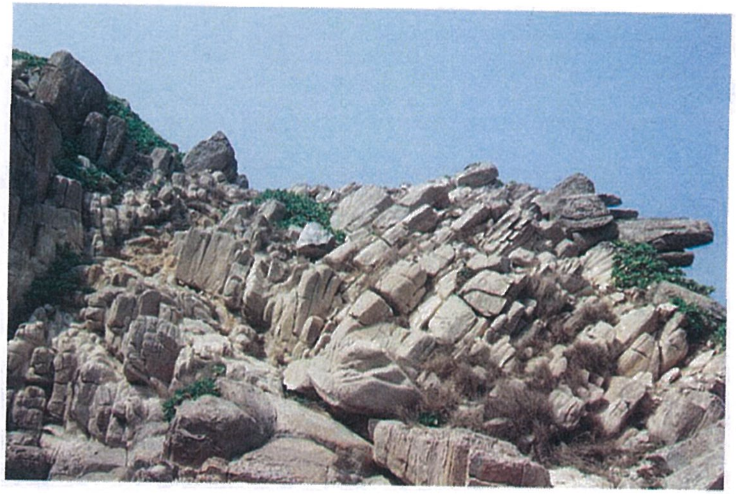

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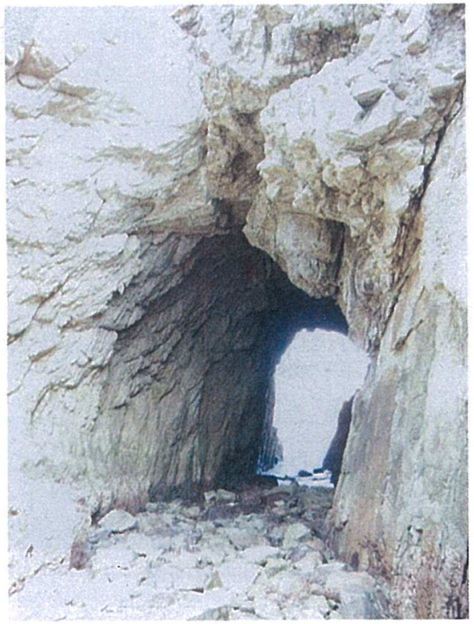

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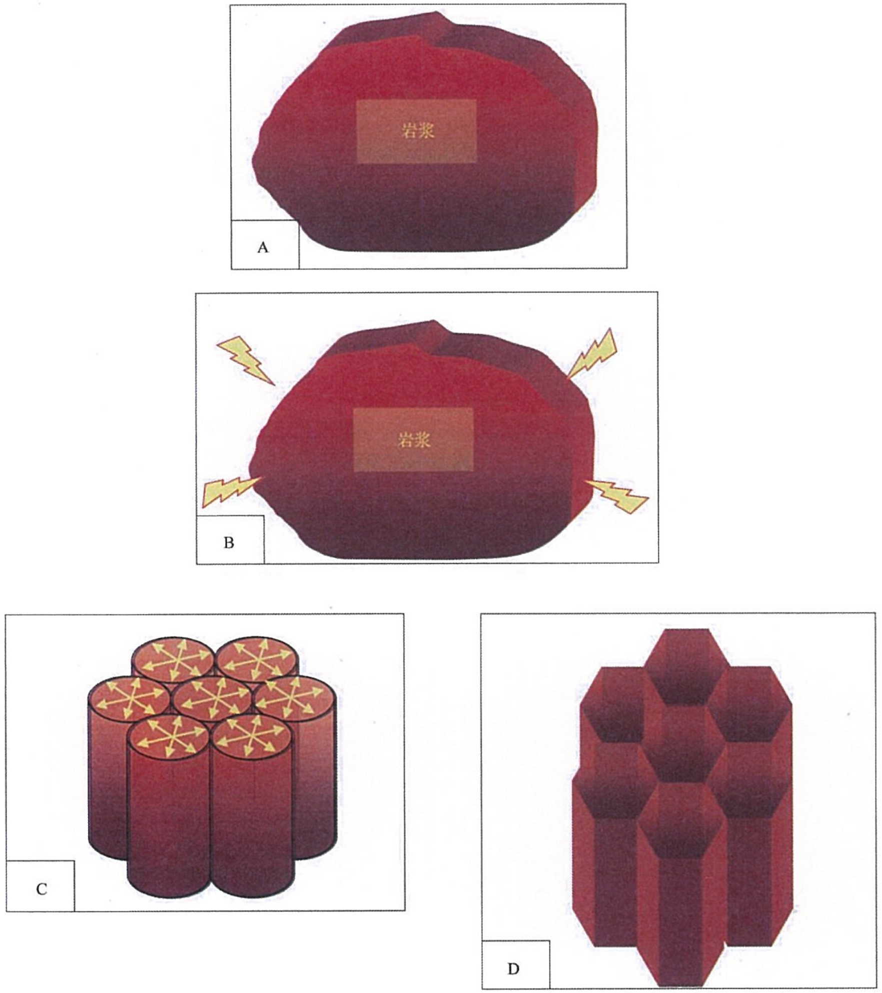


图 26　A.地底之下存在液态的岩浆，酸性岩浆的温度约在 900℃左右，当温度高于此值岩浆会保持液态；B.当温度下降，岩浆之黏度增加，此时有外来的应力震动出现；C.震动使岩浆产生不同中心的收缩；D.最后形成了六方柱结构

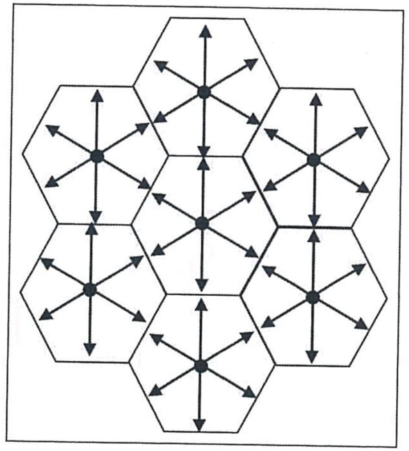
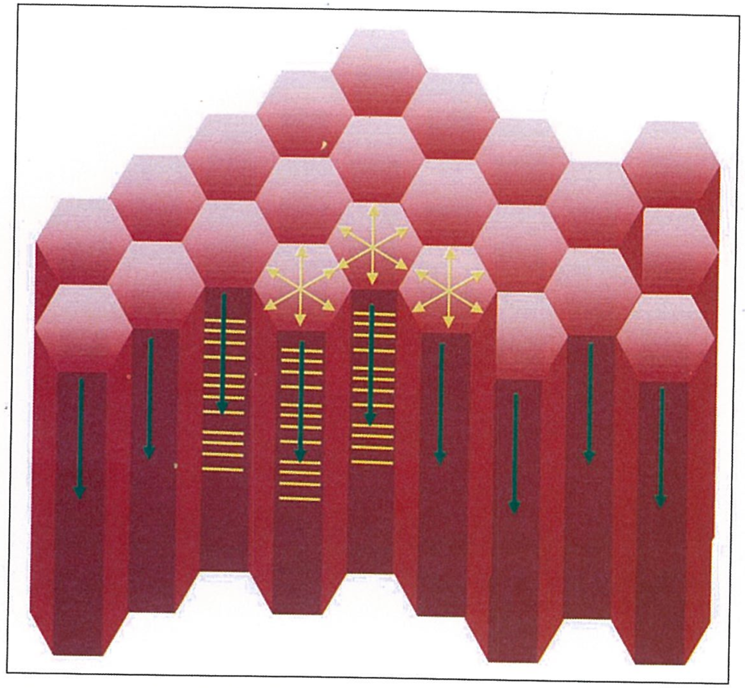


图 27　六方柱节理形成机理与岩浆冷却收缩中心的关系



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7 结　语

国内填海已有五十多年的历史，深圳的填海也积累了二十多年的经验，并取得了一定的技术成果。本文在总结这些工程经验的基础上，提出了一些岩土工程理论和设计参数选取的观点及施工技术。但是，我们也清醒地认识到，填海岩土工程问题比陆地上的填海岩土工程问题复杂得多，比如填海地基效果的检测技术还不成熟，如目前比较先进的探地雷达技术在检测残留淤泥的厚度存在较大误差，还应辅以地质钻探方法；海水对电磁波的吸收影响还无法修正等等，仍是我们要继续攻关的重要问题。填海过程和工后沉降监测既要引起重视，还要有系统的方法和有效手段，只有真实的数据才能进行深入的理论研究并指导工程实践。

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General Practice of Ground Investigation Works in Hong Kong Special Administrative Region

Yuen Kam-ming, Dennis

(Geological Society of Hong Kong－Professional Branch)

Abstract: The future development in Hong Kong Special Administrative Region ("Hong Kong" in short to be used in this paper) requires reasonably large amount of ground investigation works. Ground investigation works in Hong Kong generally includes retrieving soil and rock core samples from the ground in order to obtain the sub-surface geological information for foundation design and slope study by means of drilling works, excavation of trial pit/trench and field/laboratory tests, etc. This paper has briefly outlined the general practice of ground investigation works carried out in Hong Kong from their preparation and design stages of ground investigation works, the use of drilling equipments and sampling tools, various field tests and their supervision by competent persons; eventually compilation of reports for use of the engineers. Of course, an account on safety issues relating to ground investigation works is also described. As a result of ground investigation work, plenty of the disused rock core samples may be re-used in the construction of pavement and carriageway, decoration material in parks or even shopping malls, rather than disposing them to landfill sites. With the hope of joint efforts of the government and developers to promote geo-science in our community by displaying the geological information and the samples recovered under their properties, the general public will be able to learn the local geology from them. Hong Kong will become a large geological museum naturally on the whole.

Introduction

Geological science is one of the elements through which the geological knowledge can be applied to engineering designs for the rapid urban developments. Geological engineering is the practical application of principles, concepts and techniques of the geological sciences to provide sustainable-engineered solutions to human needs.

Geologists in Hong Kong generally work in contracting firms, consultants and the government. They produce geological logs, geological maps and reports; build-up of geological models; provide first-hand geological information for the subsequent geotechnical design by engineers. Due to the fast-paced urban development, there has been extensive sub-surface geological information obtained from ground investigation works mainly over the last 30 years. This information certainly is useful to the better understanding of the geological constraints and conditions in developing the areas concerned.

Prior to the development, such as the design of foundations for public housing, slope foundation, tunnels and bridges construction etc., ground investigation works to the construction sites are essential, which includes investigation by sinking drillholes, rock/soil slope investigation etc. In the scope of this paper, the general practice of ground investigation works for development of Hong Kong is described in details. The ground investigation procedures from the planning stage through the execution of ground investigation fieldwork, sampling tools, compilation of report, attention to environmental issues, safety concerns and environmental conservation are presented.

The retrieved geological information is very valuable and important for the design of urban developments. The disused rock core samples are also used for environmental purposes by re-using them in construction works.

Purpose of Ground Investigation

The purpose of ground investigation works for all types of developments in Hong Kong generally has similar goal to collect the underground information as much as possible and to build up geological models to facilitate the required designs.

Ground investigation works need to be carried out once the preliminary plan for a development has been endorsed. Ground investigation works are usually conducted at several stages namely: (a) feasibility study for ground condition by carrying out drilling of some boreholes; (b) detailed design by sinking more boreholes at locations of proposed structures of the development and conducting field and laboratory tests when its layout is available; and (c) sinking some more boreholes for confirmation of rock head level or soil properties as ground information for the engineer's design. At feasibility stage of ground investigation, boreholes are usually sunk over the entire site so that general geological information can be obtained for a preliminary ground assessment of the site. At this stage, there will be limited ground information available at the locations of the proposed structures. Following the next stage of ground investigation, drilling works are based on the designed layout plan and the boreholes are specifically located at the proposed structures to obtain the comprehensive ground information for the foundation/slope design. Last batch of boreholes are required to sink in the ground exactly at the pile/foundation locations or geotechnical structures in order to verify the ground conditions with respect to the foundation/slope design at the last stage of ground investigation works. In addition to sinking boreholes in ground investigation works, excavation of trial pits; trial trenches and slope stripping are also executed for locating the underground utilities (water pipes, sewerage pipes, electricity cables, telephone lines and gas pipes etc.), identifying if any adverse joint sets which may affect slope/foundation design. Surface stripping and drilling on slope surface help to retrieve sufficient sub-soil information for slope stability study too.

Planning Ground Investigation Works

Prior to the commencement of ground investigation fieldwork, a series of procedures have to be fulfilled. The engineer plans and designs the number and locations of boreholes, trial pits or slope stripping to be carried out on site. Site meetings with relevant parties, including the contractor's representatives, site inspectorate staff and land-owner representative, to apply/confirm site access and discuss the ways for carrying out ground investigation works smoothly as well as avoiding causing possible problems. A works order/instruction will be issued which stipulates all the requirements of the ground investigation works with a site layout plan. Setting out borehole locations is required on site as soon as instructions of ground investigation works are provided. Afterwards, contractor will mobilize drill rigs and equipments to the site and the drilling operation is ready.

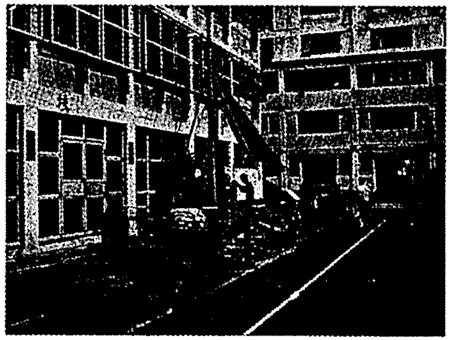

Fig. 1 General set up of works area for ground investigation

General drilling equipments include, but not limited to drill rig, drilling rods and casings, water tank for re-circulated water with silt removal facilities, electricity generator, portable site office (usually using metal container) and mobile toilet. Due to sunny weather of Hong Kong, the set up of a shading area above the drill rig using tarpaulin sheets or similar for the drillers is generally necessary.

Set up of Drilling Equipment

Ground investigation works will be carried out under different site circumstances:

(1) within an active construction site where site formation works are in progress and site access are obtained from the site formation contractor or relevant authorities; (2) within government land (under the control of Lands Department); (3) on public carriageway/footpath; (4) within private land lot.

Drill rigs and equipments are generally mobilized to site by crane lorry. However, the borehole locations may not always be convenient enough which are adjacent to an access road, they may be located miles up a squatter area where the access roads are narrow, as such the drill rigs and equipments need to be dismantled and carried manually through narrow access. In some cases, timber scaffolding is erected for the purpose of access and as working platform when ground investigation work is carried out on sites with difficult access. In some of the very remote site areas such as remote islands, mountainous terrain where transport of drill rigs and equipments are difficult, they are inevitably be transported by helicopter or other methods to the sites.

Sometimes, ground investigation works have to be carried out within uncovered car parks that are still in operation. Extra efforts were to be made to liaise with the car park owner for releasing available parking space at proposed borehole locations from time to time. However, through better communication and liaison, difficulty in completing the ground investigation works can be overcome generally.

Fig. 2 Access for inspection of slope stripping

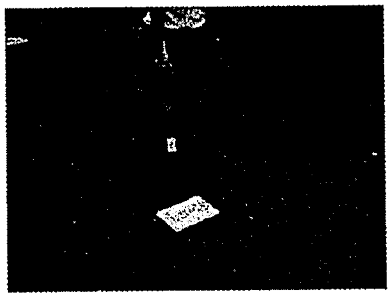

Fig. 3 Detection of underground utilities

In Hong Kong, excavation permits are required from the government for ground investigation works to be carried out on government land including public carriageway and footpaths. A set of regulations regarding safety and reinstatement requirements to the openings of ground needs to be followed strictly. There may be numerous underground utilities particularly in urban area including telephone lines, television cables, pressurized water pipes, sewerage pipes, high voltage electricity cables, and gas pipes etc. underneath a site. Therefore detection of underground utilities at the site is necessary before the actual execution of ground investigation works. It is useful to obtain updated utility plans from relevant utility

undertakers for reference before the commencement of any work. The general practice for detection of underground utilities in Hong Kong is to use geophysical techniques such as Radar detection instrument. Mobilization of drill rigs to borehole locations can then be arranged. Inspection pits are excavated manually at borehole locations to ensure that utilities are not located in their way of drilling and the maximum depth of this sort of excavation is generally 2m deep. Drilling work can then be proceeded according to the instructions.

In the past, there had been a few accidents in the industry involved with sinking boreholes which had hit the high voltage electricity cable (e. g. 13. 2 kV) and damaged a pressurized water pipe in the middle of carriageway. As a result, great loss from the damages was incurred.

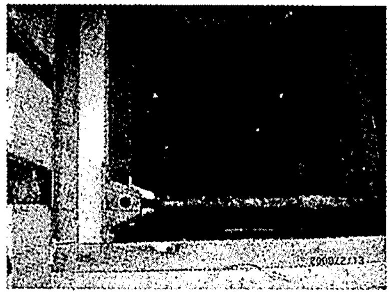

Fig. 4 Timber shoring for excavation of trial pit

Sometimes, trial pits/trial trenches will also be excavated manually for taking large undisturbed soil samples (block samples) and in-situ tests (sand replacement tests). The maximum depth of excavation is generally 3m with support of timber shoring.

Sampling and Field Tests

The choice of sampling methods in ground investigation works depends on the geological condition of the ground, the type of ground information to be obtained and the design criteria required by the engineer. Therefore the engineer will collect all relevant ground information of the site to obtain a preliminary perception of the ground conditions and resolve the existing or possible engineering problems that he may anticipate. The amount and types of ground investigation works required on the specific site may then be determined. Different ground investigation method will be adopted for different soil/rock types, for example: (1) marble terrain may be cavernous and attention must be drawn when a borehole is sunk, otherwise the drilling rods/casings may be lost if it encounters a large cavity; (2) recovering of cavity deposits requires certain sampling techniques by drillers; (3) triple-tube core barrel using foam as drilling medium (instead of water) may be ideal in sampling kaolin within a rock mass. In order not to lose the details of any portion of the recovered rock cores with very fractured rock or numerous kaolin-infill joints in boreholes for slope design, triple tube core barrel will be used which usually produces satisfactory results.

Fig. 5 SPT is in operation

Standard Penetration Test (SPT) is widely used as field tests for ground investigation in boreholes for many years in Hong Kong. It is an assemblage of equipment composed of an automatic release trip hammer, drill rods, SPT sampler including a coupling, split barrel and driving shoe. When the sampler is placed in position at specified depth, the hammer (weighs 63.5 kg) will drop and hit the sampler into the ground. The number of blow count with respect to penetration is recorded for design reference. On the other hand, soil sample is recovered in an aluminium liner within the split barrel.

Fig. 6 SPT sample is recovered in liner protected by rubber caps

The sample collected in the liner is a disturbed sample and is usually used for the identification of soil types and fabrics by geologists. Correct test results marked on plastic sample jars containing the small disturbed samples from the driving shoe, liner samples etc. are also important so that the results of tests are consistent with the borehole logs. Previously, there have been a few research of improvement to the traditional SPT equipments carried out by some organizations. In future, SPT can be carried out in a more effective and convenient way unaffected by the inclement weather/possible human errors when the research results are fruitful.

Retractable Triple-Tube barrel is used to recover undisturbed soil samples from the in-situ ground. This sample is "Mazier sample". The sampler is lowered into the ground by hydraulic means. The soil sample recovered in the 1m plastic liner is sealed with molten wax at both ends and protected by rubber caps to keep moisture of the sample.

Details of the sample (such as contract no., works order no., borehole no., depth of sample and percentage of recovery etc.) are marked on the rubber caps as well as on the plastic liner for identification. The sample is placed in an upright position so that it may be kept in the same condition as it had been in the ground.

Fig. 7 The undisturbed samples are kept in upright position

Since the samples recovered are undisturbed samples, they are used for laboratory testing to assess the soil properties that can be adopted for geotechnical design. Sometimes, the samples are required to be split into 2-halves for inspection of soil textures and soil strata identification.

In case no recovery of soil is experienced in a retractable triple tube barrel probably due to the fact that soil is too cohesive or too sandy, a spring core catcher may be applied at the lower end of the sampler to improve recovery. However, this method may disturb the

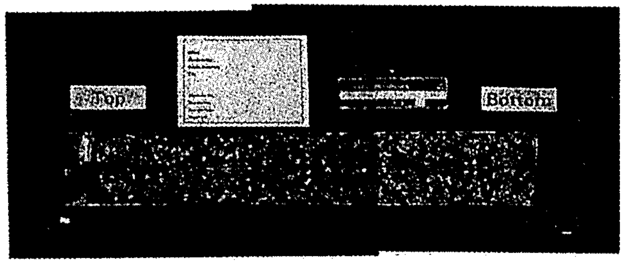

Fig. 8 Split undisturbed sample for inspection

integrity of the sample to some extent.

Rock core samples are normally recovered by double/triple tube core barrels in a borehole. The widely used double-tube core barrel has two sizes in Hong Kong, namely 101mm (T2) and 76mm (TN) internal diameter. Our general practice for coring rock samples is to use larger diameter core barrel at shallow depths. In this case, the smaller rock core barrel (TN) can be used to drill at greater depths in the borehole without the need of reaming the borehole when the T2 rock core barrel cannot proceed further into in the rock.

When some highly weathered/very fractured rock or colluvium are encountered, triple tube core barrel using foam as drilling medium may be required to collect as much sample as possible without being disturbed by the drilling water, such that the texture of the highly weathered rock or the matrix of colluvium can be preserved for detailed study.

The percentage of recovery by these rock core samplers in a core run represents the quality of rock in the ground and the contractor may determine the depth of termination of drilling in a borehole with the use of these data according to the instructions provided. The engineer may also select some representative rock cores for point load testing to verify the rock strength at particular depth of ground.

The recovered samples (disturbed small soil samples and rock cores) are carefully transferred to wooden core boxes. The details of every small-disturbed soil samples are marked on the plastic sample jars and depth indicators are given at both ends of rock cores. The samples containing in core boxes will be carefully studied, logged and photographed for the compilation of ground investigation reports.

For security reasons, the core boxes are chained, locked and kept in secure places temporarily on site. They are then delivered to the core stores for safety custody as soon as possible and kept in core stores until the completion of respective contracts. The core boxes of samples will then be disposed of at designated disposal ground (i.e. the public filling reception facilities) following the requirements of the government.

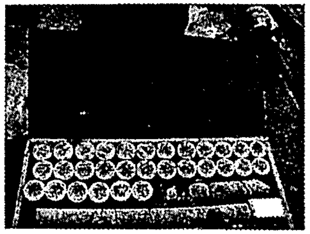

Fig. 9 Soil & rock samples are kept in wooden core box

Fig. 10 Samples are kept safety in core boxes

Supervision of Works

Due to the rapid urban development of new commercial/residential buildings and major structures like new tunnels, bridges etc. and private/government housing redevelopment projects in Hong Kong, more ground investigation works are needed in the coming years. In order to maintain good standard of ground investigation works, the technically competent persons (works supervisors) will supervise ground investigation fieldwork according to the requirements of the government during the progress of ground investigation works. They are required to attain qualifications from institutions and assessed by the government authorities. All ground investigation fieldworks shall be supervised and endorsed in accordance with the requirements of the ground investigation contracts. Therefore, supervision of fieldwork is a very essential part of the ground investigation that proved the field tests as well as the soil and rock samples recovered from the ground are in accordance with the required work procedures.

Safety Issues

Where the ground investigation work sites are located in a street or on a slope, all work areas are fenced by barriers to secure the safety of the public. When ground investigation works are carried out within an active construction site, liaison with site formation contractor is essential on site safety issues especially when drilling work is near a blasting zone or along the haul roads of construction sites. Usually, induction safety briefings will be conducted in site office before any work commences in the site.

Sufficient barriers and traffic signs are required to separate the working areas and haul roads of construction sites so as to safeguard the workers from getting injured by construction plants/lorries. According to the regulations of the government, all moving parts of a drill rig and machinery shall be protected by metal safety guards. The exhaust fume pipe of

Fig. 11 Site safety set up for timber working platform

Fig. 12 Safety guard secures safety of drillers from moving parts of drill rig

drill rigs should generally be fixed at a level higher than the height of a driller; as such the driller shall not be injured by inhaling poisonous fumes.

Shades or shelters are required to be set up above the works area when the drillers are working under sunshine in high temperature. Guidelines should also be provided to the drilling crew whenever there are thunderstorms and lightning, they can keep themselves in safe places.

Sufficient drinking water is essential which shall be provided on site for the consumption of workers especially during very hot weather to prevent them from suffering heat stroke. For ground investigation works, crane lorries are usually deployed to mobilize drill rigs and machinery. Lifting heavy machinery and core boxes of samples require special attention due to the possible occurrence of industrial accidents. Banksman is therefore required to watch the traffic condtion in the vicinity of the crane lorry when it is under lifting operation.

Earplugs or ear mufflers, safety hard hats (safety helmets) and reflective jackets are the general personal safety equipment. Wearing a safety hard hat is a compulsory requirement of the government when one enters a construction site. The ears of the drillers are vulnerable to injury when they are consistently exposed to noisy environment at work; ear protection by wearing earplugs or mufflers is essential in order not to pose permanent damage to their ears.

On the other hand, the noise generated by the drill rigs should be reduced to minimum by taking every measure especially when the working sites are close to school, hospital, church etc. (They are the noise sensitive receptors). Besides, full body safety belts are required for workers working on scaffold platforms. Valid certificate of scaffold shall be issued by a competent person every two weeks which is required to be displayed at the scaffold after his inspection.

Since the outbreak of dengue fever (a type of mosquito decease) a few years ago, prevention measures for dengue fever has been implemented in construction sites by means of suppressing the rate of mosquito breeding through clearing the ponding water on depressed ground, disused tires on site, bamboo ends etc. As such, the working site areas should be kept dry as far as possible. In addition, mosquito larvicide's spray is applied regularly at all working locations. Posters of prevention of mosquito breeding are put up at prominent locations of the working areas. Some guidelines are provided to workers such as wearing light coloured long sleeved clothes and to apply "mosquito-off" sprays. Not until early this year that the A/H1N1 influenza pandemic decease has been spread out worldwide. Some construction companies have prepared their own guidelines and request their employees for attention and report to their employers immediately for proper arrangement should they have contracted the disease.

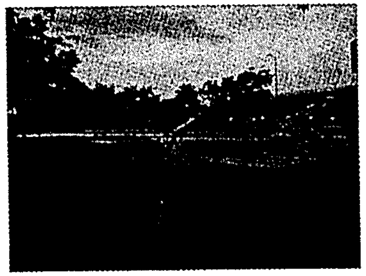

Fig. 13 Sound level meter

Environmental Compliance

Waste and garbage in bags or rubbish bins should be covered properly on site and disposed off the working sites regularly; water for drilling works should be recycled as far as possible and it should be treated through a de-silting water tank before discharging to the designated public drains. We need to take some careful measures to avoid polluting air when grouting borehole is in operation by setting up temporary facilities so that the quantity of fine particles suspending in the air due to grouting will be greatly reduced.

Fig. 14 Ponding water on depression of ground is cleared as far as possible

Nowadays, the construction industry has utilized sound level meter to measure the noise level generated from the ground investigation works. The noise level generated by ground investigation works will be under control.

All plants and equipments to be used on site shall be properly maintained in good operating condition and construction activities shall be effectively sound-reduced by means of silencers, mufflers, acoustic shields or screens to avoid disturbance to any nearby noise sensitive receivers (schools, hospitals etc.) or to carry out drilling works at particular time slots so as to avoid disturbing the neighbours. If the noise level exceeds the limits under the government regulations, ground investigation works have to be halted unless rectifications are taken.

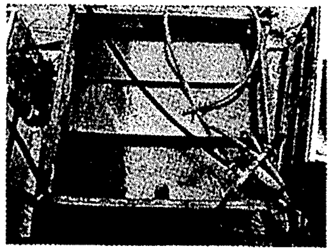

Fig. 15 Water-tank with silt removing facilities

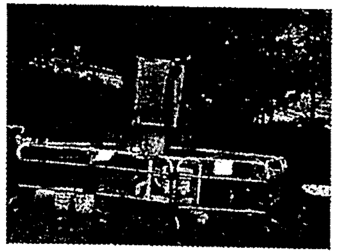

Fig. 16 Facilities to avoid cement particles from polluting the air during grouting

Borehole Logging and Ground Investigation Records

The soil and rock samples recovered from boreholes require careful handling and protected from being damaged for future reference and that these samples are logged by qualified geologists. The qualifications and experience of geologists are required to be assessed by the government authorities through examinations or have attained qualifications from tertiary institutions.

Fig. 17 Silencers/ acoustic shields

The borehole logs with photographs of the samples and field test results are compiled in ground investigation fieldwork reports, which are very important ground investigation information that the engineers use them as a basis for their foundation and slope designs. Geologists, who possess geological experience and professionalism, will sign on every ground investigation records, such as borehole logs, trial pit logs etc. since they are the competent persons for geological logging and responsible for the correctness of the borehole record. A borehole log should be an accurate and comprehensive record of the ground conditions. To achieve this requires both care and vigilance of the driller, logger and checker. An experienced geologist can always possess a 3-dimensional view in the ground and construct the geological history of a place as if he were the witness to the happening of the geological events in the past.

In Hong Kong, the logging practice is carried out with reference to Geoguide 3 "Guide to Rock and Soil Descriptions" published by the government. The results of borehole logs obtained from many construction sites logged by geologists in Hong Kong generally consist of the surface fill materials, alluvium/colluvium, some with marine deposits, sapprolitic material and the rock of various weathering grades including dykes and some geological structures occasionally. The description of the recovered samples in a borehole log consists of elements for engineers design, such as SPT "N-values'", degree of density of sand, stiffness of silt and clay material as well as strength of rock cores etc.

In order to guarantee the quality and standard of the results of ground investigation works prepared by the Competent Person (logging) of contractors, checking the ground investigation records by experienced professional geologist of the client is recommended. It is understood that it has been the practice of qualified geologists of some government offices and consultants, who involve in ground investigation works, to check logging results of soil and rock samples so as to deliver reliable ground investigation information to the engineers. It is hoped that all government offices and consultants will deploy professional geologists to enhance the standard of logging samples from boreholes, trial pits, rock slopes etc. in the near future.

Recommendations for Environmental Conservation Through Ground Investigation

Many miles of rock cores retrieved from the ground will be disposed after the completion of projects. It will be considered as a waste of the Earth's resources as well as human resources, not to mention the waste of money for the ground investigation. After the collection of the disused rock cores by other government departments and universities for research/teaching purposes, we may make use of the disused rock cores for construction of pavement, as hard core for the road base of carriageway, planter in parks and housing estates or as decoration to shopping malls etc. There has been success of using disused rock cores for paving footpaths in other region of the world (e.g. Taiwan).

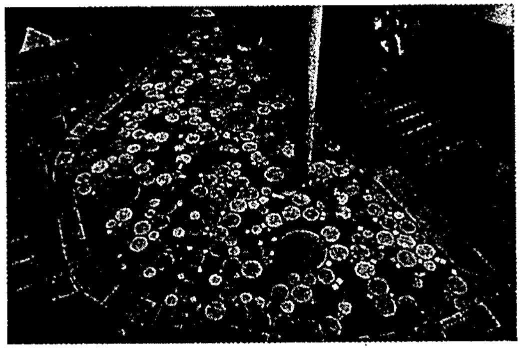

Fig. 18 Disused rock core paving for footpath - 1. (Hualien, Taiwan)

Hong Kong contains fascinating geological heritage, including dramatic landforms such as the red beds on Port Island, sedimentary formations in Ping Chau and jointed rock columns in High Island and Ninepin Islands. Apart from the existing landforms and the spectacular geological scenery of Hong Kong, it can become a city with geological knowledge at every corner of the housing estates, government/commercial buildings and even at street corners as education purpose. It can become unique in the world.

To do this, the government may encourage developers in Hong Kong to contribute a small area in their buildings/properties to display the geological information obtained right below the ground. The public can, in this way, share our experience and results of the geological findings, not only from the universities, Geological Society of Hong Kong - publications of the Civil Engineering Development Department (CEDD), etc., but also conveniently from shopping malls, office buildings, every public housing estates where geological models and information can be displayed right in front of the general public.

Fig. 19 Disused rock core paving for footpath - 2 (Hualien, Taiwan)

The display of geological information can be in the form of geological models at the lobby of a building, along the exposed rock surface of an access road of housing estate showing the geological section (e.g. granitic/volcanic rock of various weathering grades with rock joint patterns and geological structures of a dyke and fault displacement). The geological sections can also be displayed on the floor protected by clear floor tile material, thus they will not occupy too much space of the buildings.

Students of primary and secondary schools or universities may be able to examine the rock cores taken out from the ground where they are stepping on; they may also take reference to the illustration and geological models of the local geology and understand it more outside their classrooms. This can be considered as a huge geological museum of Hong Kong on the whole and would probably be the first region in the world that possesses display of local geology over the entire city.

In this manner, people are able to know the type of rock(s) lying below their home; if an ancient fault or dyke runs across the ground under the commercial centre, market or basket ball court; any underground cavities in marble rock under the foundation of their buildings and other geological structures beneath their homes. The virtual geology of Hong Kong can be unveiled in front of the people. People will know more about geology and their awareness in geology can promote preservation to our geological heritage successfully in long run. Hong Kong would be proud of itself as being the city/region in the world to possess such great innovation.

Summary

The content of this paper has briefly outlined the general practice of ground investigation works carried out in Hong Kong, which may be taken as a reference of ground investigation works for the fast-paced urban development in coming decade. As a result of ground investigation work, we may use the disused rock cores for construction of pavement, as hard

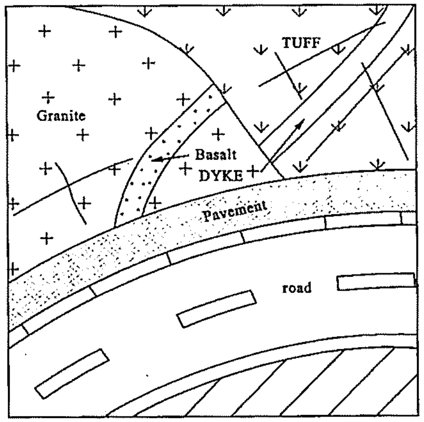

Fig. 20 Geological structures on rock exposure along a section of a road (schematic drawing by D. Yuen)

core for carriageway, decoration material in parks or even shopping malls. With the joint efforts of the government and developers by displaying the geological information and results obtained immediately below the developments, the geology under government/commercial buildings and housing estates will be unveiled in front of the general public and eventually it will promote preservation to our geological heritage in the future.

Acknowledgement

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